UNIVERSIDAD CATÓLICA DE SANTA MARIA

FACULTAD DE CIENCIAS E INGENIERIAS FISICAS Y FORMALES

PROGRAMA PROFESIONAL DE INGENIERIA MECANICA, MECANICA ELECTRICA Y MECATRONICA

“CARACTERIZACION DE UN NUEVO PAVIMENTO BLANDO USANDO COMO BASE CAUCHO RECICLADO Y POLIMERO DE ALTA DENSIDAD (HDPE) RECICLADO”

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Para optar el Título Profesional:
Ingeniero Mecatrónico
Ingeniero Mecánico Electricista

Arequipa - Perú

2013

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DEDICATORIA

A la memoria de mi madre Virginia con el más grande de mis recuerdos, a quien eternamente agradeceré por guiarme en mi formación profesional.

A mi padre Godofredo con inmenso amor y gratitud por su preocupación y sacrificio en mi formación profesional.

A mis Hermanos Dhilner y Rina por su constante aliento y apoyo moral.

Luis Carlos Atamari Chahuara

A mis padres Catalina y Oswaldo por guiarme por el buen camino y por darme su amor y apoyo incondicional, porque gracias a sus consejos y ejemplos dignos de esfuerzo y perseverancia logre una de mis metas mas anheladas.

A mis hermanos Lucho, Wilson y Luis quienes estuvieron apoyándome en todo momento.
A todos los ingenieros que contribuyeron en la elaboración de esta Tesis.

Gabriel Walter Condorpocco Huamaní

RESUMEN

“CARACTERIZACION DE UN NUEVO PAVIMENTO BLANDO USANDO COMO BASE CAUCHO RECICLADO Y POLIMERO DE ALTA DENSIDAD (HDPE) RECICLADO”

Los pavimentos blandos son materiales que se obtienen de una mezcla óptima de caucho reciclado y polietileno de alta densidad o baja densidad dependiendo del uso o utilización del mismo.

En este trabajo realizamos mezclas a diferentes porcentajes de caucho y HDPE reciclado pasándolo por diferentes tamices (mallas) aplicándole diferentes pruebas mecánicas como son:

- Rebote.
- Dureza.
- Tracción.

Quedando demostrado que el mejor porcentaje para este pavimento es 85 % de caucho 15 % de HDPE pasando por la malla Nº 4 obteniendo como resultados un buen comportamiento mecánico y un bajo costo.

Todos los parámetros usados para la fabricación de probetas y la realización de ensayos están basados en las Normas ASTM con designación F 1487, ASTM D412, DIN 53504, ISO 37, ISO 1798, JIS K6251.

ABSTRACT

"CHARACTERIZATION OF A NEW PAVEMENT USING AS BASE SOFT RUBBER POLYMER RECYCLING AND HIGH DENSITY (HDPE) RECYCLED"

The pavements are soft materials that are obtained from an optimal mix of recycled rubber and polyethylene high density or low density depending on the use or use of the same.

This paper made mixtures at various percentages of rubber and HDPE recycling by passing it different strainers (meshes) by applying different mechanical tests such as:

- Rebound.
- Hardness.
- Traction.

It was demonstrated that the best percentage for this pavement is 85 per cent of rubber 15 per cent of HDPE passing through the mesh No. 4 obtaining as results a good mechanical behavior and a low cost.

All parameters used in the manufacture of test specimens and testing are based on standards with designation ASTM F 1487, ASTM D412, DIN 53504, ISO 37, ISO 1798, JIS K6251.

INTRODUCCION

Durante los últimos años se han implantado sistemas de calidad que controlan los procesos y el material en la empresas que fabrican caucho; en este sentido las empresas recicladoras ya han impuesto la misma filosofía de calidad, al igual que en los materiales vírgenes, de tal modo que las empresas recuperadoras con un mínimo de proyección futura ya expenden los materiales con determinada certificación. Por el contrario, no existen datos que den a entender que las empresas recuperadoras apliquen la misma filosofía sobre los residuos que recuperan.

En la última década, en muchos países se ha acentuado la preocupación por la disposición de residuos sólidos, que por sus características no biodegradables y alto volumen en que se producen, constituyen un grave problema para el medio ambiente; entre estos se encuentran los residuos de caucho como EVA (etileno vinil acetato), PU (poliuretano), y SBR (hule estireno-butadieno), así como los productos fabricados con este último material que al concluir su vida útil vienen a sumarse a la acumulación de este tipo de residuos como es el caso de los neumáticos; muchos de los cuales, son quemados en condiciones no controladas generando un grave deterioro en la calidad del aire y agravando la contaminación ambiental excesiva.

Por otro lado el desarrollo de materiales alternativos empleados en la industria de la construcción es un acontecimiento que se ha incrementado en los últimos años, en donde el aprovechamiento de diferentes residuos generados en las ciudades es el eje central de esta investigación. Esta situación obedece principalmente a dos causas, una como estrategia para la disminución de los altos volúmenes de residuos generados y la segunda al cumplimiento de las exigencias para poder reciclar, en donde es factible el empleo del material o del pavimento blando a desarrollarse.

Los neumáticos desechados constituyen un grave problema medioambiental en nuestra ciudad y en el mundo entero. Las principales dificultades generadas por este residuo, tienen que ver con su disposición final, dado que la mayoría de los neumáticos fuera de uso, se encuentran desechados y juntados ocupando gran espacio, o en casos extremos son quemados por algunas fábricas que lo usan como combustible, también contribuye a la proliferación de roedores, insectos y otros posibles focos de infecciones.

Una vez que los plásticos y neumáticos han cumplido la misión para los que fueron fabricados y termina la vida útil de los mismos son simplemente acumulados, es por esta razón que es necesario realizar estudios para poder reutilizar los materiales desechados generando así un nuevo producto.

Para poder realizar esta investigación y viendo la necesidad que requería el Laboratorio de Materiales de Fabricación del Programa Profesional de Ingeniería Mecánica, Mecánica Eléctrica y Mecatrónica, se vio por conveniente Diseñar y Construir una **Maquina Mezcladora de Cauchos con Resistencias** Tipo Brabender con su respectiva **Termo Prensa de Conformado** para **Donación** de nuestro Programa y Alma Mater.

CAPITULO I

PLANTEAMIENTO METODOLOGICO

1. PLANTEAMIENTO METODOLOGICO

1.1 JUSTIFICACION

El desarrollo del presente trabajo nos permite adoptar una nueva forma de minimizar la contaminación reutilizando productos que conlleven a la misma y al mismo tiempo aprovechar de ellos.

Actualmente, el estudio sobre las posibilidades de utilizar los residuos, es uno de los objetivos prioritarios de carácter medioambiental en la investigación científica y técnica, para ello es necesario alcanzar un conocimiento profundo sobre los distintos tipos de residuos, el volumen de los mismos, las posibilidades técnicas, la repercusión económica, las limitaciones de uso y las precauciones que requiere su empleo. Además de asignar para cada residuo de los diferentes tipos de caucho el mejor aprovechamiento entre los usos posibles, a fin de obtener el mayor valor añadido.

Parte de la solución al problema que se va a plantear es la reutilización de caucho reciclado para la obtención de nuevos pavimentos blandos ya que el uso de estos es muy diverso en parques infantiles, guarderías u otros, se pretende desarrollar un enfoque que ayude a minimizar la contaminación usando los materiales reciclados que mediante la combinación de polietilenos de alta densidad (HDPE) reciclado y caucho granulado reciclado de neumáticos nos proporcione un nuevo producto.

1.2 PROBLEMA OBJETO DE INVESTIGACION

En el desarrollo del presente trabajo de investigación sobre pavimentos blandos busca identificar el efecto de la mezcla en diferentes porcentajes del caucho reciclado (triturado) y polietileno de alta densidad reciclado picado, así como evaluar las posibles modificaciones de las propiedades mecánicas del nuevo producto según Normas ASTM.

1.3 OBJETIVOS

1.3.1 Objetivo General.

Determinar la proporción optima de mezcla y evaluar las propiedades mecánicas, mediante ensayos mecánicos de acuerdo a las Normas existentes ASTM con designación F 1487, ASTM D412, DIN 53504, ISO 37, ISO 1798, JIS K6251.

1.3.2 Objetivos Específicos.

- Analizar el grado de dureza de estos pavimentos blandos.
- Determinar su resistencia a la elongación de estos pavimentos blandos.
- Contribuir a la eliminación de residuos sólidos, para mejorar la calidad de vida en la ciudad de Arequipa.
- Encontrar un nuevo pavimento blando, que en su producción no se utilice productos contaminantes, o procesos que contaminen el medio ambiente; es decir un proceso y producto ecológico.
- Contribuir dándole un valor agregado a los productos resultantes de la preparación de neumáticos en desuso reciclándolos con el polietileno de alta densidad reciclado.
- Evaluar la posibilidad de producir un pavimento blando con menor costo que el convencional.

1.4 HIPOTESIS

La unión o combinación de caucho reciclado triturado y polietileno de alta densidad darán como resultado un nuevo pavimento blando, con buenas propiedades de acuerdo a Norma ASTM con designación F 1487.

1.5 PRODUCTOS DEL PROYECTO

Como productos se obtendrán:

- ✓ Una mezcla optima de caucho reciclado triturado y polietileno de alta densidad reciclado, para la generación de un pavimento blando que serán utilizados en pisos de jardines, pisos de albergues, y centros de salud o donde este sea necesario.
- ✓ Una mezcla optima de caucho reciclado, triturado y polietileno de alta densidad reciclado para la generación de un pavimento blando de menor costo y que cumpla con los requerimientos especificados en las normas ya expuestas.

1.6 IDENTIFICACION DE LAS VARIABLES

En estas mezclas o combinaciones se evaluaran los diferentes porcentajes, tamaños de grano de caucho y polietileno reciclado triturado.

a. **Variable Independiente**: Ensayo de resiliencia, ensayo de dureza, ensayo de tracción.
b. **Variable Dependiente**: Porcentajes de caucho y granulometría y costo.

1.7 IMPACTO MEDIO AMBIENTAL

Durante la elaboración de este proyecto de investigación, se han tomado las medidas correspondientes para el cuidado del medio ambiente. Teniendo en cuenta dos puntos importantes, en primer lugar, el impacto derivado durante la realización del proyecto y en segundo lugar, el impacto que con lleva en general el plástico y el caucho en la naturaleza.

1.8 IMPACTO DE LA REALIZACIÓN DEL TRABAJO

Fueron tomadas en cuenta las medidas correspondientes durante la realización de este proyecto como: reciclaje de residuos, buen manejo de residuos, ahorro de energía durante los ensayos sin hacer un consumo excesivo de éstos; y sobre todo la limpieza de los equipos usados.

1.9 IMPACTO MEDIO AMBIENTAL DEL PLÁSTICO Y CAUCHOS

Los residuos son aquellos productos que ya no son utilizables por quien los genero y que usualmente se tiran a la basura. Estos dos productos que se están utilizando para generar pavimentos blandos son generalmente desechados indiscriminadamente. A diferencia de otros muchos materiales que llegan a los vertederos, los plásticos y cauchos no se disuelven en el agua ni se pudren. Trayendo consigo una ventaja y una desventaja:

- Una ventaja: Porque, al no descomponerse, no liberan ningún producto nocivo.
- Desventaja o inconveniente: Porque se acumulan sin desaparecer.

CAPITULO II

MARCO TEORICO

2. MARCO TEÓRICO

2.1 INTRODUCCIÓN

Se denominan materiales plásticos a un numeroso grupo de materiales poliméricos orgánicos (los compuestos por moléculas orgánicas gigantes), que son plásticos, es decir, poseen durante unintervalo de temperaturas propiedades de elasticidad y flexibilidad que permiten moldearlas y adaptarlas a diferentes formas y aplicaciones hasta conseguir una forma deseada por medio de extrusión, moldeo o hilado. Las moléculas pueden ser de origen natural (celulosa, cera, caucho, etc.), o sintéticas (polietileno, nylon).

Los plásticos se caracterizan por una relación resistencia/densidad elevada, unas propiedades excelentes para el aislamiento térmico y eléctrico y una buena resistencia a la corrosión, a los ácidos, álcalis y disolventes. Las enormes moléculas de las que están compuestos pueden ser lineales, ramificadas o entrecruzadas, dependiendo del tipo de polímero. Las moléculas lineales y ramificadas son termoplásticas (se ablandan con el calor), mientras que las entrecruzadas son termoestables (se endurecen con el calor).

2.2 CLASIFICACIÓN Y PROPIEDADES DE LOS POLÍMEROS

Los polímeros son grandes agrupaciones de monómeros unidos mediante un proceso químico llamado polimerización al ser obtenidos por un proceso químico su clasificación es muy diversa esto lo desarrollaremos más adelante. Los plásticos proporcionan el balance necesario de propiedades que no pueden lograrse con otros materiales por ejemplo: color, poco peso, tacto agradable y resistencia a la degradación ambiental y biológica.

Las propiedades y características de la mayoría de los plásticos (aunque no siempre se cumplen en determinados plásticos especiales) son estas:

- Fáciles de trabajar y moldear,
- Tienen un bajo costo de producción,
- Poseen baja densidad,
- Suelen ser impermeables,

- Buenos aislantes eléctricos,
- Aceptables aislantes acústicos,
- Buenos aislantes térmicos, aunque la mayoría no resisten temperaturas muy elevadas,
- Resistentes a la corrosión y a muchos factores químicos;
- Algunos no son biodegradables ni fáciles de reciclar, y si se queman, son muy contaminantes.

2.2.1 Clasificación de los polímeros

La clasificación de un polímero dependerá de diversos parámetros: método de síntesis, estructura, configuración, composición, uso final, estado físico, etc. Analizaremos al polímero según su:

a) Composición química

Atendiendo a su composición química, los polímeros pueden clasificarse en:

- **Polímeros Inorgánicos:** Son polímeros en los que no intervienen monómeros de hidrocarburo en su composición. Se pueden clasificar atendiendo a su composición en siliconas (formadas básicamente por silicio y oxígeno), azufres poliméricos, fosfacenos (fósforo y nitrógeno) y fibras de carbono y de grafito, que si bien contienen carbono, éste no se encuentra formando parte de moléculas de hidrocarburo.
- **Polímeros Orgánicos:** Son los plásticos convencionales, estando formados por hidrocarburos o derivados de ellos. Se clasifican según el tipo de monómeros que intervienen en su formación (poliamidas, polivinilos, etc.).

b) Origen

En cuanto a su origen podemos distinguir tres tipos de polímeros:

- **Polímeros naturales:** Son los polímeros generados por la actividad de los seres vivos, que los utilizan con fines estructurales, funcionales y de reserva energética. A este grupo pertenecen las proteínas, los ácidos nucleídos y los polisacáridos, siendo estos últimos los que presentan un mayor interés en cuanto a sus aplicaciones.

- **Polímeros de transformación:** son polímeros obtenidos por transformación de polímeros naturales.
- **Polímeros sintéticos:** Son polímeros sintetizados mediante técnicas de laboratorio o industriales, directamente a partir de las unidades de monómero.

c) Monómeros de partida

Según los monómeros que constituyen los polímeros, éstos pueden clasificarse en:

- **Homopolímeros:** formados a partir de un solo tipo de unidades de monómeros.
- **Heteropolímeros o Copolímeros:** formados a partir de dos o más tipos diferentes de monómeros. A este grupo pertenecen las proteínas, que pueden contener hasta 20 unidades diferentes, y los ácidos nucleídos.

Los polisacáridos y los polímeros sintéticos pueden ser tanto homo como heteropolímeros, si bien en este caso el número de unidades diferentes que participan no suele ser superior a 2 o 3.

d) Estructura de la cadena

Según este criterio, los polímeros pueden clasificarse en dos grandes grupos:

- **Lineales:** son aquellos en los que las cadenas están formadas por monómeros que presentan sólo dos puntos de unión con las otras unidades monoméricas, dando lugar a estructuras unidimensionales.
- **Ramificados:** Los monómeros presentan tres o más puntos de unión, dando lugar a estructuras bidimensionales o tridimensionales.

e) Según el orden de las cadenas

Según el orden se pueden presentar las cadenas poliméricas en el estado sólido podemos distinguir dos grupos:

- **Cristalinos:** este término no estrictamente correcto aplicarlo en el caso de los polímeros ya que éstos no dan lugar a estructuras tridimensionales ordenadas (están más próximas a los llamados cristales líquidos), sin embargo se emplea para designar aquellos polímeros cuyas largas cadenas se ordenan paralelamente unas a otras, uniéndose entre ellas a través de enlaces (puente de hidrógeno, etc.) De esta forma, el material resulta presenta una mayor resistencia a la tracción.
- **Amorfos:** En este tipo de polímeros, las cadenas no se alinean ni se producen uniones transversales entre ellas. Esto hace que si se calienta el material las cadenas pueden deslizar unas respecto otras, se ablandan el polímero volviéndose pegajoso, pudiendo llegar a fundir. A temperaturas inferiores a la que se produce el estado pegajoso, los polímeros amorfos son blandos y elásticos, y, a temperaturas más bajas, se endurecen y adoptan un aspecto vítreo.

f) Respuesta al calor

Es quizás uno de los criterios más empleados a la hora de clasificar a los plásticos. Según este criterio, los polímeros pueden clasificarse en:

- **Termoplásticos:** Son aquellos que al exponerlos al calor pueden fundirse o reblandecerse varias veces sin que cambie su estructura y propiedades, es decir, que pueden moldearse de nuevo. Son, en general, polímeros con bajas temperaturas de fusión y solubles en disolventes orgánicos. La mayoría de los polímeros con estructura lineal pertenecen a este grupo.
- **Termoestables:** son polímeros que al calentarse sufren cambios químicos y estructurales que provocan su endurecimiento, y por tanto al enfriarse y solidificar lo hacen de forma irreversible. Este comportamiento se debe, generalmente, a que se producen un aumento de la polimerización por reacciones de entrecruzamiento entre las

cadenas. Son polímeros de punto de fusión elevado (aunque pueden degradarse y descomponerse antes de fundir), e insolubles en disolvente orgánicos. La mayoría de los polímeros con estructura bi o tridimensionales pertenecen a este grupo.

2.3 PROPIEDADES DE LOS POLÍMEROS

2.3.1 MASA MOLECULAR MEDIA Y LONGITUD DE LAS CADENAS

Muchos polímeros no están constituidos por moléculas bien definidas, sino mezclas de moléculas de diferente tamaño, ya que el proceso de crecimiento de las cadenas poliméricas está sujeto a las leyes de la probabilidad; es decir, la polimerización puede progresar en diferente grado en la misma reacción. Por este motivo no se habla estrictamente de masa molecular, sino de masa molecular promedio, que corresponderá a la longitud media de las cadenas poliméricas.

Hay que tener presente además que los polímeros presentan propiedades físicas y químicas muy distintas de las que poseen los materiales formados por moléculas sencillas. Así, suelen presentar una mayor su inercia química, que los hace inatacables por los ácidos, los álcalis y por los agentes atmosféricos; una elevada resistencia mecánica, que los hace resistentes a la rotura y al desgaste; un elevado poder dieléctrico; además de su elasticidad, su fácil teñido, su baja densidad y su fácil obtención a bajas temperaturas, que permite su fabricación a gran escala.

2.3.2 DUREZA Y FLEXIBILIDAD

La dureza o robustez que ofrece un material de naturaleza polimérica va a depender esencialmente de las fuerzas de Van der Waals y de los puentes de hidrógeno que puedan establecerse entre sus cadenas. Recordemos que las fuerzas de Van der Waals aparecen entre moléculas neutras como resultado de la polarización eléctrica y que su intensidad aumenta con la masa molecular. No obstante, la dureza de los materiales plásticos suele ser baja.

Por su parte, la flexibilidad depende de la posibilidad de desplazamiento de unas cadenas respecto a otras, aunque en conjunto estén empaquetadas de un modo compacto. Esta facilidad de desplazamiento se encuentra en mayor medida en polímeros no polares donde las uniones entre cadenas son más débiles.

2.3.3 CONDUCTIVIDAD TÉRMICA Y ELÉCTRICA

La conductividad térmica de los plásticos es muy baja, disminuyendo cuanto más desordenada sea la estructura molecular del mismo. Son por tanto buenos aislantes, tanto del frío como del calor.

En cuanto a la conductividad eléctrica, ésta es muy pequeña ya que el número de electrones libres para la conducción es prácticamente nulo al estar constituidos por compuestos covalentes.

2.3.4 RESISTENCIA:

La resistencia a la tracción, en general, no es pequeña en comparación con otros materiales, oscilando entre 4 y 10 Kg./mm2, siendo los plásticos termoestables más resistentes, debido a su estructura tridimensional, que los termoplásticos. Dentro de estos últimos, los que presentan cadenas rígidas son más resistentes que los que no presente cadena rígida. En lo que se refiere a la resistencia al choque, existen algunos tipos de plásticos que presentan valores muy altos.

2.4 OBTENCIÓN DE POLÍMEROS

Las reacciones por las que los monómeros se unen entre sí para formar un polímero son básicamente de dos tipos: de adición y de condensación.

2.4.1 POLÍMEROS DE ADICIÓN

La característica fundamental de este tipo de reacción es que el polímero se forma por unión directa de las unidades monoméricas entre sí, sin que se elimine ningún tipo de molécula residual. Estas reacciones se basan en la existencia de uno o varios enlaces insaturados en el monómero, que se transforman en enlaces simples en el polímero. Hay que tener en cuenta que, si el monómero posee más de un enlace insaturado, la reacción puede proceder de varias formas, dando lugar a diferentes polímeros con propiedades que pueden llegar a ser totalmente diferentes. En cualquier caso, los polímeros resultantes presentarán una estructura lineal, siendo en general plásticos termoplásticos.

Se trata de reacciones en cadena en las que la primera adición de un monómero a otro, produce una especie intermedia muy reactiva que promueve sucesivas adiciones.

2.4.2 POLÍMEROS DE CONDENSACIÓN

Mientras que la polimerización por adición se basa en una reacción en cadena, cuyos eslabones son las moléculas en crecimiento, en la polimerización por condensación no se presenta tal cadena, sino que procede paso a paso, por sucesivas condensaciones entre moléculas de monómero poli funcional, con eliminación de una pequeña molécula (generalmente agua). Esta liberación constituye la característica fundamental de la polimerización por condensación.

Este tipo de reacciones, a diferencia de las anteriores, presentan equilibrio químico, lo que hace que las longitudes de las cadenas formadas, que también presentarán una estructura lineal, sean sensiblemente menores que la de los polímeros de adición.

2.5 PLÁSTICOS SINTÉTICOS

Los plásticos sintéticos se diferencian de los plásticos de origen natural en la naturaleza de la materia prima. A diferencias de estos últimos, los sintéticos no se preparan a partir de alguna sustancia polimérica, sino que parten de los monómeros que van a constituir el polímero plástico. En la actualidad, la fuente de dichos monómeros es el petróleo, no obstante, dado que las existencias mundiales de petróleo tienen un límite, se están investigando otras fuentes de materias primas, como la gasificación del carbón.

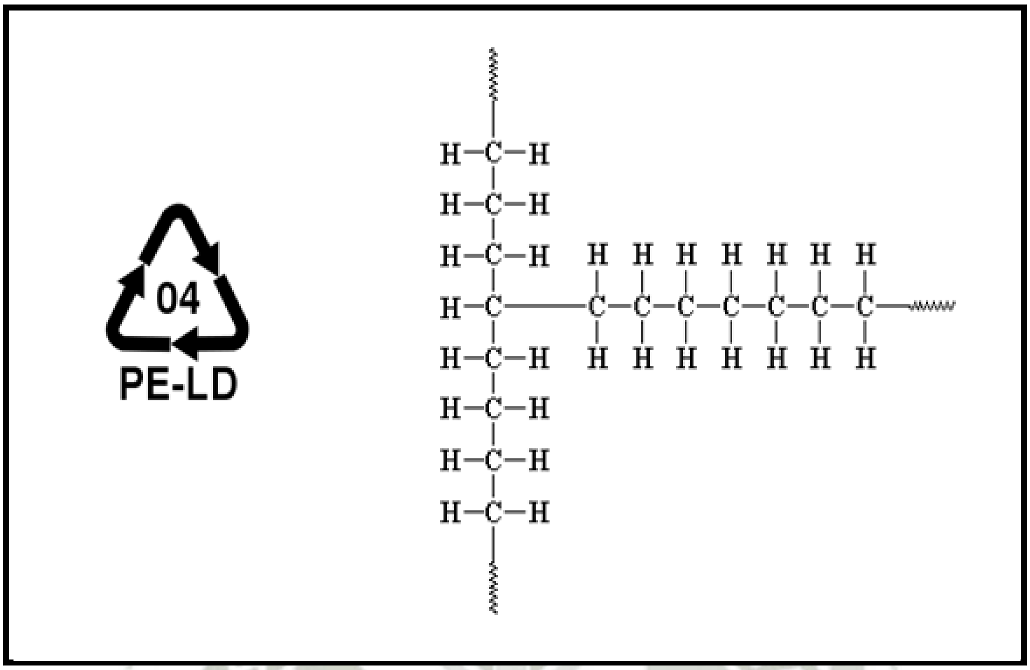
2.5.1 POLIETILENO (PE)

Se obtiene por polimerización del etileno, siendo el polímero de cadena más sencilla, mediante un proceso cuyo resultado depende de la presión a la que éste se ha llevado a cabo. A presiones altas (entre 1.000 y 3.000 atm) se obtiene el llamado polietileno de baja densidad (0.915–0.935 gr/cc), y a presiones normales y a unos 70ºC, en presencia de catalizadores, se obtiene el polietileno de alta densidad (0.935–0.975 gr/cc). Sus características varían ampliamente, según su peso molecular. Puede existir bajo la forma cristalina (elástico, oscuro, poco soluble, deformable) o la forma amorfa (duro, resistente, más claro, más soluble). Tiene gran inercia química y es resistente a la corrosión y a los hongos. Posee gran impermeabilidad a líquidos y vapores.

a) El polietileno de baja densidad (LDPE), Se obtiene por polimerización del etileno a altas presiones (aproximadamente 1200 atm y 200º C) con oxígeno o catalizador de peróxido y por mecanismo de radicales libres. Es un sólido más o menos flexible, según el grosor, ligero y buen aislante eléctrico. Se trata de un material plástico que por sus características y bajo coste se utiliza mucho en envasado, revestimiento de cables y en la fabricación de tuberías. Los objetos fabricados con LDPE se identifican, en el sistema de identificación americano SPI (Society of The Plastics Industry), con el siguiente símbolo en la parte inferior o posterior:

FIGURA Nº2.1 :

Nomenclatura y estructura del LDPE



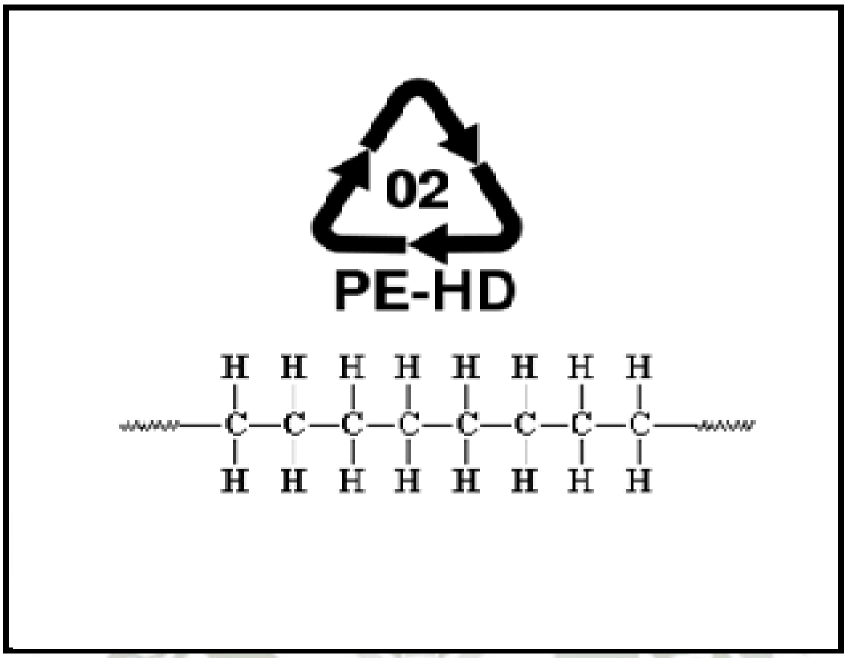
Fuente:Libro de Química de Raymond Chang.

b) El polietileno de alta densidad (HDPE) presenta una mayor resistencia mecánica y soporta temperaturas entre los –200ºC y los 100ºC. Se obtiene por polimerización del etileno a presiones relativamente bajas (1-200 atm), con catalizador alquilmetálico (catálisis de Ziegler) o un óxido metálico sobre sílice o alúmina (procesos Phillips y Standard Oíl). Su resistencia química y térmica, así como su opacidad, impermeabilidad y dureza son superiores a las del polietileno de baja densidad. Se emplea en la construcción y también para fabricar prótesis, envases, bombonas para gases y contenedores de agua y combustible y tuberías.

Los objetos fabricados con HDPE se identifican, en el sistema de identificación americano SPI (Society of The Plastics Industry), con el siguiente símbolo en la parte inferior o posterior:

FIGURA Nº 2.2:

Nomenclatura y estructura del HDPE



Fuente: Libro de Química de Raymond Chang.

2.6 COMPARACIÓN DE PROPIEDADES:

CUADRO Nº 1

PROPIEDADES MECÁNICAS del HDPE - LDPE

PROPIEDADES	HDPE	LDPE
Modulo Elástico E (Nmm2)	1000	200
Coeficiente de fricción	0.29	-----
Modulo de Tracción (GPa)	0.5-1.2	0.1-0.3
Relación de Poisson	0.46	-----
Resistencia a Tracción (MPa)	15-40	5-25
Esfuerzo de Rotura (Nmm2)	20-30	8-10
Elongación a Ruptura (%)	12	20
Temperatura máxima de utilización(ºC)	55-120	50-90

Temperatura de reblandecimiento (ºC)	140	110
Temperatura de cristalización (ºC)	130-135	105-110
Resistencia a los ácidos –concentrados	Buena - Aceptable	Buena - Aceptable
Resistencia a los ácidos –diluidos	Buena	Buena
Resistencia – Álcalis	Buena	Buena
Resistencia a los Alcoholes	Buena	Buena
Resistencia a las Cetonas	Buena - Aceptable	Buena - Aceptable
Resistencia a las Grasas y Aceites	Buena - Aceptable	Buena - Aceptable

Fuente: Libro de James Shackelford de Ciencia de Materiales.

2.7 VENTAJAS Y DESVENTAJAS AL USAR HDPE Y LDPE:

CUADRO Nº 2

COMPARACION DE PROPIEDADES DEL HDPE - LDPE

POLIETILENO DE ALTA DENSIDAD	POLIETILENO DE BAJA DENSIDAD
VENTAJAS	**VENTAJAS**
✓ Elasticidad. ✓ No se deforma permanentemente. ✓ Es un producto reciclable. ✓ Fácil de transportar. ✓ Tiene una vida útil bastante larga. ✓ Es flexible. ✓ Es resistente a cualquier forma de corrosión. ✓ Su costo de adquisición e instalación es sumamente reducido. ✓ Se puede procesar en grandes láminas, lo que reduce la necesidad de otros materiales. ✓ Resistencia a movimientos sísmicos. ✓ Resiste ácidos, elementos químicosaltamente corrosivos y bacterias.	✓ Alta resistencia química. ✓ Buena resistencia al impacto en bajas temperaturas. ✓ Características eléctricas excelentes.

DESVENTAJAS	DESVENTAJAS
✓ Baja barrera a los gases, como oxigeno, dióxido de carbono. ✓ Baja barrera a los olores, sabores, aromas. ✓ Baja – mediana transparencia, de los envases ✓ Alta migración de grasas y aceites	✓ Temperatura máxima de funcionamiento baja. ✓ Baja resistencia ultravioleta ✓ Inflamable. ✓ Poca resistencia a la tensión ambiental y a agrietarse.

Fuente: Libro de James Shackelford de Ciencia de Materiales.

2.8 CAUCHOS

2.8.1 Origen.

El lugar de origen del caucho es el centro y sur de América, donde muchas civilizaciones la usaron de diferentes formas, por ejemplo: como pelotas de juego (en las civilizaciones Mesoamericanas), tipos de zapato de goma (en la Cultura Maya) y como tiras para sostener productos de piedra y metálicos.

El origen del nombre caucho se remonta hacia mucho antes de la primera visita de Colón a América, en donde los indios peruanos conocían al caucho como cauchue y es de este nombre de donde se deriva su nombre actual. Debido a las visitas de los españoles y otros europeos al continente americano, surgió el ímpetu por conocer más a fondo el caucho y es así que en 1736 Charles de La Condamine hizo los primeros estudios, luego le siguieron otros científicos como el británico Joseph Priestley (1770), quién descubrió que el caucho podía ser utilizado como borrador de trazos hechos a lápiz. Sin embargo, la primera aplicación comercial que se le dio al caucho fue el de realizar un método de impermeabilizar tejidos al tratarlos con caucho disuelto en trementina.

Actualmente el caucho es muy usado en numerosas industrias y constituye una materia prima importante por sus diversas propiedades, las cuales serán explicadas en puntos posteriores.

2.8.2 Teoría del Caucho.

El caucho natural es una sustancia orgánica formada por moléculas gigantescas que están entrelazadas entre sí. Dichas moléculas son gigantescas porque el caucho se va formando a través de monómeros, los cuales representan eslabones que están enlazados por cadenas moleculares.

Dependiendo de la fuerza de enlace de los monómeros, el caucho puede adquirir distintos grados de resistencia al estiramiento o deformación, característica que se conoce mayormente como viscosidad. Además el caucho, sea natural o sintético, se caracteriza por su elasticidad, repelencia al agua y resistencia eléctrica.

Generalmente el caucho posee altas fuerzas de atracción intermoleculares ya que al estirarse dichas moléculas, tienden a orientarse en la dirección del esfuerzo. Las altas fuerzas de atracción generan en el caucho un comportamiento cristalino, cosa que no ocurre cuando las moléculas de caucho se desordenan y lo vuelven amorfo.

Como ya mencionamos anteriormente, el caucho tiene distintos grados de resistencia al estiramiento, para la cual es importante definir dos fases dentro de todas sus características ya mencionadas:

- **Fase elástica:** se da cuando las fuerzas de atracción entre sus moléculas son grandes y no permiten la deformación del caucho. Por el contrario, ante una fuerza de estiramiento, el caucho vuelve a su configuración inicial.

- **Fase plástica:** el resbalamiento de las moléculas de caucho, producto de la aplicación de una fuerza, genera una deformación que permite moldear, mezclar o extrusión al caucho.

Estas dos fases coexisten en el caucho y son importantes para el proceso de vulcanización (que será explicado más adelante) que se pueda aplicar en él. Por tanto ante la falta de estas fases, se utilizan diversas cargas químicas que generan en el caucho un comportamiento elástico y plástico.

2.8.3 Caucho natural

El caucho natural se obtiene de cierto tipo de árboles (especies Hevea, Ficus y otras) que exudan una substancia blanca y lechosa, el “látex”, cuando se hace una incisión profunda en su corteza (el árbol no se daña).

El látex contiene 30-36% de caucho en forma de pequeñísimas gotas en suspensión, el que es obtenido en forma sólida por “coagulación” mediante acido fórmico ($HCOOH$) o acético ($CH3COOH$) a un pH de 4,8 a 5,0.

2.8.3.1 Obtención de caucho natural

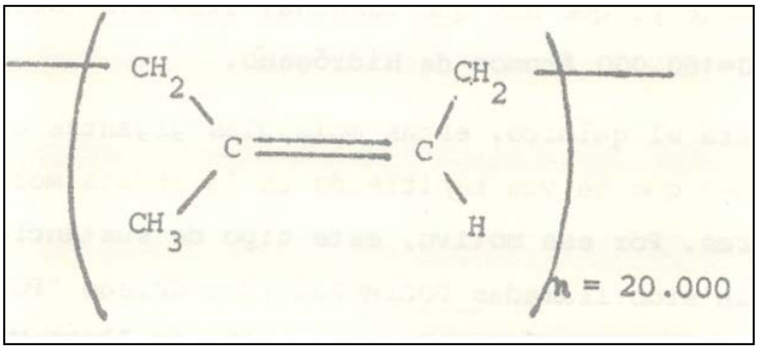
Para recoger el látex de las plantaciones, se practica un corte diagonal en ángulo hacia abajo en la corteza del árbol. El corte tiene una extensión de un tercio o de la mitad de la circunferencia del tronco. El látex exuda desde el corte y se recoge en un recipiente. La cantidad de látex que se extrae de cada corte suele ser de unos 30 ml. Después se arranca un trozo de corteza de la base del tronco para volver a tapar el corte, normalmente al día siguiente. Cuando los cortes llegan hasta el suelo, se deja que la corteza se renueve antes de practicar nuevos cortes.

2.8.3.2 Propiedades generales.

El caucho natural es un polímero lineal que tiene como principal monómero al Isopreno 2- metilbutadieno cuya fórmula química es $C5H8$ el cual es un líquido de relativa volatilidad. En la figura 2.3 se muestra la composición química del caucho.

FIGURA Nº 2.3.

COMPOSICIÓN QUÍMICA DEL CAUCHO.



Fuente: Libro de Química de Raymond Chang.

La unión de los enlaces de los monómeros puede formar cadenas cortas y largas, las cuales dependiendo de su variabilidad de tamaño explican la viscosidad del caucho. A continuación se describirá a las principales propiedades del caucho natural que influirán en el proceso de vulcanización:

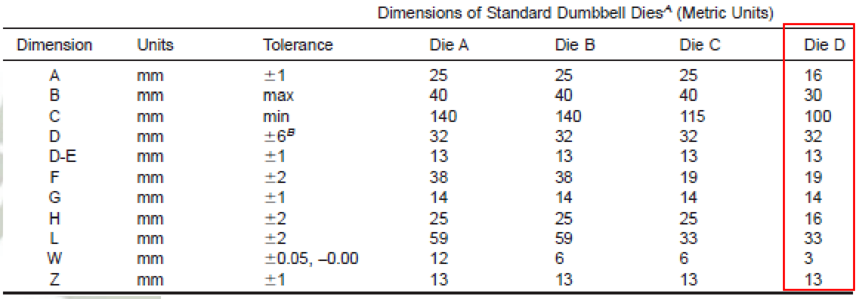
- **Resistencia mecánica:** El caucho natural es el que presenta más marcadamente el fenómeno de cristalización, por tanto tiene una buena resistencia mecánica que consiste en la resistencia contra todo tipo de rotura que puede ser producida por fuerzas de tracción, torque, flexión, compresión, desgarre y abrasión.
- **Desgarramiento y fatiga:** La resistencia al desgarre por parte del caucho natural es buena. Esta se mide haciendo un corte inicial a una probeta de caucho, luego se le realiza un estiramiento donde se observa el grado de desgarre. La rotura o crecimiento del corte (fatiga) inicial determinará la resistencia del caucho natural.
- **Histéresis:** El caucho es un material visco elástico, el cual consume energía y retarda su deformación ante una fuerza. La histéresis está representada por esa energía que no permite fácilmente la deformación del caucho. Es importante indicar que a 200 º C el caucho natural es muy blando porque sus soluciones son menos viscosas, por lo que a temperaturas entre 100 ºC y 150 ºC ya se puede procesar fácilmente.

- **Resiliencia:** Es la medida de elasticidad ante la aplicación de fuerzas dinámicas. En el caso del caucho, ésta es medida mediante la aplicación de las fuerzas provenientes de péndulos que rebotan a determinada altura sobre el caucho. La resiliencia del caucho entonces estará entendida como la relación de la elasticidad producida por el choque de una fuerza proveniente de un péndulo a determinada altura.
- **Tracción:** Las características de Tracción son, junto con la dureza, las que con mayor frecuencia se incluyen en las especificaciones tanto de cauchos sintéticos como naturales.

  Este ensayo se llevó a cabo de acuerdo a las dimensiones establecidas por la norma ASTM D412. Se eligió la probeta tipo D.

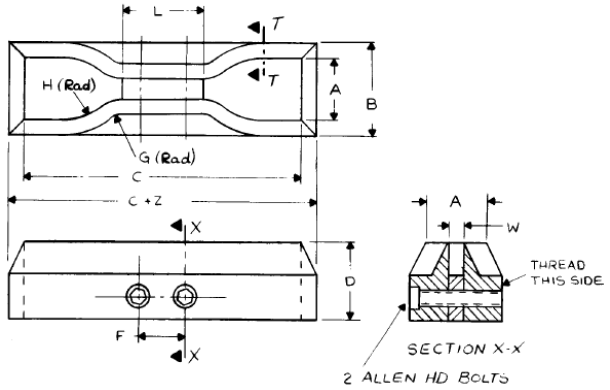
CUADRO Nº3

Dimensiones De La Probeta Para Ensayo De Tracción



Dimensions of Standard Dumbbell Dies[A] (Metric Units)

Dimension	Units	Tolerance	Die A	Die B	Die C	Die D
A	mm	±1	25	25	25	16
B	mm	max	40	40	40	30
C	mm	min	140	140	115	100
D	mm	±6[B]	32	32	32	32
D-E	mm	±1	13	13	13	13
F	mm	±2	38	38	19	19
G	mm	±1	14	14	14	14
H	mm	±2	25	25	25	16
L	mm	±2	59	59	33	33
W	mm	±0.05, −0.00	12	6	6	3
Z	mm	±1	13	13	13	13



Fuente: Norma ASTM D412.

Para medir la tracción de un elastómero, se utiliza un dinamómetro (Instron). Se toma la muestra (probeta de forma halterio o anular), se sujeta cada extremo y luego se procede a estirarla a velocidad constante, hasta su rotura. La tensión requerida para romper la muestra representa la resistencia a la tracción del material. Mientras dura el estiramiento de la muestra, va midiendo la fuerza (F) que está ejerciendo. Cuando conocemos la fuerza que se está ejerciendo sobre la muestra, dividimos ese número por el área (A) de la muestra.

El resultado es la tensión que está experimentando la muestra.

F / A = Esfuerzo.

Puesto que la carga de rotura es la fuerza aplicada sobre la muestra dividida por el área de la misma, tanto la tensión como la carga de rotura se miden en unidades de fuerza por unidad de área, generalmente N/cm2. La tensión y la resistencia también pueden ser medidas en mega pascales (MPa). Resulta sencilla la conversión entre diferentes unidades, ya que 1 MPa = 100 N/cm2.

Otras veces, la tensión y la resistencia se miden en las viejas unidades del sistema inglés, libras por pulgada cuadrada, o psi. Para convertir psi a N/cm2, el factor de conversión es 1 N/cm2 = 1.45 psi

Normas

ASTM D412, DIN 53504, ISO 37, ISO 1798, JIS K6251.

- ***ASTM D412***: Ensayo de tracción sobre caucho vulcanizado y elastómeros termoplásticos.

  La norma ASTM D412 especifica las condiciones de ensayo para determinar las propiedades de tracción de elastómeros moldeados y troquelados. Debido a la extensibilidad que los cauchos y elastómeros exhiben, se requieren generalmente extensómetros para medir con precisión la elongación o estiramiento durante la carga aplicada. Anexo
- ***ISO 1798:1999:*** Resistencia a la Tracción y Alargamiento a la Rotura de los materiales poliméricos flexibles celulares.

  La ISO 1798 investiga la resistencia a la tracción y las propiedades de deformación de los materiales poliméricos flexibles celulares cuando se extienden a una velocidad constante de desplazamiento hasta el fallo. En principio, la muestra de ensayo está soportada entre dos mordazas de sujeción y se instala un extensómetro para una longitud de referencia dada. La muestra se estira hasta que rompe a una velocidad constante de desplazamiento. La carga y la deformación se registran durante la prueba, y se utilizan para determinar la resistencia a la tracción y alargamiento a la rotura.

- **Elongación, Alargamiento a la Rotura**

Las propiedades mecánicas de un caucho no se remiten exclusivamente a conocer cuán resistente es.
La resistencia nos indica cuánta tensión se necesita para romper algo. Pero no nos dice nada de lo que ocurre con la muestra mientras estamos tratando de romperla. Ahí es donde corresponde estudiar el comportamiento de Elongación de la muestra polimérica.

La Elongación es un tipo de deformación. La deformación es simplemente el cambio en la forma que experimenta cualquier cosa bajo tensión. Cuando hablamos de tensión, la muestra se deforma por estiramiento, volviéndose más larga. Obviamente llamamos a esto elongación.

Por lo general, hablamos de porcentaje de elongación, que es el largo de la muestra después del estiramiento (L), dividido por el largo original (L_0), y multiplicado por 100. $(L / L_0) \times 100 = \%$ Elongación.

Normas: ASTM D412, DIN 53504, ISO 37, EN ISO 1798, JIS K6251
Existen muchas cosas relacionadas con la elongación, que dependen del tipo de material que se está estudiando. Dos mediciones importantes son la elongación final y la elongación elástica.

La elongación final es crucial para todo tipo de material. Representa cuánto puede ser estirada una muestra antes de que se rompa. La elongación elástica es el porcentaje de elongación al que se puede llegar, sin una deformación permanente de la muestra. Es decir, cuánto puede estirársela, logrando que ésta vuelva a su longitud original luego de suspender la tensión. Esto es importante si el material es un elastómero. Los elastómeros tienen que ser capaces de estirarse bastante y luego recuperar su longitud original. La mayoría de ellos pueden estirarse entre el 200% y el 700% y volver a su longitud original sin inconvenientes.

- **Propiedades de fricción y desgaste:** el desgaste o abrasión del caucho, se produce cuando éste, es sometido a una fricción contra una superficie que provoca el desprendimiento de pequeñas partículas de caucho. Otras consideraciones a tomar en cuenta, es que el caucho es insoluble en agua y a determinadas temperaturas tiene distintas características que son las siguientes:

2.8.4 CAUCHO SINTÉTICO

El caucho sintético es un tipo de elastómero, invariablemente un polímero obtenida artificialmente por reacciones químicas conocidas como condensación o polimerización a partir de determinados hidrocarburos insaturados.

El caucho sintético tiene como compuesto básico al monómero, el cual forma moléculas grandes al ir entrelazándose con monómeros de su mismo tipo.

Un elastómero es un material con la propiedad mecánica de poder sufrir mucha más deformación elástica bajo estrés que la mayoría de los materiales y aun así regresar a su tamaño previo sin deformación permanente. El caucho sintético sirve como un sustituto del caucho natural en muchos casos, especialmente cuando se requieren propiedades mejoradas de los materiales.

2.8.4.1 PRINCIPALES TIPOS DE CAUCHO SINTÉTICO.

A través del tiempo se han desarrollado numerosos tipos de caucho con propiedades específicas, los cuales sirven para aplicaciones especiales en la industria. A continuación se mencionará y se hará una breve descripción de algunos tipos de caucho sintético utilizados en la industria:

- **Poliisoprenonatural (NR) y sintético (IR)**

El caucho natural y el poliisopreno sintético ambos tienen una histéresis extensible y buenas características extensibles frente al calor. La naturaleza muy específica del poliisopreno sintético proporciona un número de factores que la distingan del caucho natural. Hay una variación mínima en las características físicas. Las condiciones de la polimerización se controlan bien para asegurar que el polímero es altamente específico químicamente. Los non polímeros son menos en el sintético que en el caucho natural.

En el proceso de fabricación del poliisopreno sintético, se requieren menos trabajo mecánico e interrupción. Los ciclos de mezcla son más cortos lo que permite ahorros de tiempo, de energía y aumento del rendimiento. Además, el poliisopreno sintético tiene más compatibilidad que el caucho natural en mezclas con solución SBR y EPDM. La uniformidad del poliisopreno sintético garantiza una calidad constante.

- **Butadieno estireno (SBR)**

El caucho estireno-butadieno, frecuentemente abreviado SBR (del inglés Styene-Butadiene Rubber) es un elastómero sintético obtenido mediante la polimerización de una mezcla deestirenoy de butadieno. Es el caucho sintético con mayor volumen de producción mundial. Su principal aplicación es en la fabricación de neumáticos.

Una de las ventajas era que su producción tenía una muy buena relación costo-utilidad. El caucho sintético fue usado para disminuir el consumo de las fuentes naturales de caucho, especialmente en el área de la fabricación de neumáticos, que en ese momento aún consistían de caucho sólido. Otros países comenzaron a copiar los esfuerzos y a la década siguiente, muchas naciones desarrolladas estaban en el negocio de la creación del SBR para ser usado en una variedad de productos.

- **Etileno - Propileno (EPDM)**

  Los elastómeros de EPDM, poseen excelente resistencia al calor, al agua, al vapor, al ozono y a los rayos UV (estabilidad de color), a la vez que tienen muy buenas propiedades de flexibilidad a bajas temperaturas. Soportan los efectos de líquidos de frenos, medios alcalinos, ambientes levemente ácidos y disolventes oxigenados. Poseen un inmejorable comportamiento frente al envejecimiento en su uso a la intemperie a largo plazo. Los elastómeros de EPDM son asimismo muy adecuados para su uso con agua caliente y vapor. Son especialmente adecuados para trabajar con líquidos de freno a altas temperaturas. Los compuestos de caucho EPDM no se recomienda su uso con gasolinas, aceites y grasas a base de petróleo y con disolventes a base de hidrocarburos.

- **Policloropreno (CR)/Neopreno.**

  Neopreno es el nombre comercial con el que se conocen los polímeros compuestos de cloropreno. Las características físicas generales del neopreno lo sitúan como un elastómero de uso de amplio espectro. Sus excelentes características de envejecimiento frente al ozono y los agentes atmosféricos a la vez que su buena resistencia a la abrasión y a la flexión, le otorgan la categoría de caucho de uso general. El neopreno es resistente a los ácidos y álcalis, retardador de llama y adecuado para su uso con aceites con base de petróleo. Las grasas animales y vegetales también proporcionan un entorno muy estable para este polímero. Se caracteriza por una buena resistencia a la flexión, excelente resistencia a la fatiga y amplía resistencia a la intemperie y el ozono. Su excelente adherencia a los metales lo hace ideal para el moldeo con insertos metálicos. El Neopreno no es eficaz en contacto con disolventes aromáticos y oxigenados.

- **Nitrilo carboxílico (XNBR)**

  Años de investigación para el desarrollo de nuevos compuestos han dado como resultado un material único que captura los beneficios de la resistencia al desgaste de los nitrilos carboxilados y a la vez la resistencia a mayores temperaturas de los nitrilos altamente saturados. Esta formulación se llama XNBR (Nitrilo Hidrogenado). Una muy alta resistencia a la tracción junto con una alta resistencia al calor y una buena resistencia química al sulfuro de hidrógeno, a inhibidores de corrosión, al vapor y al petróleo hace de este elastómero un excelente puente entre los nitrilos comunes y los fluorocarbonos.

- **Poliacrílico (ACM)**

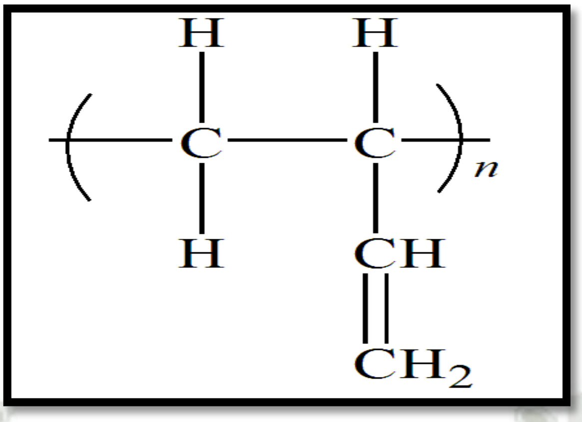
  Los compuestos de Poliacrilato (ACM) están diseñados para soportar altas temperaturas sin perder resistencia a los hidrocarburos. Especialmente diseñados para aplicaciones en aceites sulfurados. Los elastómeros ACM son asimismo resistentes a la oxidación, el ozono, los disolventes alifáticos, la luz del sol y la intemperie y poseen una baja permeabilidad a los gases. Los cauchos Poliacrílicos son capaces de soportar altas temperaturas pero su resistencia a bajas temperaturas es relativamente pobre.

- **Polibutadieno (BR)**

  Es un gas incoloro de olor parecido al de la gasolina, producido en la destilación del petróleo y usado para la fabricación de caucho sintético SBS. El caucho fabricado por la polimerización de butadieno es duro y a temperatura ambiente tiene un comportamiento elastomérico, mientras que a altas temperaturas puede ser procesado como plástico. Es difícil de tratar y presenta baja histéresis.

FIGURA Nº2.4

Estructura del Polibutadieno



Fuente: Libro de Química Raymond Chang

- **Poliisobutileno (IIR)** Es conocido por su excelente resistencia al agua, vapor, álcalis y disolventes oxigenados. Otra de su característica más sobresaliente es su baja permeabilidad a los gases. El butilo es capaz de proporcionar una alta absorción de energía (amortiguación) y una buena resistencia al desgarro. Su buena resistencia al calor, la abrasión, el oxígeno, el ozono y la luz solar dependen del nivel de saturación del polímero.

  Muy buena resistencia a los ácidos fluidos y a los detergentes, así como los ácidos fuertes. El Butilo sin embargo, muestra una pobre resistencia a aceites a base de petróleo, gasolinas y disolventes a base de hidrocarburos.
- **Polietileno Clorosulfonado (CSM)/HYPALON):** Los compuestos de Hypalon proporcionan una excelente resistencia al ozono, a la oxidación, a la luz solar (degradación de color) y a la intemperie. Poseen asimismo una excelente resistencia a los ácidos y los álcalis y una buena resistencia a gran variedad de productos químicos con excepción de combustibles y disolventes. Poseen una muy buena resistencia mecánica.

- **Butadieno Acrilo-Nitrilo (NBR):** El NBR, conocido también como Buna-N y Nitrilo es un elastómero basado en un copolímero de acrilonitrilo butadieno. El NBR es inherentemente resistente a los fluidos hidráulicos, aceites lubricantes, fluidos de transmisión y otros productos a base de petróleo no polar, debido a la estructura polar de este elastómero. Los nitrilos también son resistentes a los agentes atmosféricos y al agua. Con la utilización de la variedad de polímeros de nitrilo y de otros ingredientes en su composición, se pueden obtener compuestos de caucho nitrilo para resistir entornos que requieren baja compresión, resistencia a la abrasión, baja temperatura de flexión, resistencia a la penetración del gas y resistencia al ozono. Por hidrogenación (HNBR), adición de ácidos carboxílicos (XNBR) o mezcla de PVC (NBR/PVC), los polímeros de nitrilo pueden satisfacer una gama más amplia de necesidades físicas o químicas.

- **Nitrilo Hidrogenado (HNBR):** El HNBR ha sido desarrollado para soportar temperaturas continuas de hasta 150 º C, manteniendo la resistencia a los aceites derivados del petróleo. Se obtiene por hidrogeneración del copolímero de nitrilo. El HNBR llena el vacío dejado por los elastómeros de NBR y FKM cuando las condiciones de alta temperatura requieren una alta resistencia a la tracción, manteniendo una excelente resistencia al aceite de motor, gas amargo, mezclas de amina/aceite y aceites lubricantes

- **Fluorocarbono (FKM)/VITON:** Los elastómeros de Viton, polímeros altamente fluorados con estructura de carbono, son utilizados en aplicaciones que requieren una elevada resistencia al ataque químico, al ozono y que requieran de una elevada estabilidad térmica (hasta 260º). Los fluorocarbonos poseen asimismo una baja deformación remanente por compresión y un excelente comportamiento al envejecimiento. Proporcionan un excelente servicio en contacto con aceites, gasolinas, fluidos hidráulicos, disolventes de hidrocarburos y combustibles. En términos generales, aumentando el contenido en flúor, la resistencia al ataque químico se mejora al mismo tiempo que se disminuyen las características de baja temperatura. Hay, sin embargo, algunos fluorocarbonos especialmente formulados con un alto contenido en flúor con muy buen comportamiento a bajas temperaturas.

- **Fluorsilicona (FVMQ):** Las siliconas fluoradas poseen propiedades químicas similares a las de los elastómeros fluorados orgánicos. Esta propiedad otorga una excelente resistencia a combustibles de hidrocarburos, aceites de petróleo y aceites de silicona. Poseen asimismo un mayor rango de temperatura operativa que los fluorocarbonos (FKM) (de -57 º C a 205 º C). Se utilizan, predominantemente, para aceites sintéticos, gasolinas y combustibles.

- **Silicona (VMQ, PMQ, PVMQ):** Estabilidad a temperatura extrema y flexibilidad a bajas temperaturas son características notorias de los compuestos de silicona. Las siliconas poseen excelente resistencia a la compresión, la luz solar, el ozono, el oxígeno y la humedad. Por su carácter inerte se utilizan ampliamente en aplicaciones médicas, farmacéuticas y alimentarias ya que no dejan olor ni sabor. Las siliconas pueden ser formulada para ser eléctricamente resistentes, conductoras o retardadoras de la llama.

- **Poliuretano (EU/AU):** Los poliuretanos se caracterizan por una resistencia excepcional a la abrasión y al desgaste. Ofrecen la resistencia a la tracción más alta entre todos los elastómeros a la vez que una buena resistencia al estiramiento. El ozono, la oxidación, la luz solar, los agentes atmosféricos y la exposición eventual al petróleo y la gasolina son ambientes adecuados para aplicaciones de este compuesto. Los poliuretanos con base de poliéter están específicamente diseñados para su uso en aplicaciones que requieran flexibilidad a baja temperatura. Los poliuretanos basados en poliéster (AU) proporcionan una mejor resistencia a la abrasión, al calor y al hinchamiento en fluidos derivados del petróleo. No son recomendables para álcalis, ácidos y disolventes oxigenados. No se recomienda el uso de los poliuretanos con base de poliéster para agua caliente, vapor y aplicaciones con alta humedad ambiental, pero estos pueden ser formulados para incrementar la resistencia a estas propiedades.

- **Epichlorohidrina (ECO/CO):** La epiclorhidrina se caracteriza por una notablemente baja permeabilidad a los gases y unas muy buenas propiedades físicas en un amplio rango de temperaturas (de-40 º C a 135 º C) a la vez que posee una excelente resistencia a los aceites derivados del petróleo. Resistencia al ozono, a la oxidación, al desgaste y a la luz del sol son otras cualidades típicas de este material.

- **Etil-Acrilato (AEM)/VAMAC):** Los compuestos de etil-acrilato poseen una excelente resistencia al envejecimiento a altas temperaturas (175 º C), y unas buenas propiedades físicas. Un alto grado de resistencia al aceite, el ozono, los rayos UV y a la intemperie así como una buena flexibilidad a bajas temperaturas son también atributos del Etil-acrilato.

2.8.5 Propiedades

Propiedades Físicas

- A bajas temperaturas, se vuelve rígido, y cuando se congela en estado de extensión adquiere estructura fibrosa.
- Calentando a más de 100 ºC., se ablanda y sufre alteraciones permanentes.
- El caucho bruto adquiere gran deformación permanente debido a su naturaleza plástica.
- La plasticidad del caucho varía de un árbol a otro y también depende de la cantidad de trabajo debido al caucho desde el estado látex, de las bacterias que lo acompañan e influyen en su oxidación y de otros factores. La plasticidad puede modificarse dentro de ciertos límites por la acción de productos químicos.

- La densidad del caucho a 0 ºC es de 0.950 a 20 ºC es de 0.934. El caucho bruto deshelado después de la masticación por cilindros fríos no varía de densidad.
- Cuando el caucho bruto ha sido estirado y deformado durante algún tiempo, no vuelve completamente a su estado original.
- Si se calienta, la recuperación es mayor que a la temperatura ordinaria. Este fenómeno se denomina deformación residual o estiramiento permanente y es propio del caucho.
- El caucho bruto absorbe agua. Los coagulantes usados en el látex al preparar el caucho afectan al grado de absorción de agua; usando ácido clorhídrico, sulfúrico o alumbre se obtienen cauchos con poder de absorción relativamente elevado. El poder de absorción de agua del caucho purificado es muy bajo.
- Gran variedad de sustancias son solubles o pueden dispersarse en caucho bruto, tales como el azufre, colorantes, ácido esteárico, N-fenil-2-naftilamina, pigmentos, aceites, resinas, ceras, negro de carbono y otras.
- El efecto deteriorante de luz y el calor sobre el caucho se reconoció largo antes del descubrimiento de la vulcanización.

Propiedades Químicas

- La solubilidad del caucho bruto en sus disolventes más comunes no es muy elevada. Para hacer una solución de 10% es necesaria cierta disociación, ya por medios químicos, empleando un oxidante, ya por medio físicos, utilizando un molino.
- Los disolventes más usados son el benceno y la nafta. Otros buenos disolventes son el tricloroetileno, tetracloroetano, pentacloroetano, tetracloruro de carbono, cloroformo, tolueno, xileno, keroseno y éter. El caucho se hincha primero poco a poco hasta las consistencias de gel y

después éste se dispersa formando una solución. El caucho bruto aumenta de 10 a 40 veces su propio peso en disolventes que a la temperatura ordinaria forman gel con el caucho.

- La viscosidad de la solución del caucho bruto es grande.
- El caucho bruto calentado hasta 200 ºC. se ablanda y sus soluciones tienen menor viscosidad, pero el número de dobles enlaces se conserva sin alteración.
- Cuando la temperatura se eleva hasta 250 ºC., los enlaces dobles se separan y tiene lugar la formación de anillos. El cambio a caucho cíclico eleva la densidad y la solubilidad, el producto obtenido es una dura y frágil resina.

2.9 VULCANIZACION DEL CAUCHO

Concepto.

El proceso de vulcanización es aquel en donde algunos materiales de composición variable y malos conductores de energía calorífica son sometidos a un calentamiento, con azufre u otro acelerante de composición similar, que tiene por finalidad producir un material uniforme que posea cualidades físicas mejoradas.

Este proceso se desarrolla durante un determinado periodo de tiempo, teniendo en cuenta que los intervalos de tiempo de cura sean los adecuados para no ocasionar ningún perjuicio al material que está siendo vulcanizado.

Durante la vulcanización del caucho, que generalmente se calienta en presencia de azufre durante un determinado periodo de tiempo, se generan dos fenómenos:

- El primero se da cuando los polímeros lineales paralelos cercanos constituyen entre sí puentes de entrecruzamiento generados por calor, por lo tanto el proceso a de ser controlado para evitar una vulcanización prematura del caucho.

- El segundo fenómeno se genera cuando los átomos de azufre encuentran espacios atractivos a lo largo de la molécula del caucho (estos espacios son llamados sitios de cura). En los sitios de cura los átomos de azufre se unen a sí mismos hasta formar una cadena que puede alcanzar el sitio de cura de otra molécula.

Ambos fenómenos permiten que el caucho sea más estable, que obtenga una mayor dureza, durabilidad y resistencia al ataque químico sin perder su elasticidad natural. Además el proceso de vulcanización hace del caucho un material termo rígido, ya que no se puede derretir en presencia de calor; es decir el caucho es sometido a un proceso irreversible donde no solamente se puede calentar en presencia de azufre, sino que también en presencia de otros aditivos como carbono, silicio, telurio, selenio y cloruro de azufre en fase líquida o de vapor.

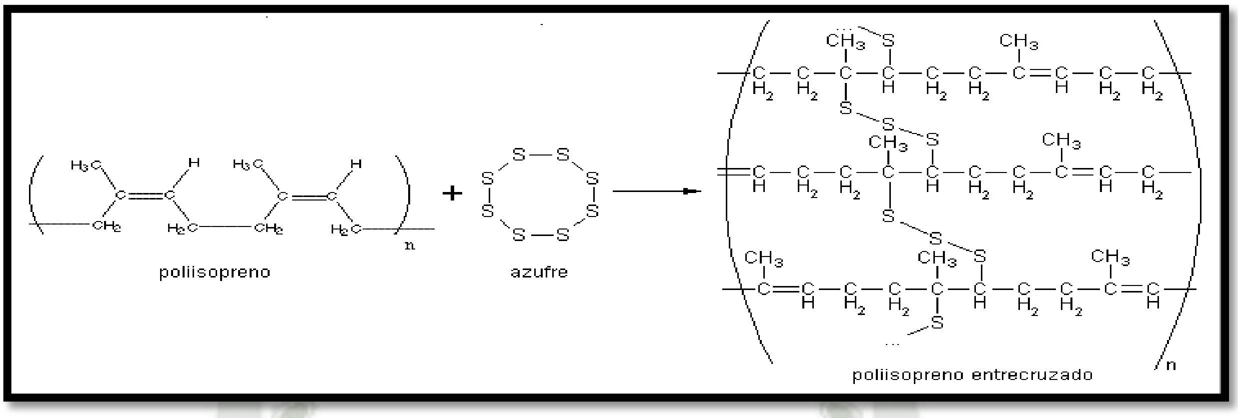
El poder calorífico generado durante la vulcanización se crea mediante fuentes que abarcan desde energía eléctrica por medio de resistencia de calentamiento, inducción y dieléctricos; corrientes de aire caliente o de gases inertes, y finalmente corrientes de agua caliente y vapor.

El azufre es un material con singulares propiedades. En determinadas circunstancias, formará cadenas de sus propios átomos. El carbono y el silicio pueden formar también esas cadenas. El proceso de vulcanización hace uso de este fenómeno.

A lo largo de la molécula del caucho, hay un número de sitios que son atractivos para los átomos de azufre. Son los llamados sitios de cura. En cada sitio de cura, un átomo de azufre se puede unir a sí mismo, y a partir de allí la cadena de átomos de azufre puede crecer hasta que alcance el sitio de cura de otra molécula. Estos puentes de azufre son usualmente de 2 a 10 átomos de largo, en contraste con los polímeros más comunes en los que la "columna vertebral" de carbonos puedes ser varios miles de veces de larga.

FIGURA Nº 2. 5

Estructura del Poliisopreno



Fuente: Libro de Química Raymond Chang

Punto de fusión del azufre es de 113ºC, su densidad es de 2.06, es soluble en acetona el sulfuro de carbono, el cloruro de azufre, el benceno y la trementina; cristaliza normalmente en el sistema rómbico. Cuando se funde a 113ºC, se convierte en un líquido amarillo, y si la temperatura aumenta lentamente se convierte en un líquido viscoso y rojizo oscuro, a medida que va alcanzando los 180 a 190ºC, volviéndose negro a 230ºC.

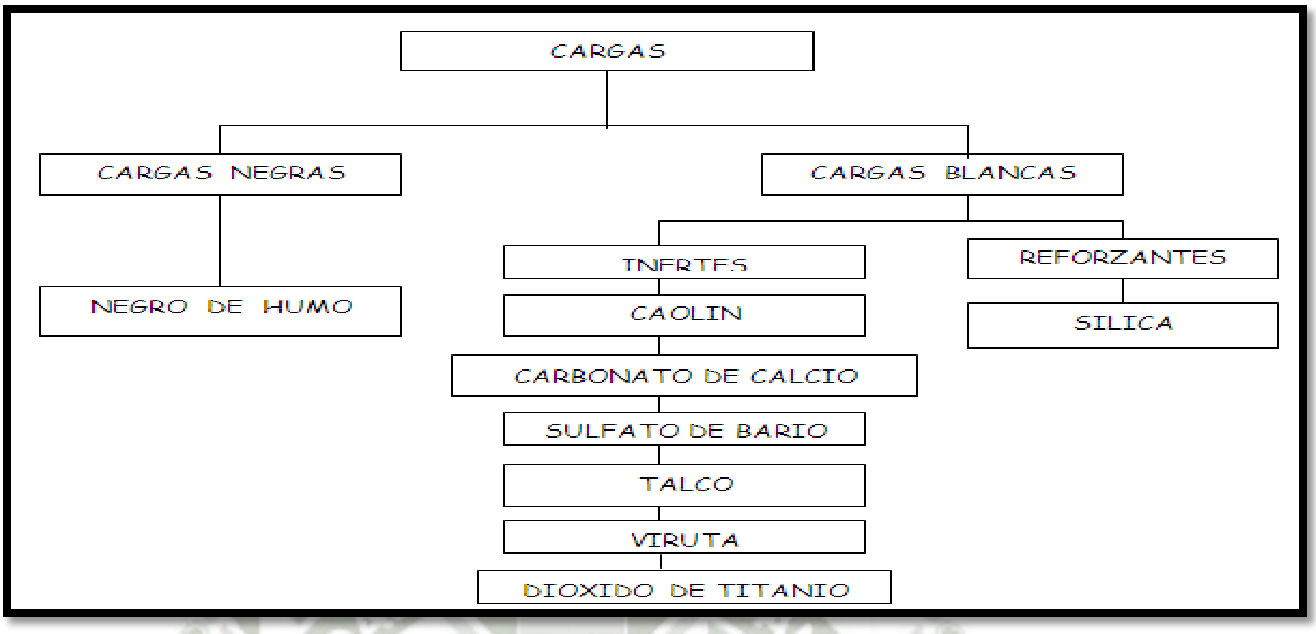
Cargas, la adición de cargas al caucho se realizan por dos razones:

- Técnica, porque logra propiedades y cualidades determinadas al producto final, en tal caso se denominan reforzante.
- Económica, porque abarata los productos elaborados, se denominan cargas inertes o no reforzante.

Las cargas es activa o reforzante cuando:
- Mejoran resistencia a la tracción
- Mejoran la resistencia a la abrasión.
- Mejoran la resistencia al desgarre.
- Aumentan la dureza.
- Aumentan la rigidez y modulo.

CUADRO Nº4

Clasificación de las Cargas Usadas en Elastómeros



Fuente: Libró de James Shackelford de Ciencia de materiales.

Negro de Humo, es un pigmento negro obtenido por descomposición térmica de hidrocarburos líquidos o gaseosos. El diámetro de una partícula individual esta en rango de los coloides, por debajo de 1200 A., la composición de partículas es carbono pseudo-grafítico amorfo, con variaciones de hidrógeno y carbono absorbidos químicamente. Mediante el microscopio electrónico el negro de humo aparece formando grupos o cadenas, el potencial reforzante de este pigmento esta poco influenciado por el tamaño del agregado y más por el tamaño de partículas dentro del mismo agregado. Cuanto menor sea el tamaño de las partículas más dificultoso es el procesado pero mayor el grado de reforzado alcanzado, cuando la estructura del negro de humo (forma total de agregados: solidez y tamaño) es mayor, corresponde compuestos crudos más viscosos y con menos nervio.

Peptizantes.

La peptización puede ser de dos tipos:

- **Peptización Física o Masticación,** es una rotura termo mecánica del caucho a temperaturas relativamente bajas, reduciendo la viscosidad, se usan los lubricantes y mejoran la procesabilidad de los compuestos.

- **Peptización química,** describe la rotura mecánica termo-óxidativa, catalizada del caucho a temperaturas elevadas, su uso está restringido al caucho natural.

Homogenizantes. Son mezclas de resinas aromáticas y alifáticas de diferente polaridad, se usan en caso de mezclas de cauchos difíciles de combinar, donde el proceso es Solvatación (asimilación de oxígeno). Es importante tener en cuenta los parámetros de solubilidad.

Plastificantes. Provocan el deslizamiento entre moléculas inhibiendo la fuerza de atracción intermolecular, facilitando la incorporación de los ingredientes al caucho, se agregan básicamente para auxiliar en las operaciones de mezclado, calandrado, extorsionado y molde. Influyen los parámetros de solubilidad al momento de mezcla.

Hay 2 formas de generar el movimiento interno molecular (resbalen unas cadenas respecto a otras), primero acortando la longitud, esto logrado con peptizantes, y la segunda provocar el deslizamiento de cadenas (lubricar) esto origina la disminución del módulo, dureza y también de su carga de rotura.

Promotores de adhesión. Son productos que se agregan a las formulaciones para aumentar la adhesión en crudo o pegajosidad de los compuestos. Son resinas de naturaleza termoplástica. Con su uso se logran mejoras en el procesado y moldeo sin alterar significativamente el módulo y la dureza del vulcanizado ya que las resinas endurecen nuevamente cuando el compuesto se enfría.

Lubricantes. Se usan en dosis relativamente bajas y permite mejorar la procesabilidad de los compuestos. Existen lubricantes internos y externos un lubricante interno servirá principalmente como modificador de la viscosidad específica y mejorará la dispersión de la carga mientras que el comportamiento de deslizamiento está influenciado en un menor grado. Un lubricante con acción predominantemente externa (plastificante) mejorará en gran medida el deslizamiento y reducirá la fricción entre el elastómero y la superficie de metal de los equipos de procesamiento, su influencia sobre la viscosidad del compuesto es marginal, altos niveles de dosis, sin embargo pueden llevar a una sobre lubricación y subsiguiente eflorescencia.

La lubricación se logra a través de una reducción de la fricción, en cuya fase inicial el lubricante cubre al elastómero y otros compuestos reduciendo la fricción contra las partes de metal del equipo de procesamiento, al elevar la temperatura, el lubricante comienza a derretirse y es moldeado en la matriz por la acción cizállate del mezclador. Tanto la velocidad y el grado de incorporación del lubricante dentro del elastómero están determinados por el punto de ablandamiento, viscosidad de ablandamiento y solubilidad, estos factores dependen de su estructura química y su polaridad.

Agentes de protección. El caucho sea natural o sintético está sujeto a deterioro por envejecimiento, que generalmente depende del grado de instauración del polímero, por lo que el caucho butílico, siliconas y algunos cauchos fluorados son los más protegidos debido a su nula instauración, caso contrario, son el butadieno, SBR y al caucho natural.

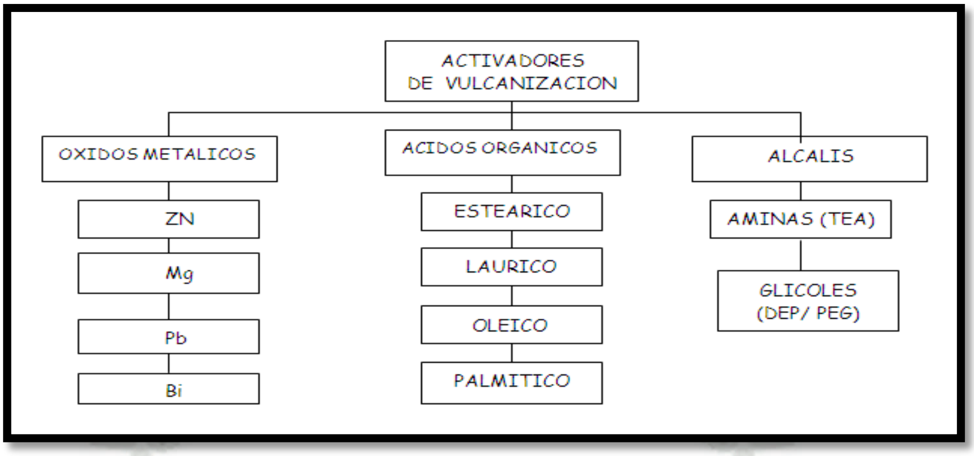
Al diferenciar entre el envejecimiento del caucho natural, este, da compuestos reblandecidos y pegajosos en su superficie, previamente a un cierto nivel de endurecimiento y fragilidad, en cambio el SBR por envejecimiento da compuestos quebradizos y endurecidos.

En ambos cauchos el deterioro por envejecimiento genera que la carga de rotura, elongación y resistencia al agrietamiento por flexión disminuyan progresivamente a medida que el material envejece. En cambio el módulo y dureza evolucionan de forma diferente según sea el caucho deteriorado.

Activadores de vulcanización. La acción conjunta de ácidos grasos (ácido esteárico y ácido oleico) en combinación con óxidos metálicos como el óxido de Zinc y el óxido de Mg activan la reacción del azufre y se denominan activadores.

CUADRO 5:

Tipos de Activantes para Vulcanización de un Elastómero



Fuente: Libro de James Shackelford de Ciencia de Materiales

La activación es una reacción entre el óxido metálico, el ácido graso y el azufre generando un jabón soluble en los polímeros, y con este aumento de solubilidad se promoverá la reacción de vulcanización.

Retardantes. Existen casos, en que la acción retardada de los acelerantes primarios no es suficiente para proteger al compuesto de un pre vulcanización durante el proceso, es ahí donde se usan los retardantes.

La vulcanización es el proceso irreversible durante el cual un compuesto de caucho, a través de un cambio en su estructura química (crosslink) se hace menos plástico y más resistente al hinchamiento por líquidos orgánicos; mientras que las propiedades elásticas son mejoradas y extendidas a un amplio rango de temperatura. Para generar esta vulcanización es necesario un agente vulcanizaste, que puede ser, el Azufre.

2.9.1 Fundamentos del proceso.

a)Durante la etapa de vulcanizado.

Como ya se mencionó en el punto anterior, el proceso de vulcanización busca la uniformidad del caucho para poder generar otras propiedades físicas dentro de él.

Para tal fin es necesario que se ejerza un control sobre aquellos factores que puede influir en la composición final del producto que se desea vulcanizar.

El primero de los dos factores esta relacionado al control de la uniformidad en la calidad de las materias primas y a la incorporación uniforme del azufre y otros aditivos durante las etapas del proceso de vulcanización. El segundo factor consiste en el control de los tiempos, presiones y temperaturas que se utilizan durante las operaciones.

Es importante mencionar que las condiciones pueden variar dependiendo del vulcanizado que se quiera obtener y de los medios con que se cuenta para éste.

Dichas condiciones generalmente son especificaciones previas del producto que consisten en determinar la dureza requerida, la cantidad de trabajo que es necesario realizar, el espesor del artículo y el tratamiento de las cargas de caucho después del tratamiento de cura.

Para poder llegar a la uniformidad y especificaciones deseadas para el producto, se hace imprescindible el uso de procedimientos que permitan manejar el aspecto térmico referente al espesor de los artículos de caucho.

Uno de los procedimientos consiste en manejar de forma escalonada las temperaturas. En un inicio se proporciona un calentamiento uniforme a toda la masa del artículo; luego, se eleva la temperatura hasta que esté próxima a la de vulcanización y finalmente, se calienta el caucho hasta alcanzar la temperatura de cura.

El segundo procedimiento consiste en realizar un enfriamiento externo lento (opuesto al procedimiento anterior donde el calentamiento era lento). Para esto se interrumpe el suministro de energía calorífica antes de llegar a la cura del caucho; luego, se sujeta a presión el molde que contiene a la masa, teniendo cuidado en que no existan otros factores (como el viento) que lo puedan enfriar. Finalmente, durante la etapa de sujeción, se introduce la energía calorífica en el seno de la masa del artículo. Este procedimiento de cura se denomina de “absorción”. Cabe resaltar que si el tamaño del producto a vulcanizar aumenta, es necesario disminuir la temperatura de cura y aumentar la duración para la misma de modo que se logre una uniformidad en todo el producto.

b) Después de la etapa de vulcanizado.

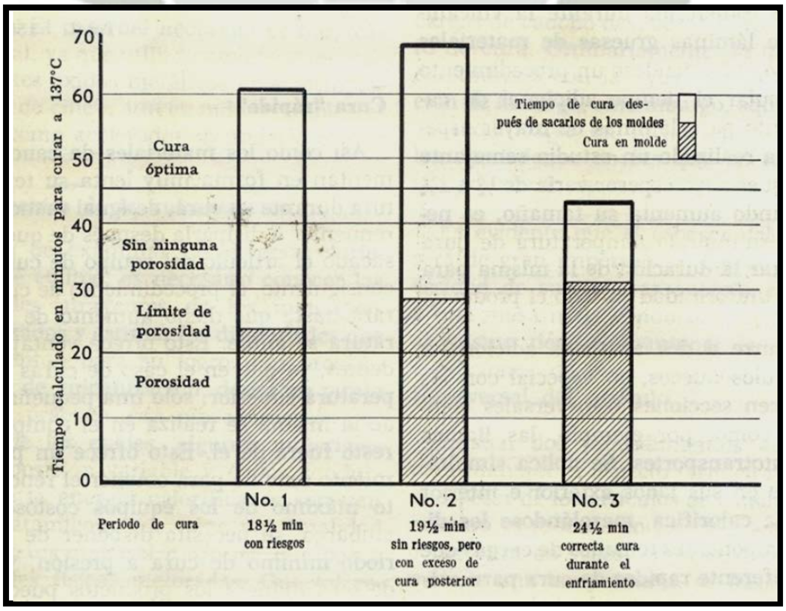
Así como el caucho aumenta su temperatura para llegar a un estado de cura, luego de ésta pasa a una etapa de enfriamiento en el cual la vulcanización termina cuando la temperatura de cura se reduce hasta un cierto nivel.

Cuando el caucho es calentado en presencia de azufre u otros acelerantes es recomendable que se disponga de un periodo mínimo de cura, ya que a ciertas temperaturas menores a ésta el producto podría resultar poroso o hincharse. Por eso es adecuado que la temperatura de enfriamiento llegue a ser igual a la de ambiente, la cual a su vez debe ser mayor a las temperaturas causantes de las porosidades en el caucho resultante del proceso de vulcanización.

A continuación se presenta el la Figura 2.6 en donde se muestra las consecuencias de cura en la misma clase de artículos, empleando tres periodos diferentes de moldeo.

FIGURA Nº 2.6:

Consecuencias de Cura empleando Tres Periodos Diferentes de Moldeo para un mismo Artículo.



Fuente: Revista del plástico.

En el primero, se ha pasado por escaso margen el límite que determina la condición porosa antes de sacarlos de los moldes, no obstante la temperatura de enfriamiento normal hasta la temperatura ambiente ha sobrepasado el límite de porosidad y se encuentra en estado de sobrecura. Para el segundo caso, si bien es cierto se elimina la condición porosa, se ha llegado a un estado de sobrecura debido a un calentamiento excesivo. Por último, en el tercer caso, la temperatura es mayor a la de porosidad y se encuentra en un estado de cura óptimo.

Está claro que de acuerdo al gráfico, las mejores curas se dan cuando los productos se obtienen con temperaturas menores y con periodos más prolongados de vulcanización.

Los periodos mínimos de cura son determinados por dos aspectos importantes, el primero de ellos es la temperatura máxima a la cual puede estar expuesto el caucho (150 ºC para el caucho natural) y el segundo aspecto esta determinado por las operaciones previas a las que son sometidos los artículos de caucho antes del vulcanizado. Las temperaturas a las que es sometido el caucho es un factor relevante en el resultado del proceso de cura, ya que al producto no se le puede inspeccionar mientras se está vulcanizando. Por lo tanto, tener un control sobre la temperatura ayudará a obtener un producto acorde con las propiedades deseadas.

2.9.2 Causas que generan un mal registro de temperaturas.

A continuación se mencionarán algunas causas que ocasionan inadecuados controles de temperatura y que por lo general hacen obtener productos defectuosos:

- Fallas en las calderas.
- Alargamientos innecesarios a las tuberías de vapor.
- Tuberías de vapor obstruidas por presencia de agua, esto ocasiona que las relaciones directas entre la temperatura y la presión cambien debido a que el vapor contenido en la tubería no está seco. La temperatura determina la rapidez de cura y debe medirse y controlarse durante la vulcanización.

- Mala colocación de los indicadores de presión y temperatura. En los casos que el vapor recorre distancias apreciables puede producirse una disminución de la temperatura, la cual varía de la originalmente pensada para el proceso de cura. Esto se debe a que las tuberías carecen de aislamiento térmico y para compensar esta pérdida de energía calorífica, es recomendable usar el vapor con algunos grados más de recalentamiento y reducir al mínimo la condensación antes de que el vapor llegue al dispositivo de vulcanización.
- Moldes sucios que impiden un contacto adecuado con la superficie de caucho. La energía calorífica transferida por conducción no sería la esperada.
- Disposición, en paralelo o serie, de las tuberías de vapor. Las tuberías colocadas en serie producen mayor diferencia de temperaturas entre sus puntos de entradas y salidas. La uniformidad de la temperatura es más adecuada disponiendo paralelamente a las tuberías, pero puede que se tenga una circulación deficiente debido a una deficiencia en las líneas. Cuando se tiene un alargamiento excesivo de las tuberías de vapor se producen pérdidas de energía calorífica, y cuando son muy cortas la circulación de vapor se hace lenta.

2.9.3 CURA ÓPTIMA.

El curado óptimo del caucho se puede escoger tomando como base propiedades adecuadas para el uso que se le quiera dar, por ejemplo: la dureza, la resistencia al desgarre, la abrasión, el agrietamiento a la flexión y otras propiedades. Además se debe tener en cuenta la vulcanización probable que experimenten los artículos cuando estén en servicio, especialmente cuando estén sometidos a calentamientos ocasionados por rozamientos internos.

2.9.4 CONTROL DEL PROCESO.

El control del proceso de vulcanización puede realizarse a través de los siguientes ensayos:

a) Determinación de la dureza, las lecturas que se pueda obtener de los durómetros son veraces cuando el caucho ya está enfriado, lo que significa esperar de 4 a 24 horas después de haber sido vulcanizado.

La medición de la dureza se puede realizar en el caucho caliente, pero puede determinar el rechazo del artículo examinado que en frío, puede ser aceptado. Es recomendable que las mediciones en caucho caliente siempre se realicen a la misma temperatura, por ejemplo puede hacerse después de que se saquen los moldes.

b) La comparación de pares térmicos entre la superficie del caucho que está siendo vulcanizado, el interior del mismo y las partes internas de autoclaves y prensas que influyen en el proceso, nos dan una idea de la uniformidad del proceso. Para esto las partes de las prensas y autoclaves deben de ser revisadas continuamente para comprobar la uniformidad térmica en su interior.

c) Ensayos que determinen la fuerzade adhesión entre las superficies de contacto de la porción de caucho y la del material que no es caucho (por ejemplo el material de los moldes metálicos).

d) Análisis químicos que determinen el contenido de azufre sin combinar proporcionan uno de los procedimientos más usados para determinar el grado de cura del caucho.

2.9.5 VALIDACIÓN DEL PROCESO PRODUCTIVO DE VULCANIZACIÓN

La validación es la verificación del resultado final de un proceso, en el cual no se puede ver, a simple vista, la transformación de la materia prima que formo parte de sus operaciones. Es así que la validación del proceso de caucho consiste en analizar y verificar los resultados de la vulcanización, para el cual no se puede observar directamente la transformación del caucho por intermedio de la transferencia de calor. Lo que si es posible es medir, acorde a algún tipo ensayo y diseño de experimentos, las propiedades del producto e ir haciendo algunos cambios pequeños, pero significativos para los principales factores que forman parte del procesamiento del caucho.

Para la presente proyecto de mejora, el tipo de ensayo a realizar será el de dureza, en base al cual, como bien ya se ha mencionado, examinaremos el proceso y sacaremos las conclusiones pertinentes al respecto.

2.10 REUTILIZACIÓN DE LOS DESECHOS SÓLIDOS EN LAS INDUSTRIAS DE LLANTAS Y NEUMÁTICOS.

La reutilización de las llantas cuyo ciclo de vida ya ha finalizado, éstas pueden ser utilizadas para la formación de arrecifes para peces, para muelles y protección para botes, como materas, para zonas de recreación (juguetes y columpios), utilizarlas para el control de la erosión, como elementos de protección para los árboles y como revestimiento de corrales.

El potencial para solucionar el problema del desecho por el uso de estos métodos es severamente limitado, es por esta razón que buscaremos una mezcla optima entre el caucho de las llantas, con polietileno de alta densidad, para darle un uso adecuado además estaremos colaborando en la preservación de nuestra ecología.

2.10.1 REENCAUCHADO.

El renovado (reencauchado) del neumático es un proceso mediante el cual se vuelve a utilizar un neumático gastado sustituyéndole la banda de rodadura.

El reencauchado se presenta como el recurso más eficaz para la recuperación de neumáticos con ahorro de material y energía. Se requiere más energía para fabricar un neumático nuevo que para reencauchado un neumático usado.

Hay dos técnicas diferentes de producción de un neumático renovado:

- ✓ Renovado en caliente: en este proceso la vulcanización se realiza en prensas con moldes a una temperatura comprendida entre 150 ºC y 160 ºC. Existe el renovado integral, donde se renueva la banda de rodamiento y los flancos (de talón a talón) y el renovado semi-integral, donde se renueva la banda de rodamiento y parte del flanco.
- ✓ Renovado en frío: en este proceso la banda de rodamiento está previamente vulcanizada y se adhiere mediante una goma (llamada

“de unión”), vulcanizándose en autoclaves a una temperatura entre 98 ºC y 125 ºC

- ✓ Renovado de banda clásico: la banda se fabrica en tiras longitudinales de unos 10 metros, que se cortan a la medida de la circunferencia del neumático.
- ✓ Renovado de banda en anillo: la banda se fabrica formando ya el anillo a la medida final de forma que no hay uniones.

2.11 TECNOLOGIAS DE REDUCCION DE TAMAÑO

Algunos de los procesos más empleados para producir polvo de caucho son: la molienda mecánica a temperatura ambiente, la molienda criogénica y la molienda húmeda.

2.11.1 MOLIENDA CRIOGÉNICA

A muy bajas temperaturas (-200ºC) el caucho se fragiliza desapareciendo su elasticidad característica siendo posible, por tanto desintegrarlo fácilmente.

El proceso de molienda criogénica viene acompañado por un primer paso de enfriamiento de las piezas de caucho con nitrógeno líquido. Este proceso produce la congelación de las piezas.

Las piezas congeladas pasan por un molino de impacto (similar a un percutor o martillo) donde son molidos en elementos más finos. El polvo obtenido se seca, se separan la fibra y el metal y se clasifica según los tamaños obtenidos.

La forma, tamaño, distribución de tamaños y características superficiales de las partículas de caucho molidas obtenidas por molienda criogénica son diferentes a las obtenidas por molienda a temperatura ambiente. Éstas últimas tienden a tener una forma irregular con una considerable rugosidad superficial y el caucho es parcialmente oxidado en la superficie debido al calor generado durante el proceso. Sin embargo, las partículas del polvo obtenidas por molienda criogénica a una temperatura por debajo de -70º C presentan una superficie relativamente suave, un amplio rango de tamaño de partícula así como una mínima oxidación superficial. Estas diferencias en la naturaleza y reactividad pueden producir diferentes propiedades en el producto final.

2.11.2 REGLA DE MEZCLAS

Con la regla de las mezclas se predicen propiedades como densidad, conductividad térmica y eléctrica (sólo para la dirección de las fibras, si son unidireccionales y continuas, ya que si no sabemos la dirección de las fibras y no se predicen sus propiedades).

Ejemplo:

$$\rho = f_{m\ x}\ \rho_m + f_{f\ x}\ \rho f$$

ρ = Densidad del material fibroso.
f_m = Fracción volumétrica de la matriz.
ρ_m = Densidad de la matriz.
f_f = Fracción volumétrica de las fibras.
ρ_f = Densidad de las fibras.

El módulo de la elasticidad se predice también con esta regla (sólo para fibras continuas y unidireccionales), pero sólo a baja tensión; a altas tensiones se deforma la matriz y contribuye poco a la rigidez del compuesto, no cumpliéndose la regla de las mezclas:

$$E = f_{f\ x}\ E_f$$

E = Modulo de la elasticidad.
f_f= Fracción volumétrica de las fibras.
E_f = Módulo de la elasticidad de las fibras.

Si la carga se aplica en dirección perpendicular a las fibras:

$$1/E = (f_m / E_m) + (f_f / E_f)$$

La resistencia de un material compuesto reforzado por fibras depende de la unión entre las fibras y la matriz.

Se puede predecir la resistencia con la regla de las mezclas para un material con fibras continuas y paralelas:

$$\sigma = f_m \times \sigma_m + f_f \times \sigma_f$$

σ = Resistencia del material.

σ_m = Tensión que actúa sobre la matriz cuando el compuesto está deformado hasta el punto donde se fractura la fibra

σ_f = Resistencia de las fibras.

2.12 CONCEPTO DE MISCIBILIDAD.

Desde el punto de vista práctico, una mezcla polimérica miscible se define como una mezcla homogénea estable que exhibe propiedades macroscópicas similares a las que se esperarían para un material homogéneo. La homogeneidad no se define en este caso a nivel de microscopio electrónico; incluso se han observado estructuras heterogéneas en polímeros amorfos.

La homogeneidad se define a un nivel tal que es similar al responsable de propiedades macroscópicas tales como la transición vítrea y la transparencia óptica (suponiendo que los dos polímeros tienen índices de refracción diferentes). Se postula por tanto, que cada mezcla polimérica tiene un “tamaño de dominio crítico” característico por encima del cual la mezcla exhibe propiedades heterogéneas y por debajo homogéneas.

Resaltemos también que el concepto del tamaño de dominio crítico es inútil para un investigador interesado en propiedades macroscópicas útiles en problemas industriales prácticos. Para ese investigador la mezcla miscible (o compatible) es aquella que exhibe una transición vítrea única Tg y la miscibilidad implica homogeneidad de la mezcla hasta una escala semejante a la responsable de los movimientos cooperativos asociados con Tg.

2.13 LA TRANSICIÓN VÍTREA EN POLÍMEROS.

Es la temperatura en el cual un polímero cambia de un estado rígido y quebradizo a otro blando y maleable, está presente sólo en polímeros amorfos y es diferente para cada polímero. Es común imaginar a la transición vítrea como a un tipo de fusión del polímero. Pero no es la manera correcta. Hay muchas diferencias importantes entre la transición vítrea y la fusión.

Existe otra gran diferencia entre fusión y transición vítrea. Cuando usted calienta un polímero cristalino a velocidad constante, la temperatura aumentará a velocidad constante. La cantidad de calor requerida para incrementar un grado Celsius la temperatura de un gramo de polímero, se denomina capacidad calorífica.

Sin embargo, la temperatura seguirá aumentando hasta que el polímero llegue a su punto de fusión. Cuando esto sucede, la temperatura se mantendrá constante por un momento, aun cuando se suministre más calor. Se mantendrá constante hasta que todo el polímero haya fundido completamente. Luego, la temperatura del polímero comenzará a ascender nuevamente. El aumento se detiene porque la fusión requiere energía.

Pero cuando se calienta un polímero amorfo hasta su Tg, sucede algo diferente. Primero se calienta y la temperatura se eleva a una velocidad determinada por la capacidad calorífica del polímero. Pero cuando se alcanza la Tg ocurre algo divertido. La temperatura sigue aumentando, no se detiene. No hay calor latente de transición vítrea. La temperatura se sigue incrementando.

Pero por encima de la Tg ya no lo hace a la misma velocidad que por debajo. El polímero experimenta un incremento en su capacidad calorífica luego de alcanzar la transición vítrea. La temperatura de transición vítrea, es un incremento de la pendiente, lo que significa, obviamente, que tenemos un aumento en la capacidad calorífica. Podemos observar un cambio en capacidad calorífica en la Tg, pero no una ruptura, como sí puede apreciarse en el caso de un polímero cristalino.

2.14 ANÁLISIS MECÁNICO DINÁMICO

La respuesta visco elástica de los materiales poliméricos es un tema de Importancia tanto teórica como práctica. Como su nombre indica el comportamiento frente a las fuerzas externas es intermedio entre un sólido elástico y un material viscoso. Es de notar la dependencia que con el tiempo y la temperatura tienen las propiedades mecánicas de los polímeros cuando se compara con otros materiales estructurales como los metales.

La visco elasticidad es una materia de gran complejidad y es posible distinguir dos aproximaciones básicas que se conocen como la aproximación mecánica del continuo y la aproximación molecular.

La primera pretende describir el comportamiento visco elástico de un cuerpo mediante un esquema macroscópico, mientras que el último pretende deducir propiedades víscoelásticas macroscópicas a partir de la arquitectura molecular.

La magnitud principal es el módulo del material y se define como la relación entre el esfuerzo aplicado y la deformación resultante. En los polímeros esta magnitud depende de la temperatura y del tiempo desde que se aplicó el esfuerzo. La variación con la temperatura explica la existencia de dos tipos de estado físicos en los polímeros: tipo caucho y vítreo.

CAPITULO III

PROCEDIMIENTO EXPERIMENTAL

3. PROCEDIMIENTO EXPERIMENTAL

Este estudio se desarrolla en el Laboratorio de Ensayo de MaterialesdelPrograma Profesional de Ingeniería Mecánica, Mecánica – Eléctrica y Mecatrónica (R - 102) de la Universidad Católica de Santa María, donde realizamos nuestras mezclas poliméricas y posteriormente se realizaran en instalaciones los ensayos respectivos en las instalaciones de la Universidad Nacional de San Agustín Arequipa.

Aquí realizamos la preparación y caracterización del polietileno reciclado, obtenido de las recicladoras existentes en la ciudad y caucho reciclado obtenido de las llantas del transporte urbano, y carga pesada, este caucho lo conseguimos triturado de las reencauchadoras ubicadas en el Distrito de Cerro Colorado. Las mezclas fueron preparadas en una mezcladora que se encuentra dentro del laboratorio esta tiene una capacidad de 100gr.

Para las mezclas se tomara como base el diseño experimental $\mathbf{2^k}$ para medir cómo influyen k factores en un proceso y descubrir si interaccionan entre ellos. Este diseño permite explorar una zona escogida del dominio experimental y encontrar una dirección prometedora para la optimización posterior. Tomaremos la granulometría y el porcentaje de polietileno de alta densidad (PEAD).

1. Identificar los factores que pueden influir en la variable respuesta y proponer un Modelo.
2. Realizar el experimento, tomando las observaciones necesarias.
3. Estimar los parámetros del modelo.
4. Contrastar si los factores influyen en la respuesta.
5. Si los factores influyen en la respuesta, detectar dónde radican las diferencias.
6. Si algún factor no influye, simplificar el modelo y repetir los pasos anteriores.
7. Realizar la diagnosis del modelo mediante el análisis de los residuos.

3.1 Caracterización de las muestras

Los materiales obtenidos, el polietileno de alta densidad fueron adquiridos, lavado y picado en las recicladoras de Pachacutec en el distrito Cerro Colorado listo para ser pasado por mallas. El caucho se obtuvo de las reencauchadoras y de plantas industriales de caucho ubicadas en el Distrito de Cerro Colorado, el caucho que conseguimos se encontró triturado, limpio y listo para usarlo.

FIGURA Nº 3.1

Caucho obtenido de las reencauchadoras

Fuente: Laboratorio Antonio Raimondi Universidad Nacional de San Agustín

FIGURA Nº 3.2

Polietileno de alta densidad

Fuente: Laboratorio Antonio Raimondi Universidad Nacional de San Agustín

a) SECADO DE LOS MATERIALES

El Polietileno de alta densidad, como el caucho; antes de pasar al proceso de mezclado fue secado en una estufa o secador que se encuentra dentro del laboratorio de Polímeros de la Universidad Nacional De San Agustín a una temperatura de 60°C durante una hora. Por debajo de la temperatura de transición vítrea (Tg), y por el cual no existirá alguna modificación en la estructura del material a utilizar.

FIGURA Nº 3.3

Secadora

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

b) GRANULOMETRÍA DE LOS MATERIALES

En este proceso determinaremos la cantidad en porcentajes de diversos tamaños que constituyen el polietileno de alta densidad, y posteriormente mezclarlo con el caucho. Se utiliza tamices Malla # 10, Malla # 8, Malla # 6, y la Malla #4.

Vaciaremos el polietileno de alta densidad directamente en el juego de tamices previamente limpiados y ensamblados y dispuestos, de arriba abajo, en orden decreciente de tamaños, de abertura con el fondo y la tapa.

Aplicaremos un movimiento, este movimiento lo daremos con una zaranda que se encuentra en las Instalaciones del Instituto Honorio Delgado Espinoza; el tiempo de tamizado será de 10 a 15 minutos.

3.2 PREPARACIÓN DE LAS MEZCLAS

La preparación de las mezclas comienza con la recolección del plástico reciclado luego se procede a hacer limpieza y secado de **polietileno de alta densidad** para posteriormente ser pasado por las mallas, al igual que el caucho. El material seleccionado, es introducido en la mezcladora, este previamente tiene que ser preparado, se quita las impurezas; para luego ser introducido el caucho triturado; la mezcladora se calienta a 130° C, homogenizamos el caucho y esperamos que se caliente, para introducir el PEAD (polietileno de alta densidad). Mezclamos los dos polímeros para formar una mezcla, aunque los polímeros no se mezclan fácilmente.

El Tiempo total de mezclado es de 15 minutos, tiempo de homogenizado del caucho es de 5 minutos, al minuto 6 introducimos el PEAD, esperamos 8 minutos más para su homogenización de la mezcla.

El control reológico lo tomamos por medio de un amperímetro, tiempos tomados a cada minuto.

FIGURA Nº3.4

Mezcladora de caucho

Fuente: Laboratorio del Programa Profesional de Ingeniería Mecánica, Mecánica Eléctrica y Mecatrónica de la Universidad Católica Santa María.

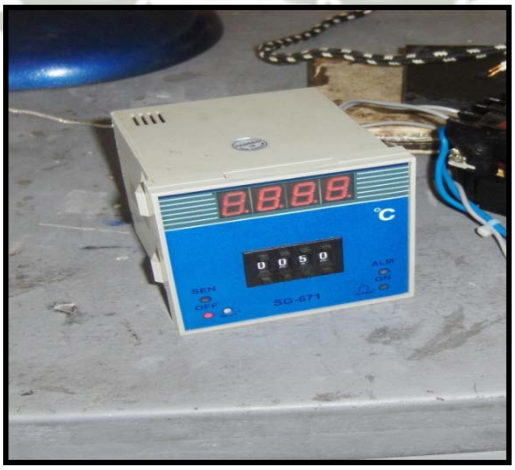
FIGURA Nº 3.5

Mezcladora de Caucho con Resistencias

Fuente: Laboratorio del Programa Profesional de Ingeniería Mecánica, Mecánica Eléctrica y Mecatrónica de la Universidad Católica Santa María.

FIGURA Nº 3.6

Pirómetro



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

FIGURA Nº 3.7

Amperímetro de Pinzas

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

3.3 PREPARACIÓN DE LAS PLACAS

a) PICADO DE LAS MEZCLAS OBTENIDAS

La masa obtenida de la mezcladora, es aplanada por la fuerza de un rodillo y prensa, posteriormente picado con la ayuda de tijeras y cúter.

Una vez picado, es pesado en una balanza electrónica.

FIGURA Nº 3.8

Mezcla Aplanado Caucho más PEAD

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 3.9

Gránulos de la Mezcla Caucho más HDPE

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 3.10:

Pesado de la mezcla

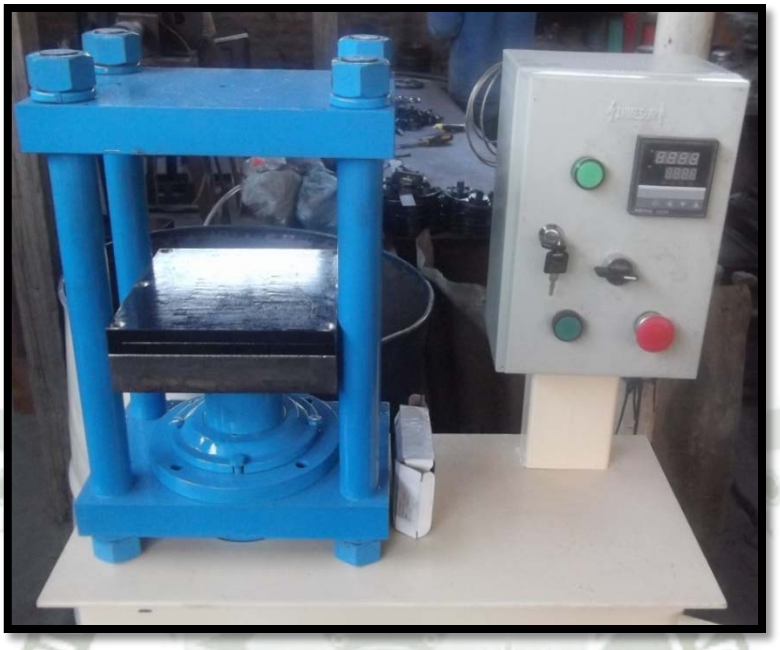
Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

3.4 ELABORACIÓN DE LAS PLACAS

Los gránulos obtenidos, previamente pesados, son llevados a unos moldes, que están dentro de la prensa de conformado, previamente acondicionado, con resistencias de cerámicos, para poder calentar los moldes, el molde es calentado a 170º C; es aquí cuando cargamos el molde, cerramos las placas, y le aplicamos una presión progresiva hasta llegar a los 100 Bar. Por un tiempo de 5 minutos, pasado este tiempo se deja enfriar los moldes a temperatura ambiente para posteriormente poder extraer las placas obtenidas en el molde.

FIGURA Nº 3.11

Termo Prensa de Conformado



Fuente: Laboratorio del Programa Profesional de Ingeniería Mecánica, Mecánica Eléctrica y Mecatrónica de la Universidad Católica Santa María.

FIGURA Nº 3.12

Moldes para la Elaboración de las Placas

Fuente: Laboratorio del Programa Profesional de Ingeniería Mecánica, Mecánica Eléctrica y Mecatrónica de la Universidad Católica Santa María.

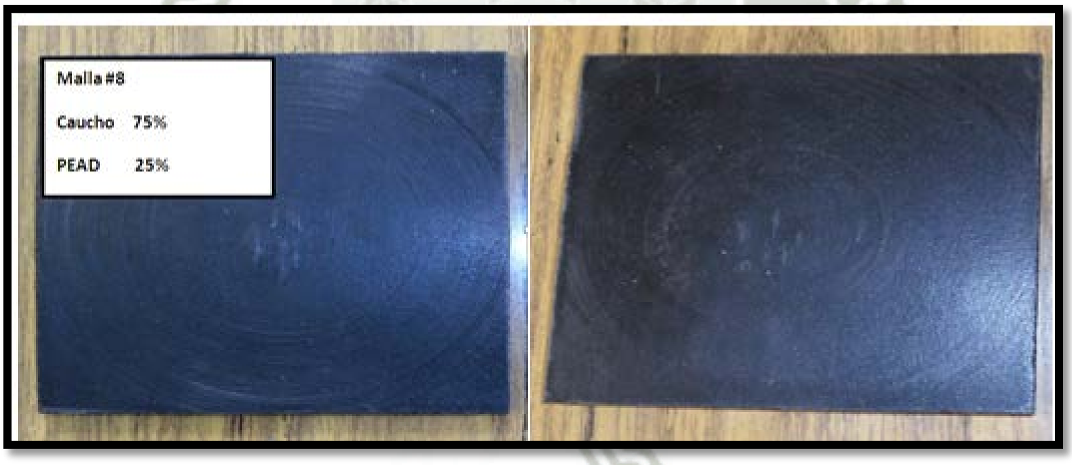
FIGURA Nº 3.13

Placas Malla # 10

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 3.14

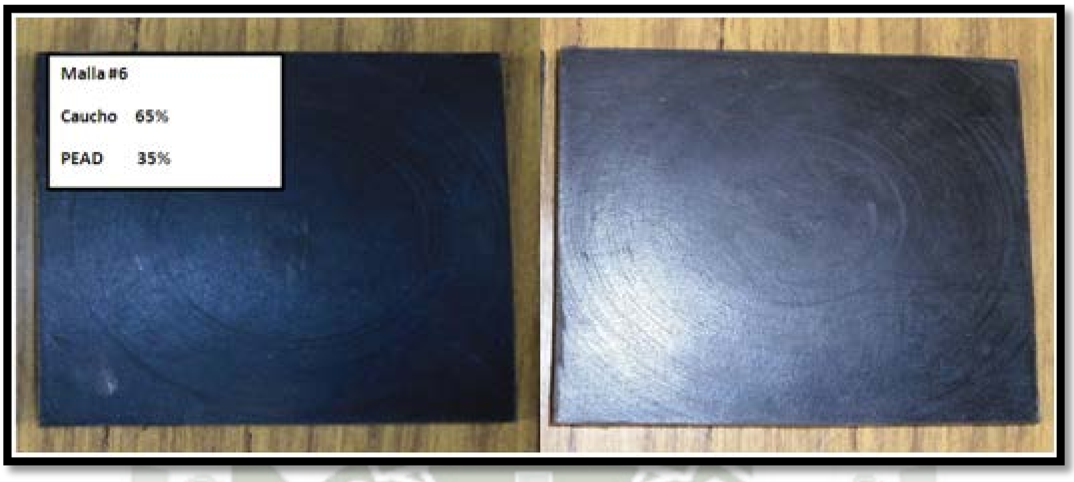
Placa Malla # 8



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 3.15

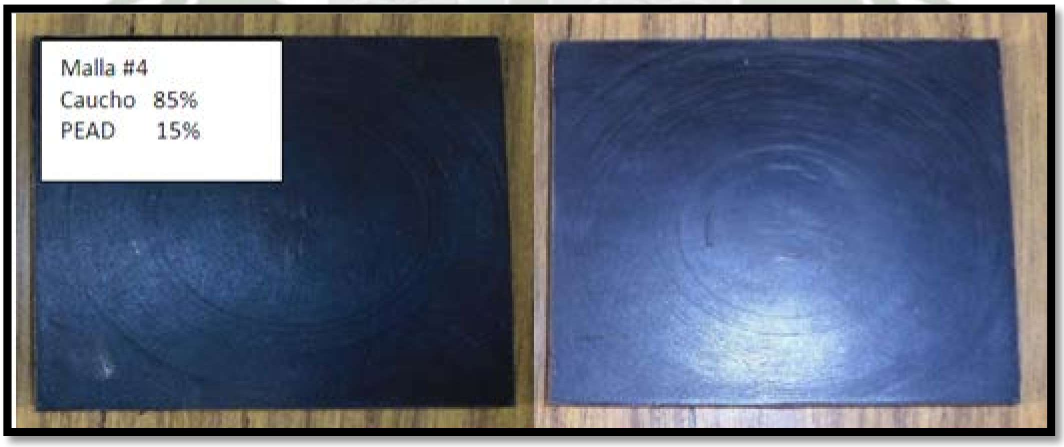
Placa Malla #6



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 3.16

Placa Malla # 4



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Una vez retirado de los moldes, son etiquetados, para que no tengamos confusiones, y realizar sus respectivos ensayos (Moldes Según Norma ASTM D3182).

Las placas obtenidas tienen la apariencia de caucho, con la resistencia suficiente (primera impresión) para ser utilizado en aplicaciones de pisos (pavimentos blandos). Estos pavimentos son ecológicos por qué no contiene adición de componentes tóxicos dañinos para el medio ambiente. Se trabaja, exclusivamente con material reciclado.

Los residuos producidos por los pavimentos de caucho reciclado no están considerados como tóxicos ni peligrosos. Los residuos de recorte, o trozos no utilizados pueden ser reutilizados. Nuestros pavimentos entonces pueden ser reciclados.

Las muestras obtenidas son cuadrados de aproximadamente 10 cm de lado con un espesor de 1.5 cm, deben tener unas superficies totalmente lisas para poder obtener unos resultados más precisos al momento de realizar las indentación, al realizar los ensayos de caída de bola (resiliencia), dureza y tracción.

3.5 ENSAYO DE IMPACTO DE CAÍDA DE BOLA

En este análisis tomamos como referencia de la Norma **ASTM F1487**. Se menciona las especificaciones de desempeño de seguridad para equipos de áreas de juego para uso público.

Este ensayo ha sido concebido con el fin de generar pautas que disminuyan el riesgo al impacto resultante de caídas.

Veremos aquí el rendimiento de amortiguación del material de superficie, la altura crítica del material de superficie.

FIGURA Nº 3.17

Equipo para en Ensayo de Caída de Impacto de Bola

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Este equipo está compuesto de una placa base de madera con tornillos reguladores para poner nivel, una placa metálica con sujetadores fijadores de las muestras de placas de caucho, un brazo de sujeción para el tubo de caída, el tubo de caída está provisto de una cinta métrica, adicionalmente de una cámara filmadora, donde registraremos y congelaremos cada caída de bola, para su respectivo análisis.

Una vez que tenemos preparado el equipo, soltamos de la parte superior una bola de acero de 0.40 metros de altura, hacemos esto en cinco repeticiones, sacamos un promedio dentro de nuestro tablas de análisis.

3.6 ENSAYO DE DUREZA

Este ensayo es para determinar la transformación de la materia prima después de realizar la mezcla. El ensayo de dureza a realizar corresponde al Método Estándar de Prueba para las propiedades del Cauchola cual pertenece específicamente a la Norma **ASTM D 2240- 03**.

El propósito de este ensayo será el de poder medir la dureza basada en la penetración de un indentador de un tipo determinado sobre las muestras a analizar. Teóricamente, los resultados de la dureza de indentación deberán ser inversamente proporcionales a la hendidura realizada y directamente proporcional al módulo de elasticidad y a la viscosidad del material. Es importante mencionar que los resultados de este ensayo dependerán en gran medida de la geometría del indentador y la fuerza aplicada sobre el material objeto de análisis; sin embargo, no existe una relación entre los valores de dureza determinados por diferentes durómetros sobre un mismo material. Las unidades de dureza a utilizar en los ensayos será la de Shore A.

FIGURA Nº 3.17

Durómetro Shore A

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

CAPITULO IV

RESULTADOS Y DISCUSIONES

4. RESULTADOS Y DISCUSIONES

En este capítulo presentaremos los resultados obtenidos en la elaboración de pavimentos blandos, seguido con las interpretaciones, de cada ensayo realizado

4.1 CARACTERIZACIÓN DE LAS MUESTRAS

a) GRANULOMETRÍA DE LOS MATERIALES

El Polietileno fue pasado por mallas Malla # 10, Malla # 8, Malla # 6, y Malla # 4. El caucho no lo pasamos por mallas ya que conseguimos un caucho triturado en un tamaño muy pequeño. Esto principalmente para su respectivo análisis reológico, al momento de las mezclas.

CUADRO Nº 6

DISTRIBUCIÓN DEL ANÁLISIS GRANULOMÉTRICO

USA Estándar ASTM E 11-61	Material Retenido (gr)	%Retenido	%Acumulado
4	234.5	46.90	46.90
6	138.2	27.64	74.54
8	95.7	19.14	93.68
10	25.5	5.10	98.78
Fondo	3.4	0.68	99.46
Total	**497.3**	**99.46**	

Perdidas (gr.)	2,7
Material retenido(gr.) + perdidas (gr.)	500
% de perdidas	0.54
% Acumulado + % de perdidas	**100**

Fuente: Laboratorio del Instituto Honorio Delgado Espinoza

Cantidad total de caucho utilizado fue de 500 gr.

Del Cuadro Nº 6 observamos que la mayor cantidad de caucho encontrado en la malla pasante # 4, aquí tenemos 46.90%; viendo los otros porcentajes, es también recomendable trabajar con malla # 6 y malla # 8.

FIGURA Nº 4.1

Malla # 4

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 4.2

Malla # 6

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 4.3

Malla # 8

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

FIGURA Nº 4.4

Malla # 10

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

4.2 RESULTADOS DE LA PREPARACIÓN DE LAS MEZCLAS

Las mezclas se toman como base el diseño experimental 2^k, este diseño permite explorar una zona escogida del dominio experimental y encontrar una dirección prometedora para la optimización posterior.

Para la optimización de las mezclas, es necesario saber cuáles son las variables independientes (ensayo a la bola, Dureza) y las variables dependientes (Granulometría medidos en mallas, y porcentaje de caucho en las mezclas).

CUADRO Nº 7

Identificación de las variables dependientes

FACTORES	Nivel (-)	Nivel (+)
Granulometría	Malla Nº 4	Malla Nº 10
Porcentaje de caucho	65 %	85 %

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

CUADRO Nº 8
Matriz con Diseño Adicionándole másMezclas para una Mejor Evaluación

	Valores actuales	
Prueba #	**A** **Granulometría**	**B** **Porcentaje de caucho**
1	Malla #10	65
2	Malla#10	75
3	Malla#10	85
4	Malla #8	65
5	Malla #8	75
6	Malla #8	85
7	Malla #6	65
8	Malla #6	75
9	Malla #6	85
10	Malla #4	65
11	Malla #4	75
12	Malla #4	85

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

4.3 RESULTADOS DEL CONTROL REOLÓGICO

CUADRO Nº 9

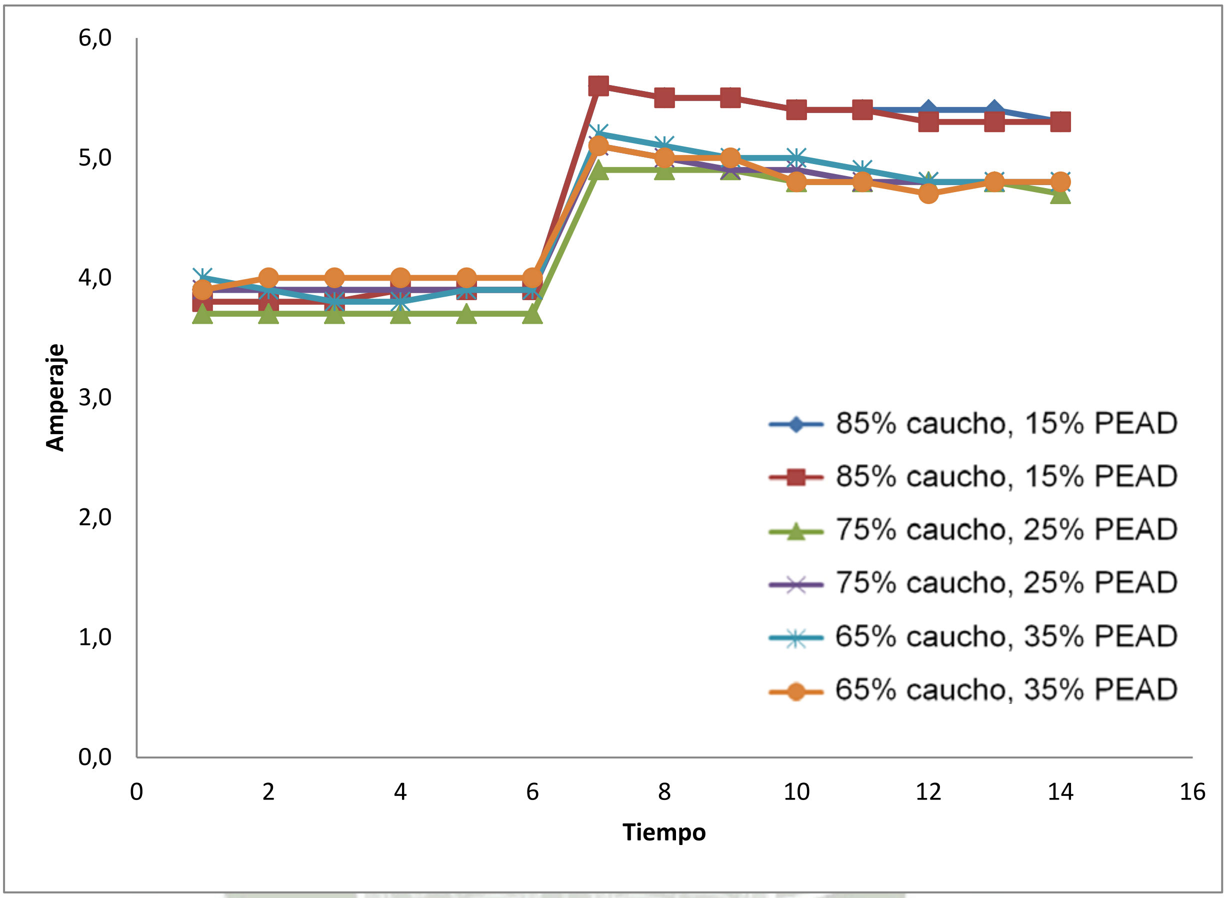
Datos Obtenidos durante el Mezclado usando Malla # 4

Malla # 4						
	85% de Caucho, 15% de PEAD	**85% de Caucho, 15% de PEAD**	**75% de Caucho, 25% de PEAD**	**75% de Caucho, 25% de PEAD**	**65% de Caucho, 35% de PEAD**	**65% de Caucho, 35% de PEAD**
Tiempo (min)	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**
1	3,8	3,8	3,7	3,9	4,0	3,9
2	3,8	3,8	3,7	3,9	3,9	4,0
3	3,8	3,8	3,7	3,9	3,8	4,0
4	3,8	3,9	3,7	3,9	3,8	4,0
5	3,8	3,9	3,7	3,9	3,9	4,0
6	3,8	3,9	3,7	3,9	3,9	4,0
7	5,6	5,6	4,9	5,1	5,2	5,1
8	5,5	5,5	4,9	5,0	5,1	5,0
9	5,5	5,5	4,9	4,9	5,0	5,0
10	5.3	5,4	4,8	4,9	5,0	4,8
11	5,4	5,4	4,8	4,8	4,9	4,8
12	5,4	5,3	4,8	4,8	4,8	4,7
13	5,4	5,3	4,8	4,8	4,8	4,8
14	5,3	5,3	4,7	4,8	4,8	4,8

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

GRAFICA Nº 4.1:

Tiempo vs Amperaje Malla # 4



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

Observamos, los primeros 6 minutos casi horizontal existiendo un consumo uniforme de energía, al agregar el PEAD aumenta su consumo, a partir del minuto 7, para posteriormente estabilizarse; además tenemos que todos los porcentajes usados para la mezcla, tienen casi el mismo comportamiento, con pequeña diferencia, del caucho al 85%, y 15% de PEAD, estimamos que aquí existe un poco más de consumo de energía.

CUADRO Nº 10

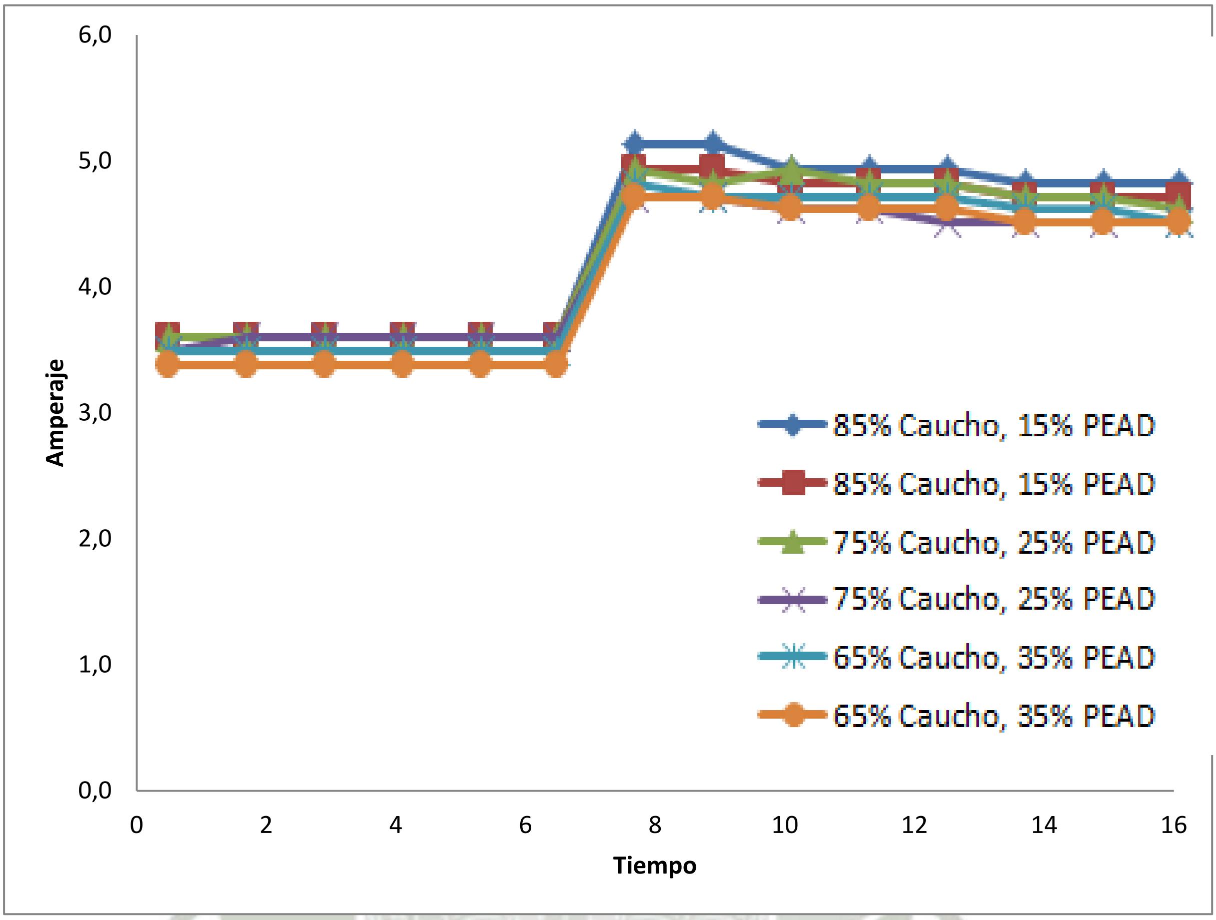
Datos Obtenidos durante el Mezclado usando Malla # 6

Malla # 6						
	85% de Caucho, 15% de PEAD	85% de Caucho, 15% de PEAD	75% de Caucho, 25% de PEAD	75% de Caucho, 25% de PEAD	65% de Caucho, 35% de PEAD	65% de Caucho, 35% de PEAD
Tiempo (min)	Amperaje (A)	Amperaje (A)	Amperaje (A)	Amperaje (A)	Amperaje (A)	Amperaje (A)
1	3,8	3,8	3,8	3,7	3,7	3,6
2	3,8	3,8	3,8	3,8	3,7	3,6
3	3,8	3,8	3,8	3,8	3,7	3,6
4	3,8	3,8	3,8	3,8	3,7	3,6
5	3,8	3,8	3,8	3,8	3,7	3,6
6	3,8	3,8	3,8	3,8	3,7	3,6
7	5,3	5,1	5,1	4,9	5,0	4,9
8	5,3	5,1	5,0	4,9	4,9	4,9
9	5,1	5,0	5,1	4,8	4,9	4,8
10	5,1	5,0	5,0	4,8	4,9	4,8
11	5,1	5,0	5,0	4,7	4,9	4,8
12	5,0	4,9	4,9	4,7	4,8	4,7
13	5,0	4,9	4,9	4,7	4,8	4,7
14	5,0	4,9	4,8	4,7	4,7	4,7

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

GRAFICA Nº4.2

Tiempo vs Amperaje Malla # 6



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Observamos, que los primeros 6 minutos casi horizontal; existiendo un consumo uniforme de energía, al agregar el PEAD aumenta su consumo, a partir del minuto 7, para posteriormente estabilizarse; además tenemos que todos los porcentajes usados para la mezcla, tienen casi el mismo comportamiento, con pequeña diferencia, del caucho al 85%, 15% de PEAD, y uno de las mezclas de 75% caucho y 25% de PEAD; estimamos que aquí existe un poco más de consumo de energía.

CUADRO Nº 11

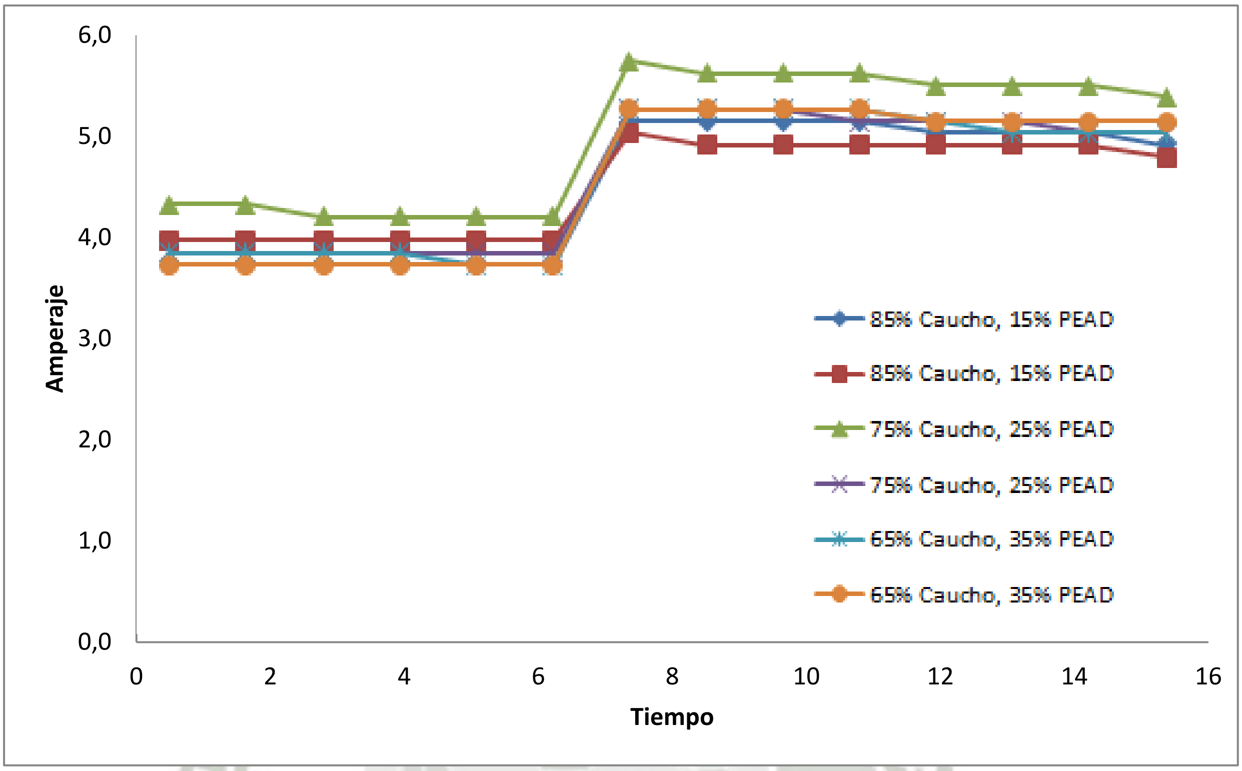
Datos Obtenidos durante el Mezclado usando Malla # 8

Malla # 8						
	85% de Caucho, 15% de PEAD	**85% de Caucho, 15% de PEAD**	**75% de Caucho, 25% de PEAD**	**75% de Caucho, 25% de PEAD**	**65% de Caucho, 35% de PEAD**	**65% de Caucho, 35% de PEAD**
Tiempo (min)	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**
1	3,7	3,9	4,2	3,8	3,8	3,7
2	3,7	3,9	4,2	3,8	3,8	3,7
3	3,7	3,9	4,1	3,8	3,8	3,7
4	3,7	3,9	4,1	3,8	3,8	3,7
5	3,7	3,9	4,1	3,8	3,7	3,7
6	3,7	3,9	4,1	3,8	3,7	3,7
7	4,9	4,8	5,4	5,0	5,0	5,0
8	4,9	4,7	5,3	5,0	5,0	5,0
9	4,9	4,7	5,3	5,0	5,0	5,0
10	4,9	4,7	5,3	4,9	5,0	5,0
11	4,8	4,7	5,2	4,9	4,9	4,9
12	4,8	4,7	5,2	4,9	4,8	4,9
13	4,8	4,7	5,2	4,8	4,8	4,9
14	4,7	4,6	5,1	4,8	4,8	4,9

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

GRAFICA Nº4.3

Tiempo vs Amperaje Malla # 8



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Observamos, los primeros 6 minutos casi horizontal existiendo un consumo uniforme de energía, al agregar el PEAD aumenta su consumo, a partir del minuto 7, para posteriormente estabilizarse; además tenemos que todos los porcentajes usados para la mezcla, tienen casi el mismo comportamiento, con pequeña diferencia, del caucho al 75%, 25% de PEAD, y uno de las mezclas de 65% caucho y 35% de PEAD; estimamos que aquí existe un poco más de consumo de energía.

CUADRO Nº 12

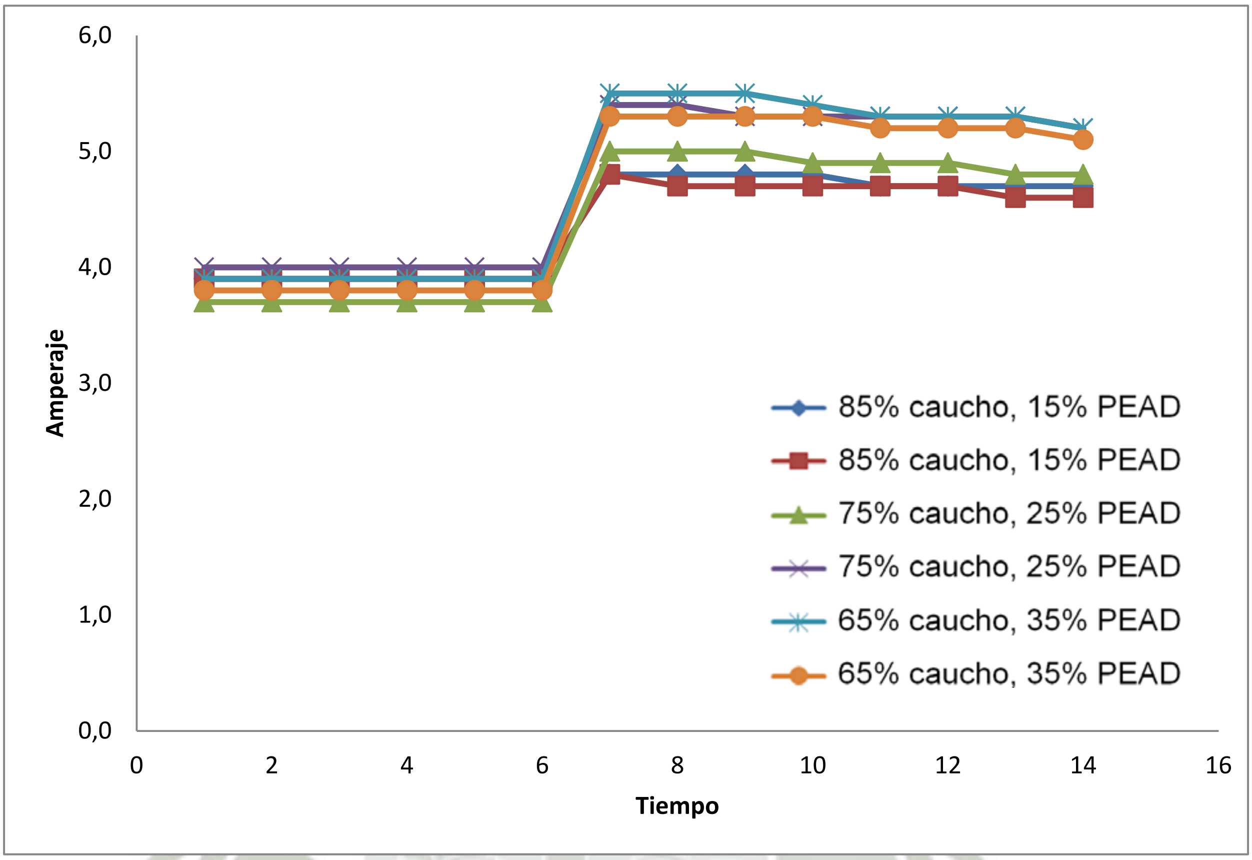
Datos Obtenidos durante el Mezclado usando Malla # 10

Malla # 10						
	85% de Caucho, 15% de PEAD	**85% de Caucho, 15% de PEAD**	**75% de Caucho, 25% de PEAD**	**75% de Caucho, 25% de PEAD**	**65% de Caucho, 35% de PEAD**	**65% de Caucho, 35% de PEAD**
Tiempo (min)	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**	**Amperaje (A)**
1	3,9	3,9	3,7	4,0	3,9	3,8
2	3,9	3,9	3,7	4,0	3,9	3,8
3	3,9	3,9	3,7	4,0	3,9	3,8
4	3,9	3,9	3,7	4,0	3,9	3,8
5	3,9	3,9	3,7	4,0	3,9	3,8
6	3,9	3,9	3,7	4,0	3,9	3,8
7	4,8	4,8	5,0	5,4	5,5	5,3
8	4,8	4,7	5,0	5,4	5,5	5,3
9	4,8	4,7	5,0	5,3	5,5	5,3
10	4,8	4,7	4,9	5,3	5,4	5,3
11	4,7	4,7	4,9	5,3	5,3	5,2
12	4,7	4,7	4,9	5,3	5,3	5,2
13	4,7	4,6	4,8	5,3	5,3	5,2
14	4,7	4,6	4,8	5,2	5,2	5,1

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

GRAFICA Nº4.4

Tiempo vs Amperaje Malla # 10



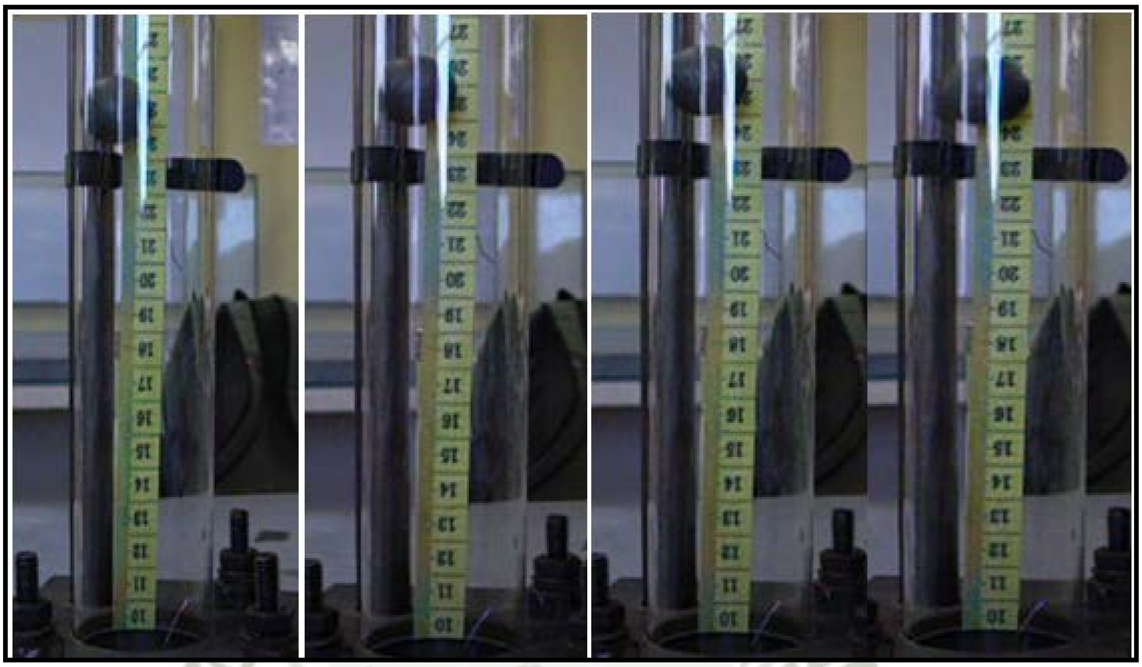
Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Observamos, los primeros 6 minutos casi horizontal existiendo un consumo uniforme de energía, al agregar el PEAD aumenta su consumo, a partir del minuto 7, para posteriormente estabilizarse; además tenemos que todos los porcentajes usados para la mezcla, tienen casi el mismo comportamiento, con pequeña diferencia, del caucho al 65%, 35% de PEAD, y uno de las mezclas de 75% caucho y 25% de PEAD; estimamos que aquí existe un poco más de consumo de energía.

4.4 ENSAYO DE IMPACTO DE CAÍDA DE BOLA

FIGURA Nº 4.5

Fotografías Tomadas Después de la Filmación



Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Para este ensayo utilizamos una cámara filmadora, para registrar las alturas correspondientes, congelamos las imágenes cuando se encontraban en la parte superior, haciendo el acercamiento respectivo, tenemos las lecturas, con un error de +- 0.1 cm.

CUADRO Nº 13

RESULTADOS OBTENIDOS EN EL ENSAYO IMPACTO DEBOLA

Prueba #	Granulometría	Porcentaje de Caucho	Altura (cm)	Promedio (cm)
1	Malla 4	65	14.5 14.6 14.8 14.5 14.6	**14.60**
2	Malla 4	85	15.9 16.0 16.3 15.8 16.3	**16.06**
3	Malla 10	65	13.4 13.5 13.6 13.5 13.8	**13.56**
4	Malla 10	85	15.2 14.8 15.5 15.1 15.0	**15.12**

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

Observando los resultados, la mejor mezcla resultaría; de la mezcla de la malla #4 y 85 % de caucho, en la elaboración de pavimentos. Sin embargo esta elección no garantiza una evaluación de las variables, cual es que tiene mayor efecto para su posterior optimización.

CUADRO Nº 14

RESULTADOS OBTENIDOS EN EL ENSAYO IMPACTO A LA BOLA CON MATRIZ DE DISEÑO ADICIONÁNDOLE MÁS MEZCLAS PARA UNA MEJOR EVALUACIÓN

Prueba #	**A** **Granulometría**	**B** **Porcentaje de caucho**	**Altura** **(cm)**	**Promedio**
1	Malla 4	65	14.5 14.6 14.8 14.5 14.6	**14.60**
2	Malla 4	75	15.2 15.0 15.2 14.9 15.1	**15.08**
3	Malla 4	85	15.9 16.0 16.3 15.8 16.3	**16.06**
4	Malla 6	65	12.5 12.3 12.4 12.5 12.2	**12.38**
5	Malla 6	75	14.0 13.8 14.0 13.9 13.8	**13.90**
6	Malla 6	85	15.2 15.3 15.5 15.5 15.7	**15.44**
7	Malla 8	65	13.9 13.8 13.6 13.5 13.5	**13.66**
8	Malla 8	75	14.5 14.6 14.4 14.5 14.6	**14.52**
9	Malla 8	85	15.2 15.4 15.4 15.2 15.3	**15.30**
10	Malla 10	65	13.4 13.5 13.6 13.5 13.8	**13.56**
11	Malla 10	75	14.2 14.3 14.1 14.5 14.2	**14.26**
12	Malla 10	85	15.2 14.8 15.5 15.1 15.0	**15.12**

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

Observando los resultados de este cuadro y para dar valides a los resultados hacemos una comparación de acuerdo de fichas técnicas de los fabricantes, donde nos dicen con las características similares a la mezcla realizada que deben de tener como mínimo 15 cm de rebote, viendo los resultados podemos afirmar que las mezclas de Mallas: 4 con 75 % de caucho, Malla 4 con 85 % de caucho, Malla 6 con 85% de caucho, Malla 8 con 85 % de caucho y la Malla 10 con 85 % de caucho, están dentro del rango de validez.

4.5 ENSAYO DE DUREZA

Tomando cinco lecturas diferentes y sacando un promedio como se muestra en los siguientes cuadros vemos que estos valores están dentro del rango establecido según las normas. La dureza aceptada es de 30 a 90 dureza Shore A.

CUADRO Nº 15

Resultados Obtenidos en la Malla # 4

PORCENTAJE	DUREZA	PROMEDIO
85% caucho 15% PEAD	79.5,79.7,81,80.1,79.7	80
75% caucho 25% PEAD	58.4,59.6,57,59.1,58	58.42
65% caucho 35% PEAD	35.1,34.9,35.4,36.1,37	35.7

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

Observación: Usando la Malla # 4 y a diferentes porcentajes de caucho y PEAD y aplicando la prueba de dureza nos damos cuenta que a mayor porcentaje de caucho reciclado el promedio de dureza Shore A aumenta.

CUADRO Nº 16

Resultados Obtenidos en la Malla # 6

PORCENTAJE	DUREZA	PROMEDIO
85% caucho 15% PEAD	75.6,76.2,75.9,76.1,76	75.96
75% caucho 25% PEAD	58.9,59.1,57.9,58.4,59	58.66
65% caucho 35% PEAD	32.1,32.9,31.4,32.1,33	32.3

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín.

Observación: Usando la Malla # 6 y a diferentes porcentajes de caucho y PEAD y aplicando la prueba de dureza nos damos cuenta que a mayor porcentaje de caucho reciclado el promedio de dureza Shore A aumenta.

CUADRO Nº 17

Resultados Obtenidos en la Malla # 8

PORCENTAJE	DUREZA	PROMEDIO
85% caucho 15% PEAD	75.5,74.7,75,75.9,74.7	75.16
75% caucho 25% PEAD	59.4,60.6,59,58.1,60	59.42
65% caucho 35% PEAD	35.1,34.9,35.4,34.1,36	35.1

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

Observación: Usando la Malla # 8 y a diferentes porcentajes de caucho y PEAD y aplicando la prueba de dureza nos damos cuenta que a mayor porcentaje de caucho reciclado el promedio de dureza Shore A aumenta.

CUADRO Nº 18

Resultados en la Malla # 10

PORCENTAJE	DUREZA	PROMEDIO
85% caucho 15% PEAD	74.5,74.7,75,73.9,74.7	74.56
75% caucho 25% PEAD	54.4,53.6,54,55.1,54	54.22
65% caucho 35% PEAD	33.1,32.9,33.4,34.1,33	33.3

Fuente: Laboratorio Antonio Raimondi De La Universidad Nacional De San Agustín

Observación: Usando la Malla # 10 y a diferentes porcentajes de caucho y PEAD y aplicando la prueba de dureza nos damos cuenta que a mayor porcentaje de caucho reciclado el promedio de dureza Shore A aumenta.

4.6 ENSAYO DE TRACCIÓN:

El alargamiento en la rotura se expresa en porcentaje:

Elongación= $(L_2- L_1)/L_1$ *100

CUADRO Nº 19

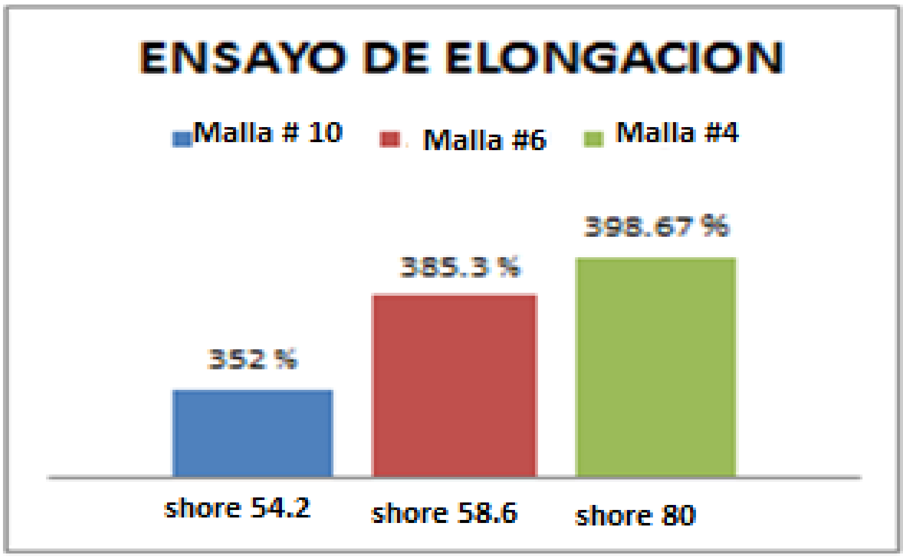
Resultados de los Ensayos de Tracción

Malla #10 (75% - 25%) **SHORE 54.2**			**Malla #6 (75% - 25%)** **SHORE 58.6**			**Malla #4 (75% – 25%)** **SHORE 80**		
L_2(mm)	L_1(mm)		L_2(mm)	L_1(mm)		L_2(mm)	L_1(mm)	
113	25	352%	119	25	376%	123	25	392%
114	25	356%	123	25	392%	125	25	400%
112	25	348%	122	25	388%	126	25	404%
		352%			**385.30%**			**398.60%**

Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica De La Universidad Católica Santa María.

GRÁFICA Nº4.6

RESULTADOS OBTENIDOS EN EL ENSAYO DE ELONGACIÓN PORCENTUAL.

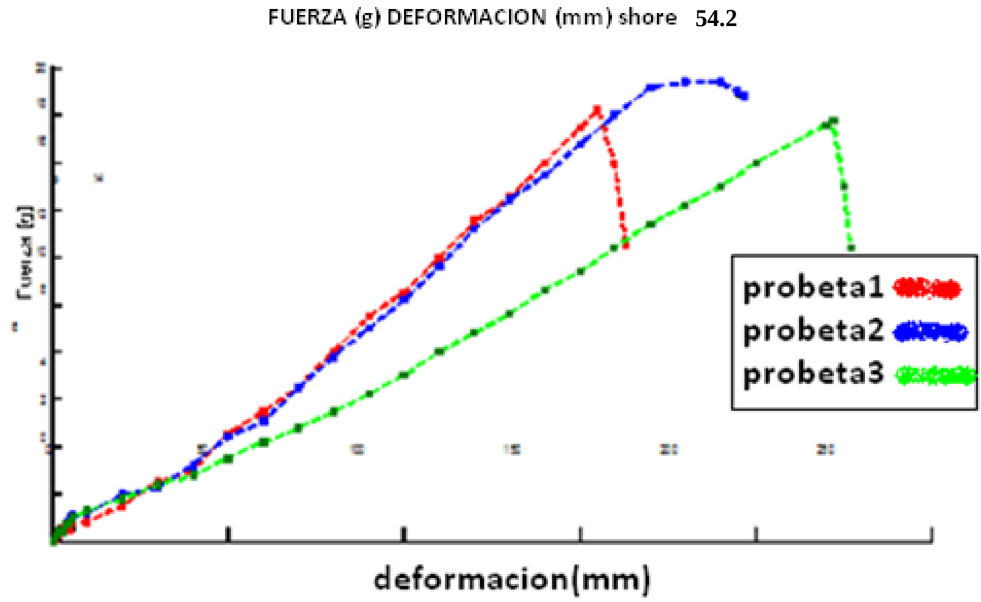


Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica De La Universidad Católica Santa María.

GRAFICASDEFUERZA - DEFORMACIÓN:

GRAFICA Nº 4.7

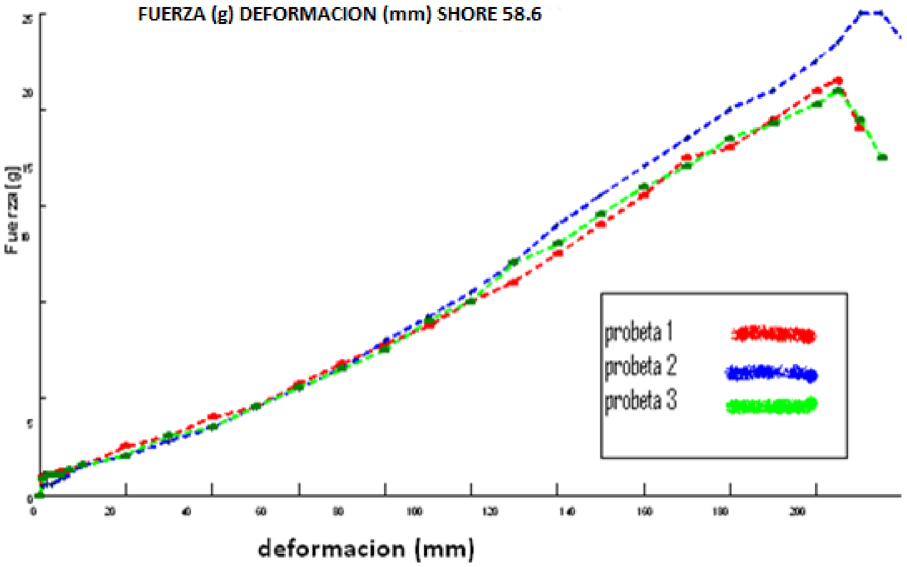
Grafica Curva de Fuerza-Deformación en Shore 54.2



Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica De La Universidad Católica Santa María.

GRAFICA Nº 4.8

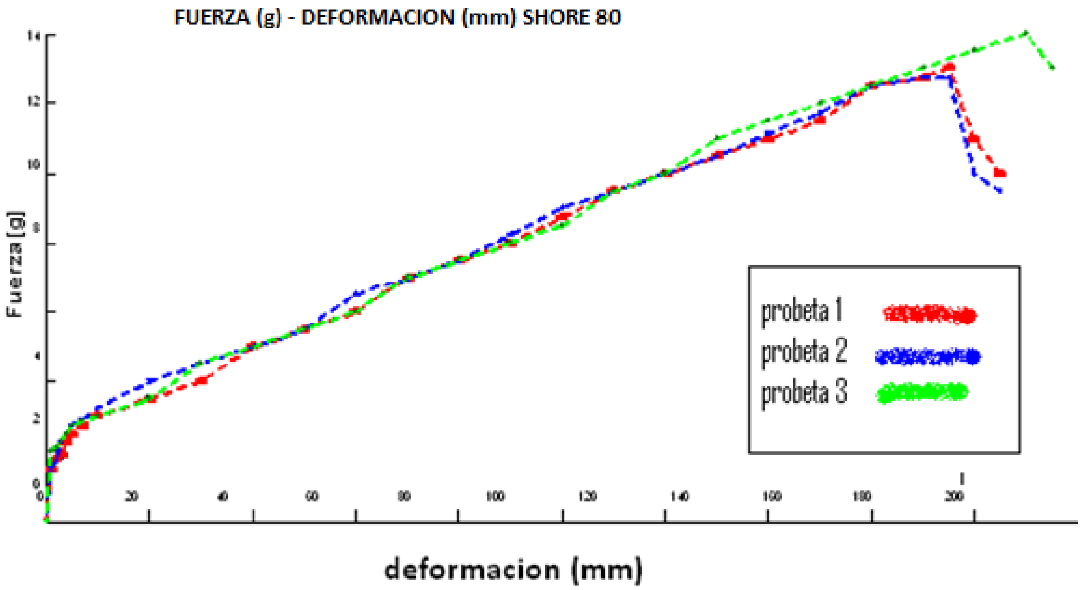
Grafica Curva De Fuerza-Deformación En Shore 58.6



Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica De La Universidad Católica Santa María.

GRAFICA Nº 4.9

Grafica Curva De Fuerza-Deformación En Shore 80



Fuente: Laboratorio Del Programa Profesional De Ingeniería De Mecánica Mecánica Eléctrica Y Mecatronica De La Universidad Católica Santa María.

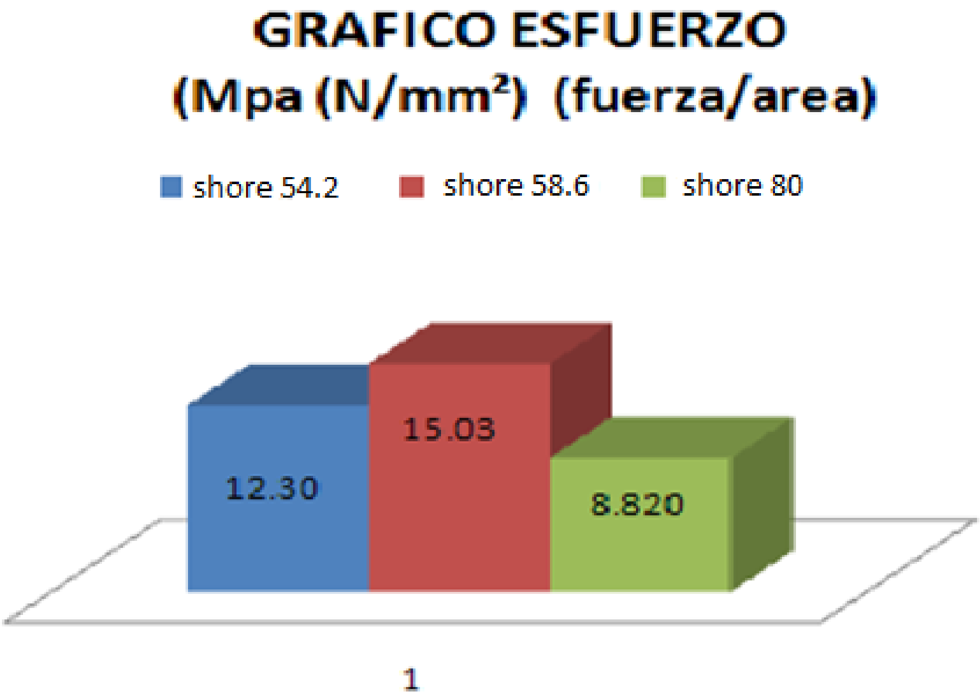
CUADRO Nº 20

FUERZA / AREA = Esfuerzo

ESFUERZO(FUERZA/AREA)					
SHORE	σ/A	σ/A	σ/A	σ/A	σ/A
	PROBETA 1 Mpa (N/mm2)	PROBETA 2 Mpa (N/mm2)	PROBETA 3 Mpa (N/mm2)	PROBETA 4 Mpa (N/mm2)	PROBETA 5 Mpa (N/mm2)
54.2	1.25	1.31	1.204	1.255	12.296
58.6	1.47	1.7	1.43	1.533	15.027
80	0.88	0.87	0.95	0.9	8.82

Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica de la Universidad Católica Santa María.

GRAFICA N° 4.10



Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica de la Universidad Católica Santa María.

4.7.COMPARACION DE RESULTADOS:

4.7.1 PAVIMENTOS TRADICIONALES

Tradicionalmente las áreas de juegos para niños las constituían las propias calles cuyo pavimento era la tierra compactada. Su dureza hace que se empiecen a utilizar otros materiales que de forma intuitiva y por la práctica, parecía que podían absorber mejor los golpes.

- **DEFICIENCIAS**

Este tipo de pavimento presenta una serie de problemas tales como:

- La absorción de impactos por caídas es insuficiente.
- La accesibilidad para dispositivos con ruedas (sillas adaptadas, carritos de bebé) queda comprometida.

- Los elementos del pavimento pueden ser utilizados como armas arrojadizas, pudiendo causar daños entre los niños.
- El mantenimiento y la limpieza son muy complicados por las razones expuestas con anterioridad.
- Elevado coste.
- La dificultad de extracción de los materiales que constituyen el pavimento, pues el uso de las graveras de ríos y playas está muy limitado, hay pocas concesiones por parte de la Administración y la obtención de éstas exigen estudios de Impacto Ambiental que las avalen.

De igual forma y a pesar de amortiguar en parte la caída de los niños, incumplen normas de seguridad tales como la Norma UNE-EN 1177. “Revestimientos de las superficies de las áreas de juego absorbentes de impactos. Requisitos generales de seguridad y métodos de ensayo”

4.7.2 PAVIMENTOS BLANDOS RECICLADOS

Se trata de un pavimento constituido por una mezcla de grano de caucho tipo SBR procedente del reciclado de neumáticos y HDPE de granulometría 1-6 mm.

El espesor es variable dependiendo de la HIC (Altura Crítica de Caída), con una capa superficial de terminación de 10 mm de espesor quees mezcla de grano de caucho de EPDM de color, con granulometría 1-4 mm.

- **Ventajas:**
  - Elevada amortiguación y absorción de impactos Son antideslizantes.
  - Aislamiento térmico y acústico.
  - Fácil mantenimiento.
  - No inflamable/ ni tóxico.
  - No tiene juntas.
  - Bajo coste.
  - Se puede reforzar y adaptar a nuevas situaciones de juego, como la instalación de elementos con altura de caída superior.

- Admite prácticamente cualquier diseño, por lo que la capacidad de accesibilidad es mayor.
- Mejor adaptación al terreno, se pueden crear suaves ondulaciones y recubrirlas con este material.

- **Desventajas:**
  - Su instalación necesita especialistas y su acabado depende de una buena ejecución.

CAPITULO V

COSTOS de EQUIPOS

5. COSTOS

Para el desarrollo del Proyecto de Investigación se realizo la donación de los maquinas para equipar el Laboratorioen la parte de Materiales no Ferrosos ya que no se contaba con estos equipos en el Laboratorio de Materiales de La Universidad Católica de Santa María puesto que son herramientas importantes para el análisis e investigación de dichos materiales y para así poder realizar y desarrollar las probetas. Las maquinas a Donarse son:

a) Mezclador Tipo Brabender.
b) Termo prensa de Conformado.

GRAFICA 5.1: Mezclador Tipo Brabender

Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica De La Universidad Católica Santa María.

GRAFICO 5.2:

TERMO PRENSA DE CONFORMADO

Fuente: Laboratorio del Programa Profesional de Ingeniería de Mecánica, Mecánica Eléctrica Mecatrónica De La Universidad Católica Santa María.

Los costos de los equipos y de cada actividad realizada de los mismos están en tiempo estándar y en tiempo óptimo. Ambos costos deben ser proporcionados por las personas responsables de la ejecución.

Los costos se deben anotar en la matriz de información (Ver Cuadro Nº21).

CUADRO Nº 21:

MATRIZ DE COSTOS

MAQUINA MEZCLADOR TIPO BRABENDER:

ITEM	ACTIVIDADES	CANTIDAD	COSTO UNITARIO	COSTO TOTAL
	ESTRUCTURA			
1	Plancha de fierro de 1/8”.	1	300.00	300.00
2	Plancha de fierro de ¼”.	1	100.00	100.00
3	Tubo de cuadrado de 4”.	1	50.00	50.00
4	Chapa de puerta.	1	10.00	10.00
5	Patas de caucho.	4	25.00	100.00
6	Eje para bisagra.	1	15.00	15.00
7	Servicio de corte, plegado, soldadura y armado.		400.00	400.00
8	Pintura.		100.00	100.00
	SISTEMA MECÁNICO			
9	Motorreductor.	1	2500.00	2500.00
10	Eje de 6”x 3” acero inox.	1	200.00	200.00
11	Disco de inox de 6” x ½”.	1	50.00	50.00
12	Eje de inox de 2”.	2	25.00	50.00
13	Plancha de inox 8” x 10”x 5/8”.	1	100.00	100.00
14	Pernos y turcas de acero inoxidable.		50.00	50.00
15	Acople de motor.	1	100.00	100.00
16	Caja reductora 1 entrada - 2 salidas.	1	300.00	300.00
17	Plancha de fierro negro de 8” x 10”x 5/8”.	1	50.00	50.00
18	Angulo de 2” x ¼”.	1	20.00	20.00
19	Servicio de maquinado.		2000.00	2000.00
	SISTEMA ELÉCTRICO			
20	Tablero de control.	1	500.00	500.00
21	Cables eléctricos.	1	200.00	200.00
22	Terminal de cable.	1	50.00	50.00
	OTROS			
23	Servicio de armado y ensamble.		800.00	800.00
		TOTAL		**S/. 8,045.00**

En el Cuadro Nº 21 se puede apreciar los costos de cada actividad realizada por el fabricante presentándonos el costo real y total de las Maquinas que se donaron al Laboratorio de Materiales de la Universidad Católica de Santa María.

CUADRO N°22:

MATRIZ DE COSTOS

MAQUINA TERMO PRENSA DE CONFORMADO:

ITEMS	ACTIVIDADES	CANTIDAD	COSTO UNITARIO	COSTO TOTAL
	ESTRUCTURA			
1	Plancha de fierro de 1/8”.	1	300.00	300.00
2	Plancha de fierro de ¼”.	1	70.00	70.00
3	Tubo de cuadrado de 4”.	1	50.00	50.00
4	Chapa de puerta.	1	10.00	10.00
5	Patas de caucho.	4	25.00	100.00
6	Eje para bisagra.	1	15.00	15.00
7	Servicio de corte, plegado, soldadura y armado.	1	400.00	400.00
8	Pintura.	1	50.00	50.00
	SISTEMA HIDRAULICO			
9	Motor eléctrico 1HP trifásico 380v.	1	400.00	400.00
10	Bomba hidráulica.	1	500.00	500.00
11	Acople de motor.	1	100.00	100.00
12	Base de bomba hidráulica.	1	50.00	50.00
13	Tanque de aceite.	1	100.00	100.00
14	Pistónhidráulico de ø 4".	1	500.00	500.00
15	Manómetrohidráulico.	1	100.00	100.00
16	Mangueras hidráulicas.	4	50.00	200.00
17	Válvula de descarga hidráulica.	1	200.00	200.00
18	Válvula de paso hidráulica.	1	100.00	100.00
19	Conexiones varias hidráulicas.	1	150.00	150.00
	SISTEMA ELECTRICO			
20	Tablero de control.	1	500.00	500.00
21	Cables eléctricos.	1	200.00	200.00
22	Terminal de cable.	1	50.00	50.00
23	Resistenciaeléctrica.	1	40.00	40.00
	SISTEMA MECANICO			
24	Ejes de 2" x 50cm	4	50.00	200.00
25	Plancha de 2" x 30x20cm.	2	100.00	200.00
26	Plancha de 2" x 20x20 cm.	1	75.00	75.00
27	Barra cuadrada de 1/2" x 6Mtrs.	1	35.00	35.00
28	Planchas de 1/2" x 20x 20 cm.	2	25.00	50.00
29	Pernos de 1/2" con volanda de presión.	12	80.00	80.00
	OTROS			
30	Servicio de armado y ensamble	1	2500.00	2500.00
		TOTAL		**S/. 7325.00**

- ✓ **COSTO TOTAL**

ITEMS	ACTIVIDADES	COSTO UNITARIO	COSTO TOTAL
1	Maquina Mezclador Tipo Brabender.	6695.00	8,045.00
2	Maquina Termo Prensa de Conformado.	5670.00	7,325.00
		I.G.V. (18%)	2766.60
		COSTO TOTAL	**S/. 18,136.60**

CONCLUSIONES

- Después de ensayar varias combinaciones de caucho y polietileno se comprobó que 85 % de caucho mas el 15 % de polietileno y con Malla N° 4; es la mejor combinación de mezcla para nuestro pavimento blando según lo realizado en el Proyecto de Investigación.

- Con este estudio contribuimos a la reducción de los residuos sólidos, pues estamos reutilizando productos desechados, como son el polietileno de alta densidad como las bolsas de plástico y el caucho proveniente de las llantas de nuestro parque automotor.

- A los pavimentos obtenidos podemos agregar color, forma, dependiendo del diseño del productor, agregándole mayor valor comercial, mejorando las utilidades de su producción.

- Al usar material reciclado disminuimos el costo de este producto en casi cerca a un 50% y vemos la importancia y el valor que podemos sacar de estos tipos de materiales desechados.

- En la producción del pavimento para zonas recreacionales, no utilizamos ningún tipo de contaminantes o soluciones que contaminan nuestro medio ambiente, todo por el contrario es una técnica limpia y el producto terminado puede ser reutilizado para la producción de más pavimentos blandos.

RECOMENDACIONES

- Se recomienda hacer ensayos de Desgaste y Abrasión según normas ASTM D2228 y ASTM D5963.

- Se recomienda hacer pruebas de permeabilidad para ver su comportamiento frente a climas adversos.

- Se recomienda hacer ensayos de Envejecimiento Acelerado según normas ASTM D573 y ASTM D1349.

- Se recomienda una mejor implementación en laboratorios el cual mejoraría enormemente los resultados generando más seguridad en las acciones a realizar.

- Se recomienda evitar el reaprovechamiento energéticamente de los neumáticos desechados como combustible alternativo, dentro de las ladrilleras de la ciudad, sustituyendo parcialmente en sus hornos a los combustibles primarios fósiles (coque de petróleo, carbón, fuel-oíl, etc.). por ser altamente contaminante

- Se recomienda seguir estudiando con granulometrías para elaborar mezclas, tanto con más plásticos o mezclas con caucho virgen para analizar sus nuevas propiedades, de los nuevos pavimentos.

- Se recomienda hacer nuevas mezclas con diferentes plásticos, para tener nuevos pavimentos.

- Se recomienda hacer mezclas con caucho virgen, para pavimentos u otras aplicaciones.

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ANEXOS

Designation: D 412 – 98a (Reapproved 2002)$^{\epsilon 1}$

Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension[1]

This standard is issued under the fixed designation D 412; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ^1 NOTE—Section 9.2 was editorially updated in January 2003.

1. Scope

1.1 These test methods cover procedures used to evaluate the tensile (tension) properties of vulcanized thermoset rubbers and thermoplastic elastomers. These methods are not applicable to ebonite and similar hard, low elongation materials. The methods appear as follows:

Test Method A—Dumbbell and Straight Section Specimens
Test Method B—Cut Ring Specimens

NOTE 1—These two different methods do not produce identical results.

1.2 The values stated in either SI or non-SI units shall be regarded separately as normative for this standard. The values in each system may not be exact equivalents; therefore each system must be used independently, without combining values.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1349 Practice for Rubber—Standard Temperatures for Testing[2]
D 1566 Terminology Relating to Rubber[2]
D 3182 Practice for Rubber—Materials, Equipment and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets[2]
D 3183 Practice for Rubber—Preparation of Pieces for Test Purposes from Products[2]
D 3767 Practice for Rubber—Measurement of Dimensions[2]
D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[2]
E 4 Practices for Force Verification of Testing Machines[3]

2.2 *ASTM Adjunct:*

Cut Ring Specimens, Method B (D 412)[4]

2.3 *ISO Standards:*

ISO 37 Rubber, Vulcanized and Thermoplastic Determination of Tensile Stress-Strain Properties[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *tensile set*—the extension remaining after a specimen has been stretched and allowed to retract in a specified manner, expressed as a percentage of the original length. (D 1566)

3.1.2 *tensile set-after-break*—the tensile set measured by fitting the two broken dumbbell pieces together at the point of rupture.

3.1.3 *tensile strength*—the maximum tensile stress applied in stretching a specimen to rupture. (D 1566)

3.1.4 *tensile stress*—a stress applied to stretch a test piece (specimen). (D 1566)

3.1.5 *tensile stress at-given-elongation*—the stress required to stretch the uniform cross section of a test specimen to a given elongation. (D 1566)

3.1.6 *thermoplastic elastomers*—a diverse family of rubber-like materials that unlike conventional vulcanized rubbers can be processed and recycled like thermoplastic materials.

3.1.7 *ultimate elongation*—the elongation at which rupture occurs in the application of continued tensile stress.

3.1.8 *yield point*—that point on the stress-strain curve, short of ultimate failure, where the rate of stress with respect to strain, goes through a zero value and may become negative. (D 1566)

3.1.9 *yield strain*—the level of strain at the yield point. (D 1566)

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[1] These test methods are under the jurisdiction of ASTM Committee D11 on Rubber and are the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved Dec. 10, 2002. Published January 2003. Originally approved in 1935. Last previous edition approved in 1998 as D 412 – 98a.

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] Detailed drawings are available from ASTM Headquarters, 100 Barr Harbor Drive, Conshohocken, PA 19428. Order Adjunct No. ADJD0412.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

3.1.10 *yield stress*—the level of stress at the yield point. (D 1566)

4. Summary of Test Method

4.1 The determination of tensile properties starts with test pieces taken from the sample material and includes the preparation of the specimens and the testing of the specimens. Specimens may be in the shape of dumbbells, rings or straight pieces of uniform cross-sectional area.

4.2 Measurements for tensile stress, tensile stress at a given elongation, tensile strength, yield point, and ultimate elongation are made on specimens that have not been prestressed. Tensile stress, yield point, and tensile strength are based on the original cross-sectional area of a uniform cross-section of the specimen.

4.3 Measurement of tensile set is made after a previously unstressed specimen has been extended and allowed to retract by a prescribed procedure. Measurement of "set after break" is also described.

5. Significance and Use

5.1 All materials and products covered by these test methods must withstand tensile forces for adequate performance in certain applications. These test methods allow for the measurement of such tensile properties. However, tensile properties alone may not directly relate to the total end use performance of the product because of the wide range of potential performance requirements in actual use.

5.2 Tensile properties depend both on the material and the conditions of test (extension rate, temperature, humidity, specimen geometry, pretest conditioning, etc.); therefore materials should be compared only when tested under the same conditions.

5.3 Temperature and rate of extension may have substantial effects on tensile properties and therefore should be controlled. These effects will vary depending on the type of material being tested.

5.4 Tensile set represents residual deformation which is partly permanent and partly recoverable after stretching and retraction. For this reason, the periods of extension and recovery (and other conditions of test) must be controlled to obtain comparable results.

6. Apparatus

6.1 *Testing Machine*—Tension tests shall be made on a power driven machine equipped to produce a uniform rate of grip separation of 500 ± 50 mm/min (20 ± 2 in./min) for a distance of at least 750 mm (30 in.) (see Note 1). The testing machine shall have both a suitable dynamometer and an indicating or recording system for measuring the applied force within ±2 %. If the capacity range cannot be changed for a test (as in the case of pendulum dynamometers) the applied force at break shall be measured within ±2 % of the full scale value, and the smallest tensile force measured shall be accurate to within 10 %. If the dynamometer is of the compensating type for measuring tensile stress directly, means shall be provided to adjust for the cross-sectional area of the specimen. The response of the recorder shall be sufficiently rapid that the applied force is measured with the requisite accuracy during the extension of the specimen to rupture. If the testing machine is not equipped with a recorder, a device shall be provided that indicates, after rupture, the maximum force applied during extension. Testing machine systems shall be capable of measuring elongation of the test specimen in minimum increments of 10 %.

NOTE 2—A rate of elongation of 1000 ± 100 mm/min (40 ± 4 in./min) may be used and notation of the speed made in the report. In case of dispute, the test shall be repeated and the rate of elongation shall be at 500 ± 50 mm/min (20 ± 2 in./min).

6.2 *Test Chamber for Elevated and Low Temperatures*—The test chamber shall conform with the following requirements:

6.2.1 Air shall be circulated through the chamber at a velocity of 1 to 2 m/s (3.3 to 6.6 ft/s) at the location of the grips or spindles and specimens maintained within 2°C (3.6°F) of the specified temperature.

6.2.2 A calibrated sensing device shall be located near the grips or spindles for measuring the actual temperature.

6.2.3 The chamber shall be vented to an exhaust system or to the outside atmosphere to remove fumes liberated at high temperatures.

6.2.4 Provisions shall be made for suspending specimens vertically near the grips or spindles for conditioning prior to test. The specimens shall not touch each other or the sides of the chamber except for momentary contact when agitated by the circulating air.

6.2.5 Fast acting grips suitable for manipulation at high or low temperatures may be provided to permit placing dumbbells or straight specimens in the grips in the shortest time possible to minimize any change in temperature of the chamber.

6.2.6 The dynamometer shall be suitable for use at the temperature of test or it shall be thermally insulated from the chamber.

6.2.7 Provision shall be made for measuring the elongation of specimens in the chamber. If a scale is used to measure the extension between the bench-marks, the scale shall be located parallel and close to the grip path during specimen extension and shall be controlled from outside the chamber.

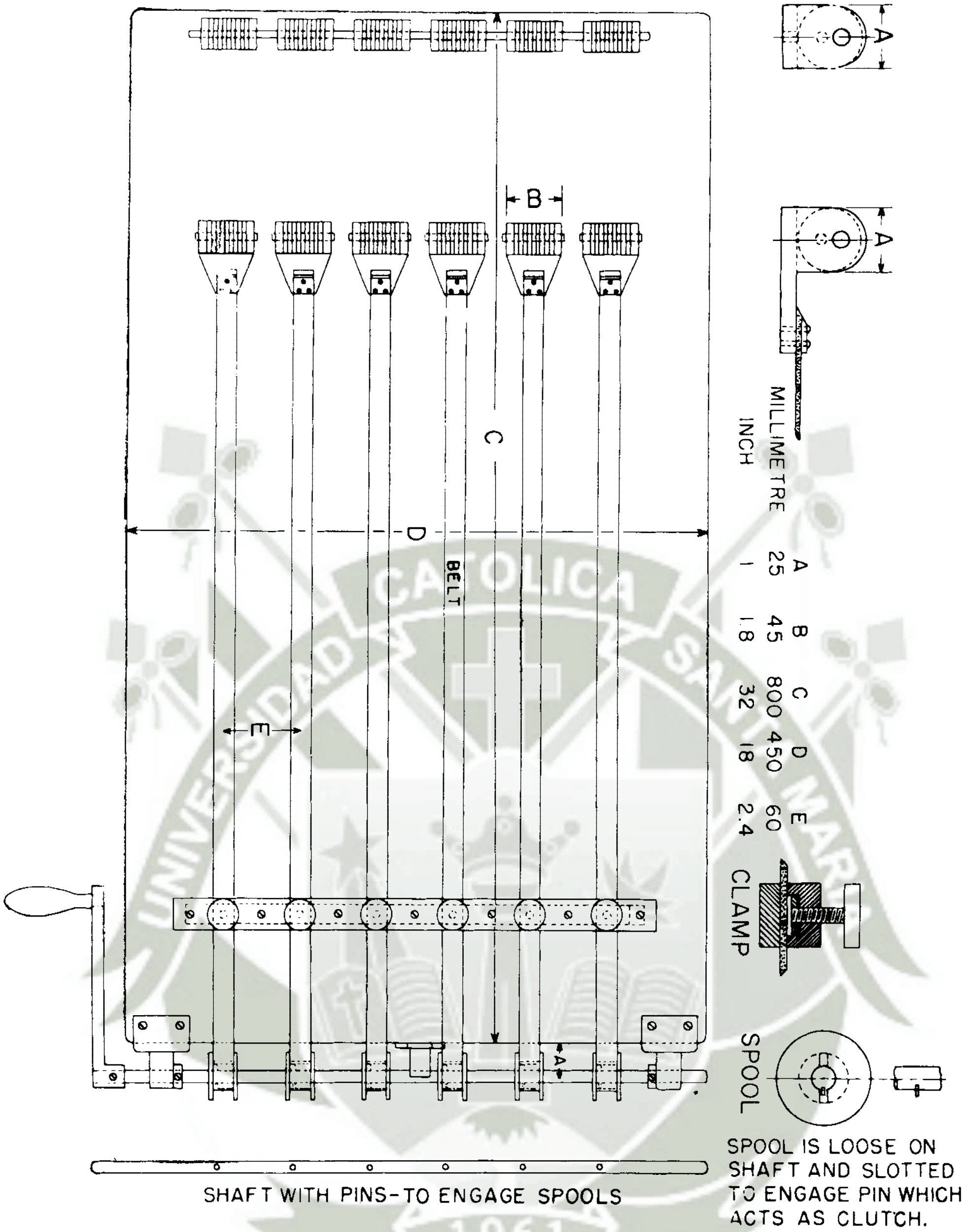
6.3 *Dial Micrometer*—The dial micrometer shall conform to the requirements of Practice D 3767 (Method A). For ring specimens, see 14.10 of these test methods.

6.4 *Apparatus for Tensile Set Test*—The testing machine described in 6.1 or an apparatus similar to that shown in Fig. 1 may be used. A stop watch or other suitable timing device measuring in minute intervals for at least 30 min, shall be provided. A scale or other device shall be provided for measuring tensile set to within 1 %.

7. Selection of Test Specimens

7.1 Consider the following information in making selections:

7.1.1 Since anisotropy or grain directionality due to flow introduced during processing and preparation may have an influence on tensile properties, dumbbell or straight specimens should be cut so the lengthwise direction of the specimen is



	A	B	C	D	E
MILLIMETRE	25	45	800	450	60
INCH	1	1.8	32	18	2.4

FIG. 1 Apparatus for Tensile Set Test

parallel to the grain direction when this direction is known. Ring specimens normally give an average of with and across the grain properties.

7.1.2 Unless otherwise noted, thermoplastic rubber or thermoplastic elastomer specimens, or both, are to be cut from injection molded sheets or plaques with a thickness of 3.0 ± 0.3 mm. Specimens of other thickness will not necessarily give comparable results. Specimens are to be tested in directions both parallel and perpendicular to the direction of flow in the mold. Sheet or plaque dimensions must be sufficient to do this.

7.1.3 Ring specimens enable elongations to be measured by grip separation, but the elongation across the radial width of the ring specimens is not uniform. To minimize this effect the width of the ring specimens must be small compared to the diameter.

7.1.4 Straight specimens tend to break in the grips if normal extension-to-break testing is conducted and should be used only when it is not feasible to prepare another type of specimen. For obtaining non-rupture stress-strain or material modulus properties, straight specimens are quite useful.

7.1.5 The size of specimen type used will be determined by the material, test equipment and the sample or piece available for test. A longer specimen may be used for rubbers having low ultimate elongation to improve precision of elongation measurement.

8. Calibration of the Testing Machine

8.1 Calibrate the testing machine in accordance with Procedure A of Practice E 4. If the dynamometer is of the strain-gage type, calibrate the tester at one or more forces in addition to the requirements in Sections 7 and 18 of Practice E 4. Testers having pendulum dynamometers may be calibrated as follows:

8.1.1 Place one end of a dumbbell specimen in the upper grip of the testing machine.

8.1.2 Remove the lower grip from the machine and attach it, by means of the gripping mechanism to the dumbbell specimen in the upper grip.

8.1.3 Attach a hook to the lower end of the lower specimen grip mechanism.

8.1.4 Suspend a known mass from the hook of the lower specimen grip mechanism in such a way as to permit the mass assembly to temporarily rest on the lower testing machine grip framework or holder (see Note 2).

8.1.5 Start the grip separation motor or mechanism, as in normal testing, and allow it to run until the mass is freely suspended by the specimen in the upper grip.

8.1.6 If the dial or scale does not indicate the force applied (or its equivalent in stress for a compensating type tester) within specified tolerance, thoroughly inspect the testing machine for malfunction (for example, excess friction in bearings and other moving parts). Ensure that the mass of the lower grip mechanism and the hook are included as part of the known mass.

8.1.7 After machine friction or other malfunction has been removed, recalibrate the testing machine at a minimum of three points using known masses to produce forces of approximately 10, 20 and 50 % of capacity. If pawls or rachets are used during routine testing, use them for calibration. Check for friction in the head by calibrating with the pawls up.

NOTE 3—It is advisable to provide a means for preventing the known mass from falling to the floor in case the dumbbell should break.

8.2 A rapid approximate calibration of the testing machine may be obtained by using a spring calibration device.

9. Test Temperature

9.1 Unless otherwise specified, the standard temperature for testing shall be 23 ± 2°C (73.4 ± 3.6°F). Specimens shall be conditioned for at least 3 h when the test temperature is 23°C (73.4°F). If the material is affected by moisture, maintain the relative humidity at 50 ± 5 % and condition the specimens for at least 24 h prior to testing. When testing at any other temperature is required use one of the temperatures listed in Practice D 1349.

9.2 For testing at temperatures above 23°C (73.4°F) preheat specimens for 10 ± 2 min for Method A and for 6 ± 2 min for Method B (see Note 3). Place each specimen in the test chamber at intervals ahead of testing so that all specimens of a series will be in the chamber the same length of time. The preheat time at elevated temperatures must be limited to avoid additional vulcanization or thermal aging. (**Warning—**In addition to other precautions, suitable heat or cold resistant gloves should be worn for arm and hand protection when testing at other than 23°C (73.4°F). A mask for the face is very desirable for high temperature testing to prevent the inhalation of toxic fumes when the door of the chamber is open.)

9.3 For testing at temperatures below 23°C (73.4°F) condition the specimens at least 10 min prior to testing.

TEST METHOD A—DUMBBELL AND STRAIGHT SPECIMENS

10. Apparatus

10.1 *Die*—The shape and dimensions of the die for preparing dumbbell specimens shall conform with those shown in Fig. 2. The inside faces in the reduced section shall be perpendicular to the plane formed by the cutting edges and polished for a distance of at least 5 mm (0.2 in.) from the cutting edge. The die shall at all times be sharp and free of nicks (see 9.2).

NOTE 4—The condition of the die may be determined by investigating the rupture point on any series of broken (ruptured) specimens. Remove such specimens from the grips of the testing machine, stack the joined-together specimens on top of each other, and note if there is any tendency for tensile breaks to occur at the same position on each of the specimens. Rupture consistently at the same place indicates that the die may be dull, nicked, or bent at that location.

10.2 *Bench Marker*—The two marks placed on the specimen and used to measure elongation or strain are called “bench marks” (see Note 4). The bench marker shall consist of a base plate containing two raised parallel projections. The surfaces of the raised projections (parallel to the plane of the base plate) are ground smooth in the same plane. The raised projection marking surfaces shall be between 0.05 and 0.08 mm (0.002 and 0.003 in.) wide and at least 15 mm (0.6 in.) long. The angles between the parallel marking surfaces and the sides of the projections shall be at least 75°. The distance between the centers of the two parallel projections or marking surfaces shall be within 1 % of the required or target bench mark distance. A handle attached to the back or top of the bench marker base plate is normally a part of the bench marker.

NOTE 5—If a contact extensometer is used to measure elongation, bench marks are not necessary.

10.3 *Ink Applicator*—A flat unyielding surface (hardwood, metal, or plastic) shall be used to apply either ink or powder to the bench marker. The ink or powder shall adhere to the specimen, have no deteriorating effect on the specimen and be of contrasting color to that of the specimen.

10.4 *Grips*—The testing machine shall have two grips, one of which shall be connected to the dynamometer.

10.4.1 Grips for testing dumbbell specimens shall tighten automatically and exert a uniform pressure across the gripping surfaces, increasing as the tension increases in order to prevent slippage and to favor failure of the specimen in the straight reduced section. Constant pressure pneumatic type grips also are satisfactory. At the end of each grip a positioning device is recommended for inserting specimens to the same depth in the grip and for alignment with the direction of pull.

10.4.2 Grips for testing straight specimens shall be constant pressure pneumatic, wedged, or toggle type designed to transmit the applied gripping force over the entire width of the gripped specimen.

11. Specimens

11.1 *Dumbbell Specimens*—Whenever possible, the test specimens shall be injection molded or cut from a flat sheet not less than 1.3 mm (0.05 in.) nor more than 3.3 mm (0.13 in.)

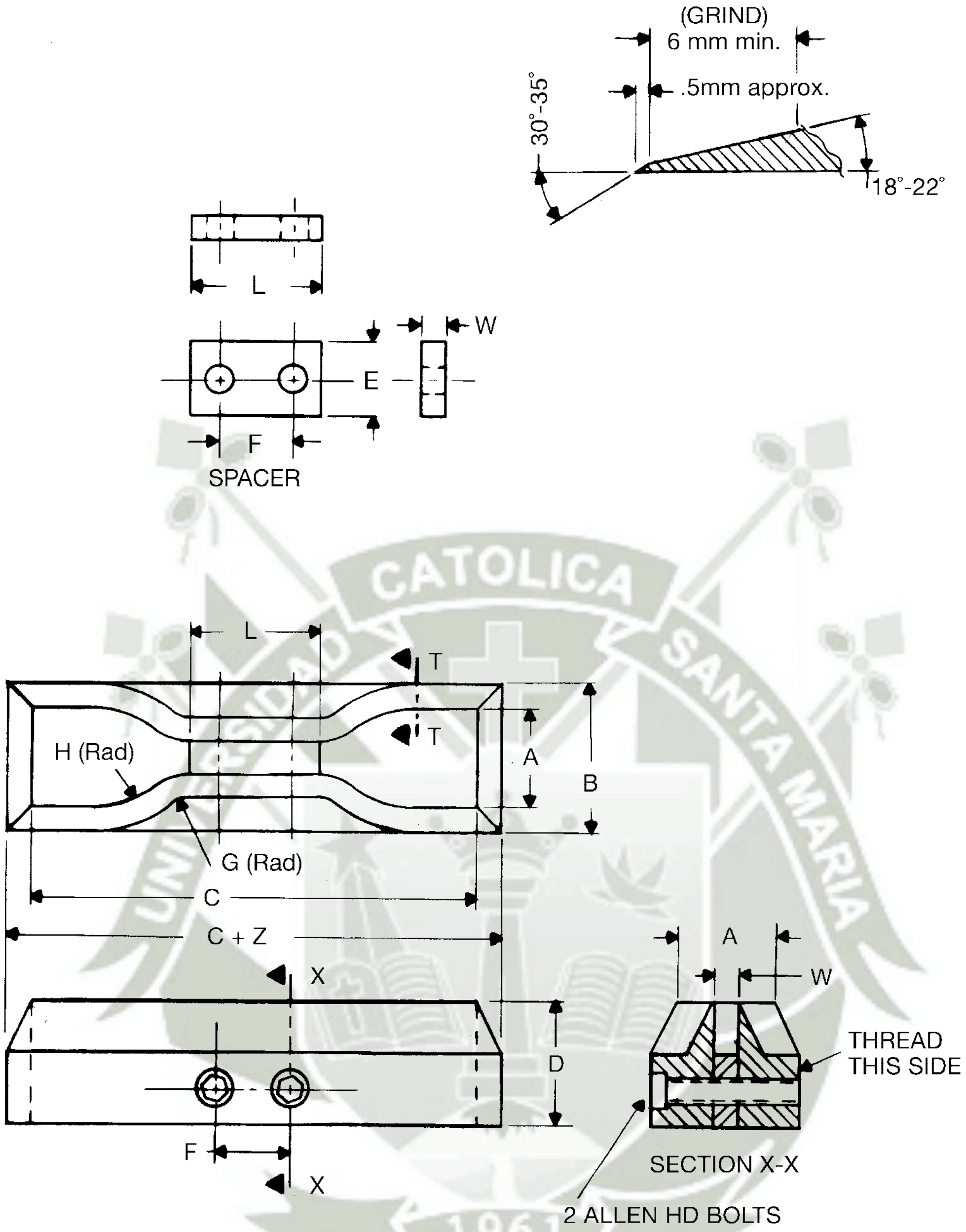


FIG. 2 Standard Dies for Cutting Dumbbell Specimens

thick and of a size which will permit cutting a specimen by one of the standard methods (see Practice D 3182). Sheets may be prepared directly by processing or from finished articles by cutting and buffing. If obtained from a manufactured article, the specimen shall be free of surface roughness, fabric layers, etc. in accordance with the procedure described in Practice D 3183. All specimens shall be cut so that the lengthwise portion of the specimens is parallel to the grain unless otherwise specified. In the case of sheets prepared in accordance with Practice D 3182, the specimen shall be 2.0 ± 0.2 mm (0.08 ± 0.008 in.) thick died out in the direction of the grain. Use Die C, Fig. 2 (unless otherwise noted) to cut the specimens from the sheet with a single impact stroke (hand or machine) to ensure smooth cut surfaces.

11.1.1 *Marking Dumbbell Specimens*—Dumbbell specimens shall be marked with the bench marker described in 10.2, with no tension on the specimens at the time of marking. Marks shall be placed on the reduced section, equidistant from its center and perpendicular to the longitudinal axis. The between bench mark distance shall be as follows: for Die C or Die D of Fig. 2, 25.00 ± 0.25 mm (1.00 ± 0.01 in.); for any other Die of Fig. 2, 50.00± 0.5 mm (2.00 ± 0.02 in.).

11.1.2 *Measuring Thickness of Dumbbell Specimens*—Three measurements shall be made for the thickness, one at the center and one at each end of the reduced section. The median of the three measurements shall be used as the thickness in calculating the cross sectional area. Specimens with a difference between the maximum and the minimum thickness

Dimensions of Standard Dumbbell Dies[A] (Metric Units)

Dimension	Units	Tolerance	Die A	Die B	Die C	Die D	Die E	Die F
A	mm	±1	25	25	25	16	16	16
B	mm	max	40	40	40	30	30	30
C	mm	min	140	140	115	100	125	125
D	mm	±6[B]	32	32	32	32	32	32
D-E	mm	±1	13	13	13	13	13	13
F	mm	±2	38	38	19	19	38	38
G	mm	±1	14	14	14	14	14	14
H	mm	±2	25	25	25	16	16	16
L	mm	±2	59	59	33	33	59	59
W	mm	±0.05, –0.00	12	6	6	3	3	6
Z	mm	±1	13	13	13	13	13	13

[A] Dies whose dimensions are expressed in metric units are not exactly the same as dies whose dimensions are expressed in U.S. customary units. Dies dimensioned in metric units are intended for use with apparatus calibrated in metric units.

[B] For dies used in clicking machines it is preferable that this tolerance be ±0.5 mm.

FIG. 2 a *(continued)*

Dimensions of Standard Dumbbell Dies[A] (U.S. Customary Units)

Dimension	Units	Tolerance	Die A	Die B	Die C	Die D	Die E	Die F
A	in.	±0.04	1	1	1	0.62	0.62	0.62
B	in.	max	1.6	1.6	1.6	1.2	1.2	1.2
C	in.	min	5.5	5.5	4.5	4	5	5
D	in.	±0.25[B]	1.25	1.25	1.25	1.25	1.25	1.25
D-E	in.	±0.04	0.5	0.5	0.5	0.5	0.5	0.5
F	in.	±0.08	1.5	1.5	0.75	0.75	1.5	1.5
G	in.	±0.04	0.56	0.56	0.56	0.56	0.56	0.56
H	in.	±0.08	1	1	1	0.63	0.63	0.63
L	in.	±0.08	2.32	2.32	1.31	1.31	2.32	2.32
W	in.	±0.002, –0.000	0.500	0.250	0.250	0.125	0.125	0.250
Z	in.	±0.04	0.5	0.5	0.5	0.5	0.5	0.5

[A] Dies whose dimensions are expressed in metric units are not exactly the same as dies whose dimensions are expressed in U.S. customary units.

[B] For dies used in clicking machines it is preferable that this tolerance by ±0.02 in.

FIG. 2 b *(continued)*

exceeding 0.08 mm (0.003 in.), shall be discarded. The width of the specimen shall be taken as the distance between the cutting edges of the die in the restricted section.

11.2 *Straight Specimens*—Straight specimens may be prepared if it is not practical to cut either a dumbbell or a ring specimen as in the case of a narrow strip, small tubing or narrow electrical insulation material. These specimens shall be of sufficient length to permit their insertion in the grips used for the test. Bench marks shall be placed on the specimens as described for dumbbell specimens in 11.1.1. To determine the cross sectional area of straight specimens in the form of tubes, the mass, length, and density of the specimen may be required. The cross sectional area shall be calculated from these measurements as follows:

$$A = M/DL \tag{1}$$

where:

A = cross-sectional area, cm^2,
M = mass, g,
D = density, g/cm^3, and
L = length, cm.

NOTE 6—A in square inches = A (cm^2) × 0.155.

12. Procedure

12.1 *Determination of Tensile Stress, Tensile Strength and Yield Point*—Place the dumbbell or straight specimen in the grips of the testing machine, using care to adjust the specimen symmetrically to distribute tension uniformly over the cross section. This avoids complications that prevent the maximum strength of the material from being evaluated. Unless otherwise specified, the rate of grip separation shall be 500 ± 50 mm/min (20 ± 2 in./min) (see Note 6). Start the machine and note the distance between the bench marks, taking care to avoid parallax. Record the force at the elongation(s) specified for the test and at the time of rupture. The elongation measurement is made preferably through the use of an extensometer, an autographic mechanism or a spark mechanism. At rupture, measure and record the elongation to the nearest 10 %. See Section 13 for calculations.

NOTE 7—For materials having a yield point (yield strain) under 20 % elongation when tested at 500 ± 50 mm/min (20 ± 2 in./min), the rate of elongation shall be reduced to 50 ± 5 mm/min (2.0 ± 0.2 in./min). If the material still has a yield point (strain) under 20 % elongation, the rate shall be reduced to 5 ± 0.5 mm/min (0.2 ± 0.002 in./min). The actual rate of separation shall be reported.

12.2 *Determination of Tensile Set*—Place the specimen in the grips of the testing machine described in 6.1 or the apparatus shown in Fig. 1, and adjust symmetrically so as to distribute the tension uniformly over the cross section. Separate the grips at a rate of speed as uniformly as possible, that requires 15 s to reach the specified elongation. Hold the specimen at the specified elongation for 10 min, release quickly without allowing it to snap back and allow the specimen to rest for 10 min. At the end of the 10 min rest period, measure the distance between the bench marks to the nearest 1 % of the original between bench mark distance. Use a stop watch for the timing operations. See Section 13 for calculations.

12.3 *Determination of Set-After-Break*—Ten minutes after a specimen is broken in a normal tensile strength test, carefully fit the two pieces together so that they are in good contact over the full area of the break. Measure the distance between the bench marks. See Section 13 for calculations.

13. Calculation

13.1 Calculate the tensile stress at any specified elongation as follows:

$$T_{(xxx)} = F_{(xxx)}/A \quad (2)$$

where:

$T_{(xxx)}$ = tensile stress at (xxx) % elongation, MPa (lbf/in.^{2}),
$F_{(xxx)}$ = force at specified elongation, MN or (lbf), and
A = cross-sectional area of unstrained specimen, m^2 (in.^{2}).

13.2 Calculate the yield stress as follows:

$$Y_{(stress)} = F_{(y)}/A \quad (3)$$

where:

$Y_{(stress)}$ = yield stress, that stress level where the yield point occurs, MPa (lbf/in.^{2}),
$F_{(y)}$ = magnitude of force at the yield point, MN (lbf), and
A = cross-sectional area of unstrained specimen, m^2 (in.^{2}).

13.3 Evaluate the yield strain as that strain or elongation magnitude, where the rate of change of stress with respect to strain, goes through a zero value.

13.4 Calculate the tensile strength as follows:

$$TS = F_{(BE)}/A \quad (4)$$

where:

TS = tensile strength, the stress at rupture, MPa (lbf/in.^{2}),
$F_{(BE)}$ = the force magnitude at rupture, MN (lbf), and
A = cross-sectional area of unstrained specimen, m^2 (in.^{2}).

13.5 Calculate the elongation (at any degree of extension) as follows:

$$E = 100[L - L_{(o)}]/L_{(o)} \quad (5)$$

where:

E = the elongation in percent (of original bench mark distance),
L = observed distance between bench marks on the extended specimen, and
$L_{(o)}$ = original distance between bench marks (use same units for L and $L_{(o)}$).

13.6 The breaking or ultimate elongation is evaluated when L is equal to the distance between bench marks at the point of specimen rupture.

13.7 Calculate the tensile set, by using Eq 5, where L is equal to the distance between bench marks after the 10 min retraction period.

13.8 *Test Result*—A test result is the median of three individual test measurement values for any of the measured properties as described above, for routine testing. There are two exceptions to this and for these exceptions a total of five specimens (measurements) shall be tested and the test result reported as the median of five.

13.8.1 *Exception 1*—If one or two of the three measured values do not meet specified requirement values when testing for compliance with specifications.

13.8.2 *Exception 2*—If referee tests are being conducted.

TEST METHOD B—CUT RING SPECIMENS

14. Apparatus

14.1 *Cutter*—A typical ring cutter assembly is illustrated in Fig. 3. This is used for cutting rings from flat sheets by mounting the upper shaft portion of the cutter in a rotating housing that can be lowered onto a sheet held by the rubber holding plate as shown in Fig. 4.

14.1.1 *Blade Depth Gage*—This gage consists of a cylindrical disk having a thickness of at least 0.5 mm (0.02 in.) greater than the thickness of the rubber to be cut and a diameter less than the inside diameter of the specimen used for adjusting the protrusion of the blades from the body of the cutter. See Fig. 3.

14.2 *Rubber Holding Plate*—The apparatus for holding the sheet during cutting shall have plane parallel upper and lower surfaces and shall be a rigid polymeric material (hard rubber, polyurethane, polymethylmethacrylate) with holes approximately 1.5 mm (0.06 in.) in diameter spaced 6 or 7 mm (0.24 or 0.32 in.) apart across the central region of the plate. All the holes shall connect to a central internal cavity which can be maintained at a reduced pressure for holding the sheet in place due to atmospheric pressure. Fig. 4 illustrates the design of an apparatus for holding standard sheets (approximately 150× 150 × 2 mm) during cutting.

14.3 *Source of Reduced Pressure*—Any device such as a vacuum pump that can maintain an absolute pressure below 10 kPa (0.1 atm) in the holding plate central cavity.

14.4 *Soap Solution*—A mild soap solution shall be used on the specimen sheet to lubricate the cutting blades.

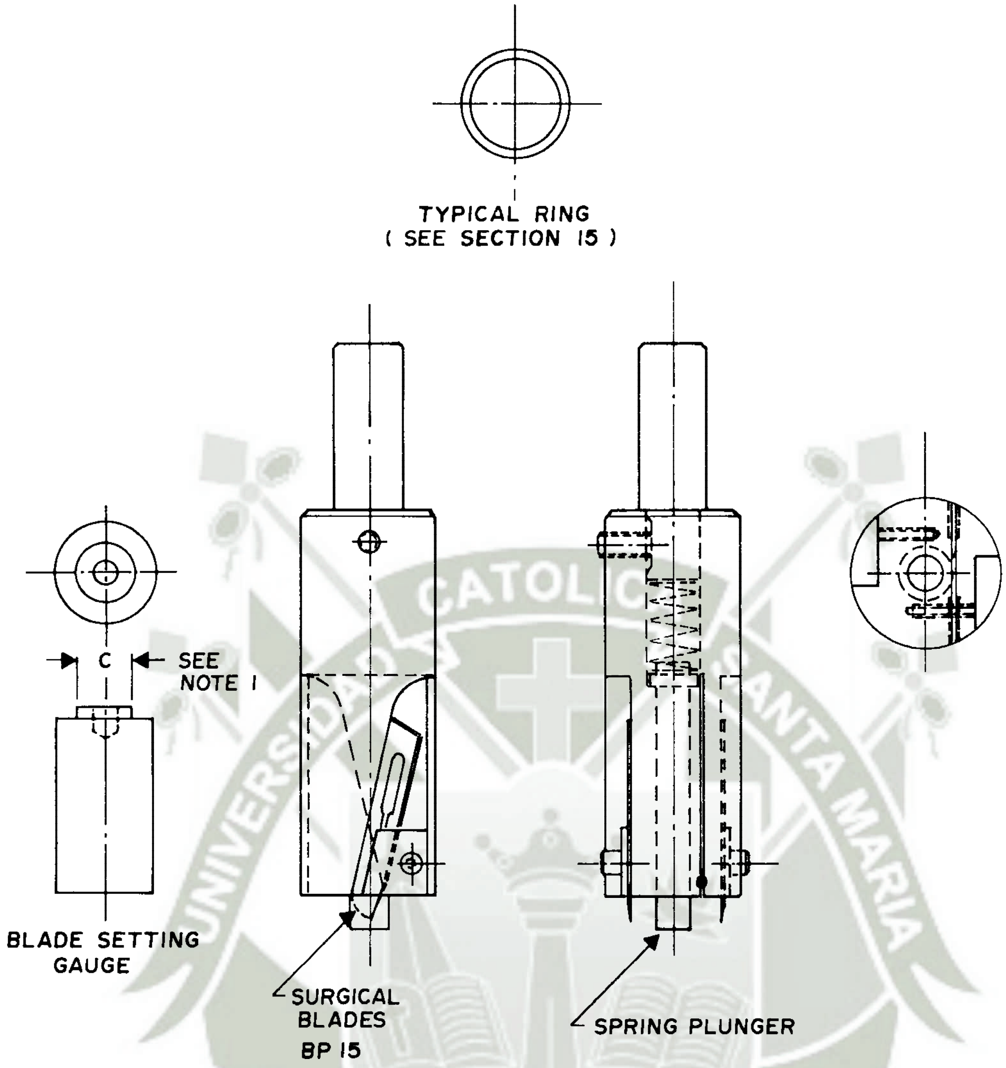
14.5 *Cutter Rotator*—A precision drill press or other suitable machine capable of rotating the cutter at an angular speed of at least 30 rad/s (approximately 300 r/min) during cutting shall be used. The cutter rotator device shall be mounted on a horizontal base and have a vertical support orientation for the shaft that rotates the spindle and cutter. The run-out of the rotating spindle shall not exceed 0.01 mm (0.004 in.).

14.6 *Indexing Table*—A milling table or other device with typical *x-y* motions shall be provided for positioning the sheet and holder with respect to the spindle of the cutter rotating device.

14.7 *Tensile Testing Machine*—A machine as specified in 6.1 shall be provided.

14.8 *Test Fixture*—A test fixture as shown in Fig. 5 shall be provided for testing the ring specimens. The testing machine shall be calibrated as outlined in Section 8.

14.9 *Test Chamber*—A chamber for testing at high and low temperatures shall be provided as specified in 6.2.



NOTE 1—Dimension *C* to be 2 mm (0.08 in.) less than the inside diameter of the ring.

FIG. 3 Typical Ring Cutter Assembly

14.9.1 The fixtures specified in 14.8 are satisfactory for testing at other than room temperature. However at extreme temperatures, a suitable lubricant shall be used to lubricate the spindle bearings.

14.9.2 The dynamometer shall be suitable for use at the temperature of test or thermally insulated from the chamber.

14.10 *Dial Micrometer*—A dial micrometer shall be provided that conforms to the requirements of Practice D 3767.

14.10.1 The base of the micrometer used to measure the radial width shall consist of an upper cylindrical surface (with its axis oriented in a horizontal direction) at least 12 mm (0.5 in.) long and 15.5± 0.5 mm (0.61 ± 0.02 in.) in diameter. To accommodate small diameter rings that approach the 15.5 mm (0.61 in.) diameter of the base and to avoid any ring extension in placing the ring on the base, the bottom half of the cylindrical surface may be truncated at the cylinder centerline, that is, a half cylinder shape. This permits placing small rings on the upper cylindrical surface without interference fit problems. Curved feet on the end of the dial micrometer shaft to fit the curvature of the ring(s), may be used.

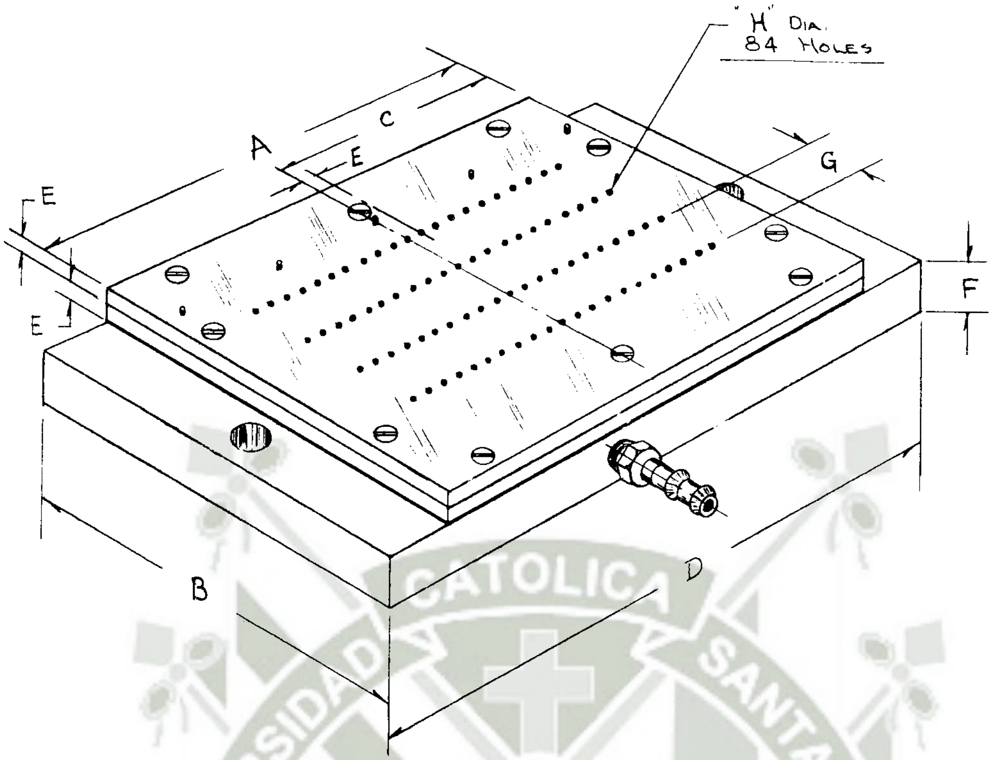
15. Ring Specimen

15.1 *ASTM Cut Rings*—Two types of cut ring specimens may be used. Unless otherwise specified, the Type 1 ring specimen shall be used.

15.1.1 *Ring Dimensions*:

	mm	in.
Type 1		
Circumference (inside)	50.0 ± 0.01	2.0 ± 0.004
Diameter (inside)	15.92 ± 0.003	0.637 ± 0.001
Radial width	1.0 ± 0.01	0.040 ± 0.0004
Thickness, minimum	1.0	0.040
maximum	3.3	0.13
Type 2		
Circumference mean	100.0 ± 0.2	4.0 ± 0.0004
Diameter (inside)	29.8 ± 0.06	1.19 ± 0.0001
Radial width	2.0 ± 0.02	0.08 ± 0.0008
Thickness, minimum	1.0	0.04
maximum	3.3	0.13

15.2 *ISO Cut Rings*—The normal size and the small size ring specimens in ISO 37 have the following dimensions given in mm. See ISO 37 for specific testing procedures for these rings.



Dimension	mm	in.	Dimension	mm	in.
A	178	7.0	F	19	0.75
B	152	6.0	G	23	0.90
C	89	3.5	H	1.5	0.062
D	229	9.0			
E	6	0.25			

FIG. 4 Rubber Holding Plate

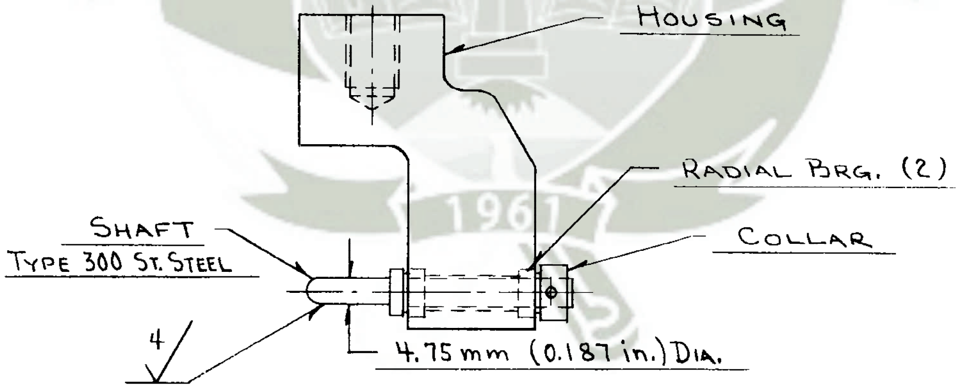


FIG. 5 Assembly, Ring Tensile Test Fixture

	Normal	Small
Diameter, inside	44.6 ± 0.2 mm	8.0 ± 0.1 mm
Diameter, outside	52.6 ± 0.2 mm	10.0 ± 0.1 mm
Thickness	4.0 ± 0.2 mm	1.0 ± 0.1 mm

15.3 *Rings Cut from Tubing*—The dimensions of the ring specimen(s) depend on the diameter and wall thickness of the tubing and should be specified in the product specification.

15.4 *Preparation of Cut Ring Specimens*—Place the blades in the slots of the cutter and adjust the blade depth using the blade depth gage. Place the cutter in the drill press and adjust the spindle or table so that the bottom of the blade holder is about 13 mm (0.5 in.) above the surface of the holding plate. Set the stop on the vertical travel of the spindle so that the tips of the cutting blades just penetrate the surface of the plate. Place the sheet on the holding plate and reduce the pressure in the cavity to 10 kPa (0.1 atm) or less. Lubricate the sheet with mild soap solution. Lower the cutter at a steady rate until it reaches the stop. Be sure that the blade holder does not contact the sheet. If necessary, readjust the blade depth. Return the spindle to its original position and repeat the operation on another sheet.

15.5 *Preparation of Ring Specimens from Tubing*—Place the tubing on a mandrel preferably slightly larger than the inner diameter of the tubing. Rotate the mandrel and tubing in a lathe. Cut ring specimens to the desired axial length by means of a knife or razor blade held in the tool post of the lathe. Lay thin wall tubing flat and cut ring specimens with a die or cutting mechanism having two parallel blades.

15.6 *Ring Dimension Measurements*:

15.6.1 *Circumference*—The inside circumference can be determined by a stepped cone or by "go-no go" gages. Do not use any stress in excess of that needed to overcome any ellipticity of the ring specimen. The mean circumference is obtained by adding to the value for the inside circumference, the product of the radial width and π (3.14).

15.6.2 *Radial Width*—The radial width is measured at three locations distributed around the circumference using the micrometer described in 14.10.

15.6.3 *Thickness*—For cut rings, the thickness of the disk cut from the inside of the ring is measured with a micrometer described in Practice D 3767.

15.6.4 *Cross-Sectional Area*—The cross-sectional area is calculated from the median of three measurements of radial width and thickness. For thin wall tubing, the area is calculated from the axial length of the cut section and wall thickness.

16. Procedure

16.1 *Determination of Tensile Stress, Tensile Strength, Breaking (Ultimate) Elongation and Yield Point*—In testing ring specimens, lubricate the surface of the spindle with a suitable lubricant, such a mineral oil or silicone oil. Select one with documented assurance that it does not interact or affect the material being tested. The initial setting of the distance between the spindle centers may be calculated and adjusted according to the following equation:

$$IS = [C_{(TS)} - C_{(SP)}]/2 \quad (6)$$

where:

IS = initial separation of spindle centers, mm (in.),
$C_{(TS)}$ = circumference of test specimen, inside circumference for Type 1 rings, mean circumference for Type 2 rings, mm (in.), and
$C_{(SP)}$ = circumference of either (one) spindle, mm (in.).

Unless otherwise specified the rate of spindle separation shall be 500 ± 50 mm/min (20 ± 2 in./min) (see Notes 6 and 7). Start the test machine and record the force and corresponding distance between the spindles. At rupture, measure and record the ultimate (breaking) elongation and the tensile (force) strength. See Section 17 for calculations.

NOTE 8—When using the small ISO ring, the rate of spindle separation shall be 100 ± 10 mm/min (4 ± 0.4 in./min).

16.2 *Tests at Temperatures Other than Standard*—Use the test chamber described in 6.2 and observe the precautionary statement in Note 2. For tests at temperatures above 23°C (73.4°F), preheat the specimens 6 ± 2 min at the test temperature. For below room temperature tests cool the specimens at the test temperature for at least 10 min prior to test. Use test temperatures prescribed in Practice D 1349. Place each specimen in the test chamber at intervals such that the recommendations of 9.2 are followed.

17. Calculation

17.1 Stress-strain properties for ring specimens are in general calculated in the same manner as for dumbbell and straight specimens with one important exception. Extending a ring specimen generates a nonuniform stress (or strain) field across the width (as viewed from left to right) of each leg of the ring. The initial inside dimension (circumference) is less than the outside dimension (circumference), therefore for any extension of the grips, the inside strain (or stress) is greater than the outside strain (or stress) because of the differences in the initial (unstrained) dimensions.

17.2 The following options are used to calculate stress at a specified elongation (strain) and breaking or ultimate elongation.

17.2.1 *Stress at a Specified Elongation*—The mean circumference of the ring is used for determining the elongation. The rationale for this choice is that the mean circumference best represents the average strain in each leg of the ring.

17.2.2 *Ultimate (Breaking) Elongation*—This is calculated on the basis of the inside circumference since this represents the maximum strain (stress) in each leg of the ring. This location is the most probable site for the initiation of the rupture process that occurs at break.

17.3 Calculate the tensile stress at any specified elongation by using Eq 2 in 13.1.

17.3.1 The elongation to be used to evaluate the force as specified in Eq 2 (13.1), is calculated as follows:

$$E = 200[L/MC_{(TS)}] \quad (7)$$

where:

E = elongation (specified), percent,
L = increase in grip separation at specified elongation, mm (in.), and
$MC_{(TS)}$ = mean circumference of test specimen, mm (in.).

17.3.2 The grip separation for any specified elongation can be found by rearranging Eq 7, as given below:

$$L = E \times MC_{(TS)}/200 \quad (8)$$

17.4 Calculate the yield stress by using Eq 3 in 13.2.

17.5 Evaluate the yield strain as given in 13.3. Since yield strain may be considered to be an average bulk property of any material, use the mean circumference for this evaluation.

17.6 Calculate the tensile strength by using Eq 4 in 13.4.

17.7 Calculate the breaking or ultimate elongation as follows (see Notes 8 and 9):

$$E = 200/[L/IC_{(TS)}] \quad (9)$$

where:

E = breaking or ultimate elongation, percent,
L = increase in grip separation at break, mm (in.), and
$IC_{(TS)}$ = inside circumference of ring test specimen, mm (in.).

17.8 The inside circumference is used for both types of rings, see 15.1.1 for dimensions. Use the inside diameter to calculate the inside circumference for Type 2 rings.

NOTE 9—Eq 8, Eq 9, and 10 are applicable only if the initial setting of the spindle centers is adjusted in accordance with Eq 7.

NOTE 10—The user of these test method should be aware that because of the different dimensions used in calculating (*1*) stress at a specified elongation (less than the ultimate elongation) and (*2*) the ultimate (breaking) elongation (see 20.1 and 20.2), it is possible that a stress at a specified elongation, slightly less (4 to 5 %) than the ultimate elongation cannot be measured (calculated).

18. Report

18.1 Report the following information:

18.1.1 Results calculated in accordance with Section 13 or 17, whichever is applicable,

18.1.2 Type or description of test specimen and with Section 13 which type of die, either U.S. Customary Units or Metric Units, was used.

18.1.3 Date of test,

18.1.4 Rate of extension if not as specified,

18.1.5 Temperature and humidity of test room if not as specified,

18.1.6 Temperature of test if at other than 23 ± 2°C (73.4 ± 3.6°F) and

18.1.7 Date of vulcanization, preparation of the rubber, or both, if known.

19. Precision and Bias

19.1 This precision and bias section has been prepared in accordance with Practice D 4483. Refer to Practice D 4483 for terminology and other statistical details.

19.2 The precision results in this precision and bias section give an estimate of the precision of these test methods with the materials used in the particular interlaboratory program as described below. The precision parameters should not be used for acceptance/rejection testing of any group of materials without documentation that the parameters are applicable to those particular materials and the specific testing protocols that include these test methods.

19.3 *Test Method A (Dumbbells)*:

19.3.1 For the main interlaboratory program a Type 1 precision was evaluated in 1986. Both repeatability and reproducibility are short term, a period of a few days separates replicate test results. A test result is the median value, as specified by this test method, obtained on three determination(s) or measurement(s) of the property or parameter in question.

19.3.2 Three different materials were used in this interlaboratory program, these were tested in ten laboratories on two different days.

19.3.3 For the main interlaboratory program cured sheets of each of the three compounds were circulated to each laboratory and stress-strain (dumbbell) specimens were cut, gaged, and tested. A secondary interlaboratory test was conducted for one of the compounds (R19160). For this testing, uncured compound was circulated and sheets were cured at a specified time and temperature (10 min at 157°C) in each laboratory. From these individually cured sheets, test specimens were cut and tested on each of two days one week apart as in the main program. The main program results are referred to as "Test Only" and the secondary program results are referred to as "Cure and Test."

19.3.4 The results of the precision calculations for repeatability and reproducibility are given in Tables 1 and 2, in ascending order of material average or level, for each of the materials evaluated and for each of the three properties evaluated.

19.3.5 The precision of this test method may be expressed in the format of the following statements that use what is called an "appropriate value" of *r, R*, (*r*), or (*R*), that is, that value to be used in decisions about test results (obtained with the test method). The appropriate value is that value of *r* or *R* associated with a mean level in Tables 1-4 closest to the mean level under consideration at any given time, for any given material in routine testing operations.

19.3.6 *Repeatability*—The repeatability, *r*, of this test method has been established as the appropriate value tabulated in Tables 1 and 2. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or nonidentical sample populations.

19.3.7 *Reproducibility*—The reproducibility, *R*, of this test method has been established as the appropriate value tabulated in Tables 1 and 2. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or nonidentical sample populations.

19.3.8 Repeatability and reproducibility expressed as a percentage of the mean level, (*r*) and (*R*), have equivalent application statements as above for *r* and *R*. For the (*r*) and (*R*) statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

19.3.9 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by the test method. Bias, therefore, cannot be determined.

19.4 *Test Method B (Rings)*:

19.4.1 A Type 1 precision was evaluated in 1985. Both repeatability and reproducibility are short term, a period of a few days separates replicate test results. A test result is the mean value, as specified by this test method, obtained on three determinations or measurements of the property or parameter in question.

19.4.2 Six different materials were used in the interlaboratory program, these were tested in four laboratories on two different days.

19.4.3 The results of the precision calculations for repeatability and reproducibility are given in Tables 3 and 4, in ascending order of material average or level, for each of the materials evaluated.

TABLE 1 Type 1 (Test Only) Precision on Method A Die C Dumbbell Test Specimens

NOTE:
Sr = repeatability standard deviation.
r = repeatability = 2.83 times the square root of the repeatability variance.
(r) = repeatability (as percentage of material average).
SR = reproducibility standard deviation.
R = reproducibility = 2.83 times the square root of the reproducibility variance.
(R) = reproducibility (as percentage of material average).

Part 1 Tensile Strength, MPa:

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
1. N18081	9.88	0.200	0.568	5.75	0.293	0.829	8.40
3. E17074	15.38	0.467	1.323	8.60	0.482	1.366	8.88
2. R19160	25.70	0.436	1.235	4.80	1.890	5.351	20.82
Pooled Values[A]	16.99	0.385	1.090	6.42	1.102	3.120	18.37

Part 2 Percent Elongation:

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
3. E17074	156.3	6.304	17.842	11.41	11.481	32.492	20.78
2. R19160	510.4	11.471	32.464	6.36	21.243	60.120	11.77
1. N18081	591.6	17.810	50.402	8.52	27.198	76.972	13.01
Pooled Values[A]	419.4	12.761	36.114	8.61	20.999	59.427	14.16

Part 3 Stress at 100 % Elongation, MPa:

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
1. N18081	1.17	0.053	0.151	12.96	0.061	0.1744	14.92
2. R19160	2.01	0.050	0.142	7.10	0.274	0.7755	38.62
3. E17074	9.08	0.489	1.385	15.25	0.738	2.0910	23.02
Pooled Values[A]	4.09	0.285	0.808	19.79	0.456	1.2915	31.60

[A] No values omitted.

TABLE 2 Type 1 (Cure and Test) Precision on Method A Die C Dumbbell Test Specimens[A]

NOTE 1:
Sr = repeatability standard deviation.
r = repeatability = 2.83 times the square root of the repeatability variance.
(r) = repeatability (as percentage of material average).
SR = reproducibility standard deviation.
R = reproducibility = 2.83 times the square root of the reproducibility variance.
(R) = reproducibility (as percentage of material average).

NOTE 2:
N18081—highly extended, low durometer CR (Neoprene).
R19160—high tensile NR.
E17047—moderately filled EPDM.

Part 1 Tensile Strength, MPa:

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
1. R19160	26.0	0.613	1.73	6.66	1.74	4.95	19.0

Part 2 Percent Elongation:

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
1. R19160	526.9	13.32	37.7	7.15	19.6	55.70	10.5

Part 3 Stress at 100 % Elongation, MPa:

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
1. R19160	1.83	0.072	0.205	11.21	0.226	0.641	34.5

[A] Seven laboratories participated in this cure and test program.

19.4.4 Repeatability, *r*, varies over the range of material levels as evaluated. Reproducibility, *R*, varies over the range of material levels as evaluated.

19.4.5 The precision of this test method may be expressed in the format of the following statements that use what is called an "appropriate value" of *r*, *R*, (*r*), or (*R*), that is, that value to

TABLE 3 Type 1 Precision—Test Method B (Rings)

NOTE:
Sr = repeatability standard deviation.
r = repeatability = 2.83 times the square root of the repeatability variance.
(r) = repeatability (as percentage of material average).
SR = reproducibility standard deviation.
R = reproducibility = 2.83 times the square root of the reproducibility variance.
(R) = reproducibility (as percentage of material average).

Tensile Strength (MPa)

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
5. MATL 5	11.5	0.666	1.885	16.3	1.43	4.06	35.3
6. MATL 6	12.7	0.274	0.775	6.0	0.83	2.35	18.5
1. MATL 1	14.6	0.367	1.040	7.1	0.40	1.15	7.9
4. MATL 4	15.0	0.553	1.565	10.4	3.03	8.59	57.2
2. MATL 2	20.3	1.293	3.660	18.0	2.47	6.99	34.4
3. MATL 3	22.3	1.556	4.405	19.6	1.55	4.40	19.6
Pooled Values[A]	15.9	0.942	2.666	16.7	1.87	5.31	33.3

[A] No values omitted.

TABLE 4 Type 1 Precision—Test Method B (Rings)

NOTE:
Sr = repeatability standard deviation.
r = repeatability = 2.83 times the square root of the repeatability variance.
(r) = repeatability (as percentage of material average).
SR = reproducibility standard deviation.
R = reproducibility = 2.83 times the square root of the reproducibility variance.
(R) = reproducibility (as percentage of material average).

Ultimate Elongation, %

Material	Average	Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*SR*	*R*	(*R*)
1. MATL 1	322.1	15.25	43.18	13.40	33.4	94.7	29.4
2. MATL 2	445.4	11.35	32.12	7.21	34.1	96.6	21.7
4. MATL 4	509.4	27.44	77.65	15.24	51.1	144.8	28.4
5. MATL 5	545.0	2.91	8.25	1.51	56.3	159.5	29.2
6. MATL 6	599.7	12.91	36.55	6.09	14.0	39.6	6.60
3. MATL 3	815.8	16.25	45.99	5.63	90.6	256.5	31.4
Pooled Values[A]	539.6	16.54	46.82	8.67	48.2	136.4	25.2

[A] No values omitted.

be used in decisions about test results (obtained with the test method). The appropriate value is that value of *r* or *R* associated with a mean level in Tables 1-4 closest to the mean level under consideration at any given time, for any given material in routine testing operations.

19.4.6 *Repeatability*—The repeatability, *r*, of this test method has been established as the appropriate value tabulated in Tables 3 and 4. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or nonidentical sample populations.

19.4.7 *Reproducibility*—The reproducibility, *R*, of this test method has been established as the appropriate value tabulated in Tables 3 and 4. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or nonidentical sample populations.

19.4.8 Repeatability and reproducibility expressed as a percentage of the mean level, (*r*) and (*R*), have equivalent application statements as 19.3.6 and 19.3.7 for *r* and *R*. For the (*r*) and (*R*) statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

19.4.9 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by the test method. Bias, therefore, cannot be determined.

20. Keywords

20.1 elongation; set after break; tensile properties; tensile set; tensile strength; tensile stress; yield point

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Designation: D 573 – 99

Standard Test Method for Rubber—Deterioration in an Air Oven[1]

This standard is issued under the fixed designation D 573; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes a procedure to determine the influence of elevated temperature on the physical properties of vulcanized rubber. The results of this test method may not give an exact correlation with service performance since performance conditions vary widely. This test method may, however, be used to evaluate rubber compounds on a laboratory comparison basis.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (For specific precautionary statement, see Note 1.)

2. Referenced Documents

2.1 *ASTM Standards:*

D 412 Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers—Tension[2]
D 1349 Practice for Rubber—Standard Temperatures for Testing[2]
D 3182 Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets[2]
D 3183 Practice for Rubber—Preparation of Pieces for Test Purposes from Products[2]
D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[2]
E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens[3]

3. Summary of Test Method

3.1 Specimens of vulcanized rubber are exposed to the deteriorating influence of air at specified elevated temperatures for known periods of time, after which their physical properties are determined. These are compared with the properties determined on the original specimens and the changes noted.

3.2 Unless otherwise specified, the determination of the physical properties shall be carried out in accordance with Test Methods D 412.

3.3 Except as may be otherwise specified in this test method, the requirements of Practices D 3182 and D 3183 shall be complied with and are made part of this test method.

3.4 In case of conflict between the provisions of this test method and those of detailed specifications or test methods for a particular material, the latter shall take precedence.

4. Significance and Use

4.1 Rubber and rubber products must resist the deterioration of physical properties with time caused by oxidative and thermal aging. This test method provides a way to assess these performance characteristics of rubber, under certain accelerated conditions as specified.

4.2 Please refer to the Annex for important information on standard compounds used for precision testing for accelerated test aging evaluation.

5. Apparatus

5.1 Type IIB ovens specified in Test Method E 145 are satisfactory for use through 70°C. For higher temperatures, Type IIA ovens are necessary.

5.1.1 The interior size shall be as follows or of an equivalent volume:

Interior size of air oven:	
min	300 by 300 by 300 mm (12 by 12 by 12 in.)
max	900 by 900 by 1200 mm (36 by 36 by 48 in.)

5.1.2 Provision shall be made for suspending specimens vertically without touching each other or the sides of the aging chamber.

5.1.3 The heating medium for the aging chamber shall be air circulated within it at atmospheric pressure.

5.1.4 The source of heat is optional but shall be located in the air supply outside of the aging chamber proper.

5.1.5 The temperature should be automatically recorded over the entire test period using a temperature-measuring device capable of measuring at the specified temperature to within ±1°C. Located in the upper central portion of the chamber near the center of the aging specimens. For apparatus

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[1] This test method is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.15 on Degradation Tests.

Current edition approved Nov. 10, 1999. Published December 1999. Originally published as D 573 – 40. Last previous edition D 573–88 (1994)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

not equipped with automatic recording capabilities, temperature shall be measured with sufficient frequency to ascertain that the temperature limits specified in 10.2 are adhered to.

5.1.6 Automatic temperature control by means of thermostatic regulation shall be used.

5.1.7 The following special precautions shall be taken in order that accurate, uniform heating is obtained in all parts of the aging chamber:

5.1.7.1 The heated air shall be thoroughly circulated in the oven by means of mechanical agitation. When a motor-driven fan is used, the air must not come in contact with the fan motor brush discharge because of danger of ozone formation.

5.1.7.2 Baffles shall be used as required to prevent local overheating and dead spots.

5.1.7.3 The thermostatic control device shall be so located as to give accurate temperature control of the heating medium. The preferred location is adjacent to the recording thermometer.

5.1.7.4 An actual check shall be made by means of maximum reading thermometers placed in various parts of the oven to verify the uniformity of the heating.

6. Sampling

6.1 The sample size shall be sufficient to allow for the determination of the original properties on three specimens and also on three or more specimens for each exposure period of the test. At least 24 h must elapse between completion of the vulcanization of the samples and the start of the aging test.

6.2 When minimum requirements are specified, one test on three dumbbells shall be considered sufficient. But if the results are below the specified requirements, two additional specimens shall be prepared from the original sample and tested. Should the results of either of these tests be below the specified requirements, the sample shall be considered to have failed to meet the specifications.

7. Test Specimens

7.1 Dumbbell-shaped specimens prepared as described in Test Methods D 412 shall be considered standard. Their form shall be such that no mechanical, chemical, or heat treatment will be required after exposure. If any adjustments (for example, to thickness) are necessary, they should be performed prior to exposure.

7.2 The cross-sectional dimensions of test specimens for calculating the physical properties shall be measured prior to exposure in the aging chamber. Gage lines used for measuring elongation shall be applied after the specimens have been aged. Only specimens of similar dimensions having approximately the same exposed areas may be compared with each other.

8. Number of Test Specimens

8.1 At least three test specimens shall be used to determine the original physical properties of each sample and also three or more specimens of the same material for each exposure period of the test.

8.2 When minimum requirements are specified, one test shall be made for tensile strength and elongation. If the results are below the specified requirements, two additional specimens shall be prepared from the original sample and tested. Should the results of either of these tests be below the specified requirements, the samples shall be considered to have failed to meet the specifications.

9. Tests of Unaged Specimens

9.1 The stress - strain properties or tensile strength and ultimate elongation and any other required properties of the original unaged specimens shall be determined within 96 h of the start of the aging period. Results on specimens that are found to be imperfect shall be discarded and retests shall be made.

9.2 When rubber compounds are to be tested for the purpose of determining compliance with specifications, it shall be permissible to determine the original properties required in 9.1 simultaneously with the determination of the values after the first aging period even though the elapsed time exceeds 96 h.

10. Procedure for Accelerated Aging

10.1 Place the specimens for aging in the oven after it has been preheated to the operating temperature. If possible, avoid simultaneous aging of a mixed group of different compounds. For instance, high-sulfur compounds should not be aged with low-sulfur compounds and those containing antioxidants shall not be aged with those having no antioxidants. Some migration is known to occur.

10.2 The operating temperature may be any elevated standard temperature as shown in Practice D 1349, as agreed upon.

NOTE 1—**Caution:** It should be noted that, for each 10°C increase in temperature, the rate of oxidation may be approximately double. With rapid aging types of rubber or those containing or contaminated by certain oxidizing chemicals, the rate of oxidation may be catalyzed to such an extent as to become violent with increasing temperatures.

10.3 Start the aging interval at the time the specimens are placed in the oven and continue for a measured time interval. The selection of suitable intervals of aging will depend on the rate of deterioration of the particular material being tested. Intervals frequently used are 2, 4, 7, and 14 days.

10.4 Use aging intervals such that the deterioration will not be so great as to prevent determination of the final physical properties. In experimental work, it is desirable to use a range of periods while for routine tests of known materials fewer intervals may be employed.

10.5 At the termination of the aging interval, remove the specimens from the oven, cool to room temperature on a flat surface, and allow them to rest not less than 16 h nor more than 96 h before determination of the physical properties. Apply the gage lines to the specimens for use in measuring elongations.

11. Physical Tests of Aged Specimens

11.1 The tensile strength and ultimate elongation or the stress - strain properties of the specimens aged for different intervals shall be determined as the intervals terminate in the progress of aging, disregarding the fact that more specimens may still be aging. In determining the physical properties after aging, the final values shall be the median of results from three specimens except that under the following conditions two additional specimens shall be exposed and tested and the median of the values for the five specimens shall be used:

11.1.1 If one or more values do not meet the specified requirements when testing for compliance with specifications.

11.1.2 If referee tests are being made. After completion of the tests, the broken specimens shall be examined visually and manually and their condition noted.

12. Calculation

12.1 Express the results of the aging test as a percentage of the change in each physical property (tensile strength, ultimate elongation, or tensile stress), calculated as follows:

$$P = [(A - O)/O] \times 100 \tag{1}$$

where:

P = percentage change in property,
O = original value, and
A = value after aging.

13. Report

13.1 The report shall include the following:

13.1.1 The results calculated in accordance with Section 12,

13.1.2 All observed and recorded data on which the calculations are based,

13.1.3 Type of aging test,

13.1.4 Aging interval,

13.1.5 Aging temperature,

13.1.6 Duration, temperature, and data of vulcanization of the rubber, if known,

13.1.7 Dates of original and final determinations of physical properties, and

13.1.8 Dimensions of test specimens.

14. Precision and Bias [4]

14.1 This precision and bias section has been prepared in accordance with Practice D 4483. Refer to this practice for terminology and other statistical calculation details.

14.2 A Type 2 (interlaboratory) precision was evaluated in 1974. Both repeatability and reproducibility are short term, a period of a few days separates replicate test results. A test result is expressed on the basis of a median value, as specified by Test Methods D 412 obtained on 3 determinations or measurements of the property or parameter in question.

14.3 Six different materials were used in the interlaboratory program, these were tested in 3 laboratories on 2 different days. These precision results were obtained for a variety of compounds prepared in accordance with Method D 15 prior to its removal from the *Annual Book of ASTM Standards*. Please see annex of Test Method D 573 for more details on this work.

14.4 The results of the precision calculations for repeatability and reproducibility for both percent tensile strength change and percent elongation change are given in Table 1, in ascending order of material average or level, for each of the materials evaluated.

14.4.1 The precision of this test method may be expressed in the format of the following statements that use an appropriate value of *r, R, (r)*, or (*R*), that is, that value to be used in decisions about test results (obtained with the test method). The *appropriate value* is that value of *r* or *R* associated with a mean level in the precision tables closest to the mean level under consideration at any given time, for any given material in routine testing operation.

TABLE 1 Type 2 Precision Results—100°C Aging

NOTE—The averaging of results for 48 and 96 h of aging gives an increased DF estimate of precision.

NOTE:
Sr = within laboratory standard deviation
r = repeatability (in measurement units)
(*r*) = repeatability (in percent)
SR = between laboratory standard deviation
R = Reproducibility (in measurement units)
(*R*) = Reproducibility (in percent)

Part 1—Percent Tensile Strength Change, 48 h

Material or Compound	Mean Test Level	Within Laboratories		Between Laboratories	
		Sr	*r*	*SR*	*R*
NR (1G)	−56.6	3.28	9.28	5.91	16.7
SBR (9B)	−14.2	3.42	9.68	3.02	8.55
NBR (1F)	−11.5	2.46	6.96	2.49	7.05
CR (2D)	−10.6	3.83	10.8	5.11	14.5
OESBR (10B3)	−7.6	2.34	6.62	5.56	15.7
IIR (2E)	−1.1	3.47	9.82	3.77	10.7
Pooled Values	...	3.18	9.00	3.90	11.04

Part 2—Percent Change in Elongation, Average of 48, 96 h Aging

Material or Compound	Mean Test Level	*Sr*	*r*	*SR*	*R*
NR (1G)	−55.6	5.08	14.4	7.79	22.0
SBR (9B)	−48.3	5.38	15.2	6.09	17.2
OESBR (10B3)	−40.5	3.20	9.06	5.11	14.5
NBR (1F)	−39.6	7.10	20.1	7.11	20.1
CR (2D)	−12.1	7.85	22.2	9.00	25.5
IIR (2E)	−6.2	2.56	7.24	3.97	11.2
Pooled Values	...	5.20	14.7	6.51	18.4

14.5 *Repeatability*— The repeatability *r*, of this test method has been established as the *appropriate value* tabulated in the precision tables. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

14.6 *Reproducibility*— The reproducibility *R*, of this test method has been established as the *appropriate value* tabulated in the precision tables. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or non-identical sample populations.

14.7 The precision results indicate that the repeatability and reproducibility of both percent tensile strength change and percent elongation change are essentially the same. Also the value of *r* or *R*, or both does not vary with the magnitude of percent elongation or percent tensile strength change. No values are given for (*r*) or (*R*) because of the near zero average values for some of the materials.

14.8 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by the test method. Bias, therefore, cannot be determined.

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[4] Supporting data have been filed at ASTM Headquarters. Request RR: D-11-1056.

15. Keywords

15.1 accelerated aging; elevated temperature; oxidative aging; rubber articles; rubber products; thermal aging

ANNEX

(Mandatory Information)

A1. FORMER TEST METHOD (D 15) COMPOUNDS USED FOR PRECISION TESTING

A1.1 Introduction

A1.1.1 Testing to develop precision data was begun by some Subcommittees in D-11 prior to the removal of ASTM Method D 15, Compound and Sample Preparation for Physical Testing of Rubber Products.[5] In this initial precision work some of the standard compounds that were currently included in D15 were used. Since that time these standard D15 compounds have been either modified or removed from the *Annual Book of ASTM Standards.* They were replaced by a series of new standards, for example, Methods D 3184 on NR, Methods D 3185 on SBR, etc.

A1.1.2 To provide a source of reference for the compounds removed from the previous D15 standard, those compounds used in measuring precision, especially those used in Subcommittee D11.15, are included in Tables A1.1-A1.6 taken directly from D15. These tables are listed below.

A1.1.3 The formulations for the compounds in Tables A1.1-A1.6 are placed in this standard temporarily. This test method is selected as a location since it is the most frequently used standard test for evaluating compounds for accelerated aging performance.

TABLE A1.1 Type A—Standard Formulations for Styrene-Butadiene Rubbers

	NBS	9B
SBR or OE-SBR		100.00
Zinc oxide	370	3.00
Stearic acid	372	1.00
Sulfur	371	1.75
Furnace black[A]	378	50.00
TBBS	384	1.00
		156.75
Batch factor		3.0

[A] Current Industry Reference Black (IRB) may be used in place of NBS 378, although slightly different results may be obtained. Weight ingredients to nearest 0.1 g for SBR and carbon black and to the nearest 0.01 g for other ingredients.

A1.2 Cure Times for Compounds

A1.2.1 The cure times for compounds selected in the D11.15 precision testing are as follows:

Compound	Time, min,	Temperature,° C
Polychloroprene (neoprene)	30	150
Natural (1G)	30	145
SBR (9B)	50	145
OE–SBR (10B3)	50	145
Butyl (2E)	80	150
NBR (1F)	40	150

A1.3 Materials and Mixing

A1.3.1 In the precision test programs that generated Type 2 Precision data for D11.15 standards, that is, that precision which includes compound weighing, mixing, and curing components of variation, a special testing procedure was employed. A common supply was set up for all the materials needed to prepare compounds in accordance with the tables of this Annex. All laboratories that participated in any interlaboratory program drew their materials from this common uniform supply; thus the within-materials source of variation was reduced to the lowest possible (practical) level.

A1.3.2 Mixes of the selected compounds were made on specified days (2 days normally being selected) to determine within-laboratory variability as specified in Practice D 4483.

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[5] Discontinued—see 1974 *Annual Book of ASTM Standards,* Part 37.

TABLE A1.2 Type A—Standard Formulations for Styrene-Butadiene Rubber Compounds (expressed on 100 Part Rubber Basis)

Material	NBS	10B1 Non-OE Rubbers	10B2 25-Oil Rubbers	10B3 37.5-Oil Rubbers	10B4 50-Oil Rubbers	10B5 62.5-Oil Rubbers	10B6 75-Oil Rubbers
SBR		100.00	...	...	...	...	...
OE-SBR			125.00	137.50	150.00	162.50	175.00
Zinc oxide	370	3.00	3.75	4.12	4.50	4.88	5.25
Stearic acid	372	1.00	1.25	1.38	1.50	1.63	1.75
Sulfur	371	1.75	2.19	2.42	2.63	2.85	3.06
Furnace black[A]	378	50.00	62.50	68.75	75.00	81.25	87.50
TBBS	384	1.00	1.25	1.38	1.50	1.63	1.75
		156.75	195.94	215.55	235.13	254.74	274.31

[A] Current Industry Reference Black (IRB) may be used in place of NBS 378, although slightly different results may be obtained.

TABLE A1.3 Standard Formulas for Neoprene Rubber Compounds[A]

Material	NBS Standard Sample No.	ID	2D
Neoprene W	...	100	100
Magnesium oxide	376	4	4
Stearic acid	372	0.5	1
SRF carbon black	382	...	29
Zinc oxide	370	5	5
2-Mercaptoimidazoline	...	0.35	0.5
Phenyl beta naphthylamine	377	2	2
Specific gravity (calculated)		1.29	1.39

[A] For mill mixing use 3 × recipe weight.

TABLE A1.4 Standard Formulas for Butyl Rubber Compounds[A]

Material	NBS Standard Sample No.	IE	2E	3E
Butyl rubber	388	100	100	100
Zinc oxide	370	5	5	3
Sulfur	371	2	2	1.75
Stearic acid	372	...	3	1
Benzothiazyl disulfide	373	...	0.5	...
Tetramethyl thiuram-disulfide	374	1	1	1
Channel black	375	...	50	...
Oil furnace black (HAF type)	378[B]	...	...	50
Specific gravity (calculated)		0.97	1.12	1.13

[A] For mill mixing use 2 × recipe weight.

[B] IRB or Industry Reference Black may be used as a suitable alternative but the same results may not be obtained.

TABLE A1.5 Standard Formulas for Nitrile Rubber Compound

Material	NBS Standard Sample No.	IF
Nitrile rubber	391	100
Zinc oxide	370	5
Sulfur	371	1.5
Stearic acid	372	1
Benzothiazyl disulfide	373	1
Gas furnace black	382	40
Specific gravity (calculated)		1.18

TABLE A1.6 Standard Formula for Testing Carbon Black

Material	NBS Standard Sample No.	IG
Natural rubber[A]	...	100.00
Stearic acid	372	3.00
Zinc oxide	370	5.00
Benzothiazyl disulfide	373	0.60
Sulfur	371	2.50
Carbon black	...	50.00[B]
Specific gravity (calculated)		1.13

[A] Available from the Firestone Tire and Rubber Co. Specially selected Liberian crepe with 600 % modulus of 700 ± 100 psi when tested in compound 1A.

[B] For all carbon blacks except FT and MT. For those blacks where 75 parts are used, the calculated specific gravity is 1.19.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

Designation: D 1349 – 99

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428
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Standard Practice for Rubber—Standard Temperatures For Testing[1]

This standard is issued under the fixed designation D 1349; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice establishes a list of standard temperatures from which selection may be made for any specific test or test method. Any standard or specification which specifies test temperatures not listed shall take precedence over this practice.

1.2 These temperatures do not apply to mixing, processing, or vulcanizing temperatures for rubber compounds. Any standard requiring preparation of a particular rubber compound should specify the conditions to be used.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Test Temperatures

2.1 The test temperatures are as follows:

°C	°F
−75	−103
−55	−67
−40	−40
−25	−13
−10	14
0	32
23	73.4
40	104
55	131
70	158
85	185
100	212
125	257
135	275
150	302
160	320
175	347
200	392
225	437
250	482

2.2 Tolerances for the test temperature, unless otherwise specified in a particular method, shall be ±2°C or ±3.6°F. This tolerance is the maximum allowable variation in the temperature of the space enclosing the specimens being tested. The average temperature of the space shall be as close as practicable to the specified temperature.

2.3 Unless otherwise specified, conditioning and testing of materials known to be sensitive to variations in temperature or relative humidity, shall be carried out at a temperature of 23 ± 2°C (73.4± 3.6°F) and a relative humidity of 50 ± 5 %.

3. Keywords

3.1 standard test temperatures

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[1] This practice is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.14 on Time and Temperature-Dependent Physical Properties.

Current edition approved February 10, 1999. Published February 1999. Originally published as D1349 – 54 T. Last previous edition D1349 – 87 (1992)$^{\epsilon 1}$.

Designation: D 1415 – 88 (Reapproved 1999)

Standard Test Method for Rubber Property—International Hardness[1]

This standard is issued under the fixed designation D 1415; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes a procedure for measuring the hardness of rubber. The hardness is obtained by the difference in penetration depth of a specified dimension ball under two conditions of contact with the rubber: (*1*) with a small initial force and (*2*) with a much larger final force. The differential penetration is taken at a specified time and converted to a hardness scale value.

1.2 This test method is identical in substance with ISO 48.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1349 Practice for Rubber—Standard Temperatures for Testing[2]

D 2240 Test Method for Rubber Property—Durometer Hardness[2]

D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[2]

2.2 *ISO Standard:*

ISO/48 Vulcanized Rubbers—Determination of Hardness (Hardness between 30 and 85 IRHD)[3]

3. Summary of Test Methods

3.1 Two procedures are given to accommodate specimens of different dimensions. The standard test is intended to be used on specimens greater than 4 mm in thickness, preferably 8 to 10 mm. The micro-tester is used on specimens less than 4 mm in thickness, on specimens thicker than 4 mm having lateral dimensions less than those specified for the standard test, or on rubber articles that do not have flat surfaces suitable for making the standard test. In both procedures, the hardness in International Rubber Hardness Degrees (IRHD) is derived from the difference in penetrations and a table or graph constructed from the table. In the micro-tester procedure, the difference in penetration must first be multipled by scale factor 6. Alternatively, the penetration-measuring instrument may be calibrated directly in IRHD.

4. Significance and Use

4.1 The International Hardness test is based on measurement of the penetration of a rigid ball into the rubber specimen under specified conditions. The measured penetration is converted into International Rubber Hardness Degrees, the scale of degrees being so chosen that 0 represents a material having an elastic modulus of zero, and 100 represents a material of infinite elastic modulus. The scale chosen also fulfills the following conditions over most of the normal range of hardness: one International Rubber Hardness Degree range represents approximately the same proportionate difference in Young's modulus, and for rubber vulcanizates in the usual range of resilience, readings in International Rubber Hardness Degrees are comparable with those given by a Type A durometer (Test Method D 2240) when testing standard specimens. The term "usual range of resilience'' is used to exclude those compounds that have unusually high rates of stress relaxation or deformational hysteresis. For such compounds, differences in the dwell time in the two hardness tests result in differences in hardness values. Readings may not be comparable when testing curved or irregularly shaped test pieces.

4.1.1 For substantially elastic isotropic materials like well-vulcanized natural rubbers, the hardness in International Rubber Hardness Degrees bears a known relation to Young's modulus, although for markedly plastic or anisotropic rubbers the relationship will be less precisely known.

4.1.2 The relation between the difference of penetration and the hardness expressed in International Rubber Hardness Degrees is based on the following:

4.1.2.1 The relation[4] between penetration and Young's modulus for a perfectly elastic isotropic material:

$$F/M = 1.9\, R^2 (P/R)^{1.35} \tag{1}$$

where:

F = indenting force,

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[1] This test method is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved Sept. 30, 1988. Published February 1989. Originally published as D 1415 – 56 T. Last previous edition D 1415 – 83.

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

[4] This relation is approximate and is included as an indication.

M = Young's modulus, MPa,
R = radius of ball, mm, and
P = penetration, mm.

4.1.2.2 Use of a probit (integrated normal error) curve to relate $\log_{10} M$ and hardness in International Rubber Hardness Degrees, as shown in Fig. 1. This curve is defined as follows:

4.1.2.3 The value of $\log_{10} M$ corresponding to the midpoint of the curve is equal to 0.364, that is, $M = 2.31$ MPa or 335 psi.

4.1.2.4 The maximum slope is equal to 57 International Rubber Hardness Degrees per unit increase in $\log_{10} M$.

5. Apparatus

5.1 The essential parts of the apparatus are as follows, the appropriate dimensions and loads being given in Table 1:

5.1.1 *Vertical Plunger*, terminating in a rigid ball.

5.1.2 *Force Applicator*—for applying a minor force and a major force to the ball the mass of the plunger and of any fittings attached to it and the force of any spring acting on it shall be included in determining the minor and major forces. This is in order that the forces actually applied to the ball shall be as specified.

5.1.3 *Measuring Device*—A mechanical, optical, or electrical device graduated either in standard units of length or in International Rubber Hardness Degrees for measuring the increase in depth of penetration of the plunger caused by the major load.

5.1.4 *Foot*—A flat annular-shaped foot that is rigidly fastened to the penetration-measuring device and normal to the axis of the plunger, and which during the test is forced against the specimen in order to determine accurately the position of the upper surface.

5.1.5 *Vibrating Device*—For example, an electrically operated buzzer, for gently vibrating the apparatus to overcome any slight friction; this should not exceed 5 % of the minor load. This device may be omitted on apparatus without any friction.

6. Test Specimen

6.1 Tests intended to be comparable must be made on specimens of the same thickness that have smooth, flat, and parallel upper and lower surfaces. Two pieces of rubber, but not more than two, may be superimposed to obtain the required thickness. The dimensions of the specimen depend on the tester used to measure the hardness.

6.2 *Standard Tester*—The standard specimen shall be between 8 and 10 mm in thickness; nonstandard specimens may be either thicker or thinner but in no case less than 4 mm thick. The lateral dimensions of both standard and nonstandard specimens shall be not less than 20 mm, and no test shall be made at a distance from the edge of the specimen less than the appropriate distance shown in Table 2.

6.3 *Micro Tester*—The standard specimen for the micro test procedure shall be between 2 and 2.5 mm in thickness; nonstandard specimens may be either thicker or thinner but in no case less than 1 mm thick. The lateral dimensions of both standard and nonstandard specimens shall be such that no test is made at a distance from the edge of less than 2 mm. When specimens thicker than 4 mm are tested on the micro tester because lateral dimensions or area of flatness do not permit testing on a standard tester, the test shall be made at a distance from the edge as great as possible. Curved specimens, for example, O-rings, may be tested with the micro tester if the specimens are mounted in such a manner as to prevent movement during the test, but the values obtained may not be

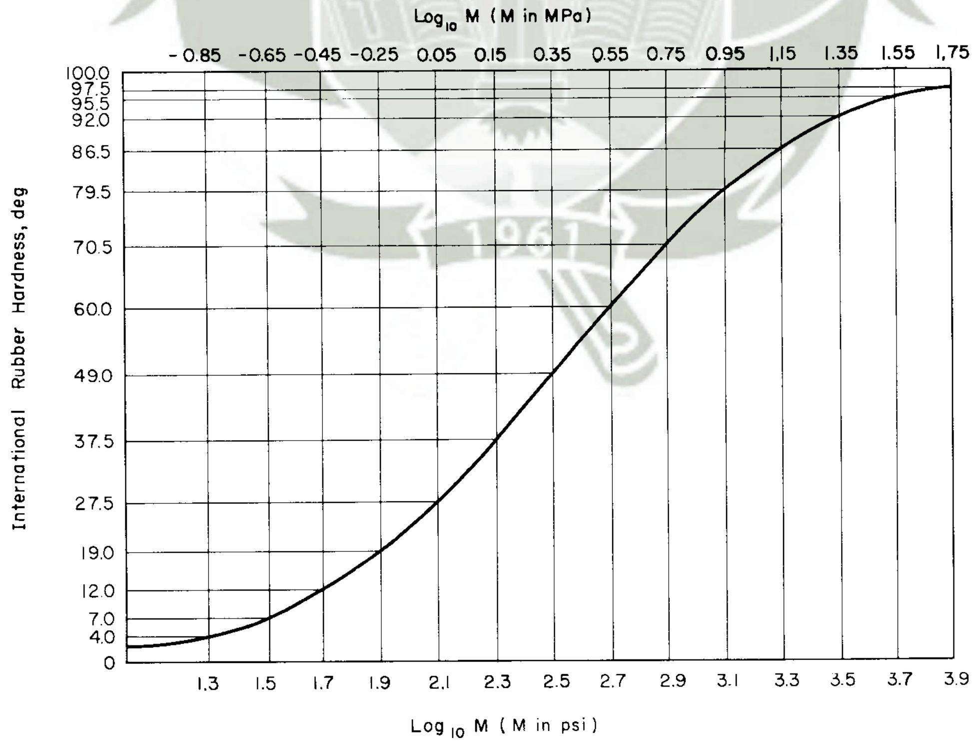

FIG. 1 Point Curve to Relate Log_{10} M and the Hardness in International Rubber Hardness Degrees

TABLE 1 Apparatus Requirements

NOTE 1—In micro testing using instruments in which the test piece table is pressed upwards by a spring, the value of the force on foot is that acting during the period of application of the total indenting force. Before the indenting force increment of 0.145 *N* is applied, the force on the foot is greater by this amount, and hence is 0.38 ± 0.03 *N*.

	Standard Testers		Micro Tester
Diameter of ball, mm	2.38 ± 0.01	2.50 ± 0.01	0.395 ± 0.005
Minor force on ball, N[A]	0.30 ± 0.02	0.29 ± 0.02	0.0083± 0.0005
Major force on ball, N[A]	5.23 ± 0.01	5.4 ± 0.01	0.1455 ± 0.0005
Total force on ball, N[A]	5.53 ± 0.03	5.7 ± 0.03	0.153 ± 0.001
Outside diameter of foot, mm	20 ± 1	20 ± 1	3.35± 0.15
Inside diameter of foot, mm	6 ± 1	6 ± 1	1.00± 0.15
Force on foot, N[B]	8.3 ± 1.5	8.3 ± 1.5	0.235± 0.03[C]

[A] Includes frictional forces in apparatus.

[B] The force should be adjusted within these limits to the actual area of the foot so that the pressure in the specimen is 30 ± 0.5 kPa.

[C] Force on foot during application of total force on ball; force on foot during application of minor force on ball, 0.2 N minimum, 0.4 N maximum.

TABLE 2 Minimum Distance from Edge of Specimen at Which Test is Made

Total Thickness of Specimen		Minimum Distance from Edge	
mm	in.	mm	in.
4	0.16	7.0	0.28
6	0.25	8.0	0.31
8	0.3	9.0	0.35
10	0.4	10.0	0.40
15	0.6	11.5	0.45
25	1.0	12.5	0.50

comparable to those obtained with flat specimens.

7. Test Temperature

7.1 The test shall be normally carried out at 23 ± 2°C (73.4 ± 3.6°F). The specimens shall be maintained at the test temperature for at least 3 h immediately prior to testing. Specimens that are affected by atmosphere moisture shall be conditioned in an atmosphere controlled to 50± 5 % relative humidity for at least 24 h. When tests are made at higher or lower temperatures, the specimens shall be maintained at the conditions of test for a period of time sufficient to reach temperature equilibrium with the testing chamber, and the temperatures shall be chosen from those specified in Practice D 1349.

8. Procedure

8.1 Condition the specimen in accordance with 7.1. Slightly dust the upper and lower surfaces of the test specimen with talc. Support the specimen on a horizontal rigid surface, and lower the foot to rest on the surface of the specimen. Press the plunger, with the minor force on the indenting ball, vertically onto the specimen for 5 s.

8.2 If the gage is graduated directly in International Rubber Hardness Degrees, turn the bezel of the gage so that the pointer indicates 100 (exercise care to avoid exerting any vertical pressure on the gage). Add the major force to the plunger and maintain the total force on the ball for 30 s (Note 1). Record the reading on the gage as the hardness in International Rubber Hardness Degrees.

NOTE 1—During the loading periods the apparatus shall be gently vibrated to overcome any friction.

8.3 If the measuring device is graduated in metric or inch units, record the movement of the plunger caused by application of the major load for 30 s. If the micro tester is used, multiply this movement by the scale factor of 6. Convert the value obtained into International Rubber Hardness Degrees by using Table 3 or a graph constructed therefrom.

8.4 Make one measurement at each of three or five different points distributed over the specimen. Take the median of these measurements rounded to the nearest IRHD for the hardness value.

9. Report

9.1 The report shall include the following:

9.1.1 Hardness expressed in International Rubber Hardness Degrees (IRHD). Values from curved or irregularly shaped specimens shall be quoted as apparent hardness,

9.1.2 Dimensions of specimen and number of pieces, that is, one or two. In the case of curved or irregularly shaped specimens: specimen description, method of mounting, and method of applying test,

9.1.3 Type of surface tested, that is, molded, buffed, or otherwise,

9.1.4 Type of tester used, that is, standard or micro, and

9.1.5 Temperature of test.

10. Precision and Bias [5]

10.1 This precision and bias section has been prepared in accordance with Practice D 4483. Refer to this practice for terminology and other statistical calculation details.

10.2 *Precision*—A Type 1 (interlaboratory) test program to determine precision was evaluated in 1981. Both repeatability and reproducibility are short term. A period of a few days separates replicate test results. A test result is the median value, as specified by this test method, obtained on five determinations or measurements of hardness.

10.3 Four different materials were used in the interlaboratory program. These were tested in six laboratories on two different days. The results of the precision calculations for repeatability and reproducibility are given in Table 4, in ascending order of material average or level, for each of the materials evaluated.

10.4 The precision of this test method may be expressed in the format of the following statements, which use an appropriate value of *r* or *R*, that is, that value to be used in decisions

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[5] Supporting data are available from ASTM Headquarters. Request RR: D11-1024.

TABLE 3 Relation Between International Rubber Hardness Degrees (IRHD) and Penetrations Differences

IRHD	Movement of Plunger		IRHD	Movement of Plunger		IRHD	Movement of Plunger		IRHD	Movement of Plunger	
	mm	mils		mm	mils		mm	mils		mm	mils
28	1.934	76.1	47	1.055	41.5	66	0.589	23.2	85	0.280	11.0
29	1.867	73.5	48	1.024	40.3	67	0.570	22.5	86	0.266	10.5
30	1.803	71.0	49	0.994	39.1	68	0.552	21.7	87	0.251	9.9
31	1.743	68.6	50	0.964	38.0	69	0.534	21.0	88	0.237	9.3
32	1.685	66.4	51	0.936	36.8	70	0.516	20.3	89	0.223	8.8
33	1.630	64.2	52	0.908	35.8	71	0.498	19.6	90	0.209	8.2
34	1.578	62.1	53	0.881	34.7	72	0.481	18.9	91	0.195	7.7
35	1.528	60.1	54	0.855	33.7	73	0.464	18.3	92	0.180	7.1
36	1.479	58.2	55	0.830	32.7	74	0.447	17.6	93	0.166	6.5
37	1.433	56.4	56	0.805	31.7	75	0.431	17.0	94	0.151	5.9
38	1.389	54.7	57	0.781	30.8	76	0.415	16.3	95	0.135	5.3
39	1.346	53.0	58	0.758	29.8	77	0.399	15.7	96	0.119	4.7
40	1.305	51.4	59	0.735	28.9	78	0.384	15.1	97	0.102	4.0
41	1.265	49.8	60	0.713	28.1	79	0.368	14.5	98	0.083	3.3
42	1.227	48.3	61	0.691	27.2	80	0.353	13.9	99	0.060	2.4
43	1.190	46.9	62	0.670	26.4	81	0.338	13.3	100	0.000	0.0
44	1.155	45.5	63	0.649	25.5	82	0.323	12.7			
45	1.120	44.1	64	0.629	24.7	83	0.309	12.2			
46	1.087	42.8	65	0.609	24.0	84	0.294	11.6			

TABLE 4 Type 1 Precision Results (IRHD)

Material	Average	Within Laboratory[A]			Between Laboratory[A]		
		S_r	r	$(r)^B$	S_R	R	$(R)^B$
Material 1	41.51	0.1140	0.3227	0.777	3.1126	8.8087	21.221
Material 2	52.67	0.4143	1.1725	2.226	2.7121	7.6752	14.573
Material 3	65.09	0.3617	1.0236	1.573	2.8652	8.1086	12.457
Material 4	75.08	0.5236	1.4818	1.974	2.8091	7.9497	10.589
Pooled values[C]	58.59	0.3915	1.1079	1.891	2.9055	8.2225	14.035

[A] S_r = repeatability standard deviation.
r = repeatability = 2.83 times the square root of the repeatability variance.
(r) = repeatability (as a percent of material average).
S_R = reproducibility standard deviation.
R = reproducibility = 2.83 times the square root of the reproducibility variance.
(R) = reproducibility (as a percent of material average).

[B] Because the hardness scale is not a linear scale, use caution in interpreting (*r*) and (*R*).

[C] No values omitted.

about test results (obtained with the test method). The appropriate value is that value of *r* or *R* associated with a mean level in Table 4 closest to the mean level under consideration at any given time for any given material in routine testing operations.

10.5 *Repeatability*—The repeatability, *r*, of this test method has been established as the appropriate value tabulated in Table 4. Two single test results, obtained under normal test procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or nonidentical sample populations.

10.6 *Reproducibility*—The reproducibility, *R*, of this test method has been established as the appropriate value tabulated in Table 4. Two single test results obtained in two different laboratories, under normal test procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or nonidentical sample populations.

10.7 Repeatability and reproducibility expressed as a percentage of the mean level, (*r*) and (*R*), have equivalent application statements as above for *r* and *R*. For the (*r*) and (*R*) statements, the difference in the two single test results is expressed as a percent of the arithmetic mean of the two test results.

10.8 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by the test method. Bias, therefore, cannot be determined.

Designation: D 2228 – 88 (Reapproved 2001)

Standard Test Method for
Rubber Property—Abrasion Resistance (Pico Abrader)[1]

This standard is issued under the fixed designation D 2228; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the abrasion resistance of soft vulcanized rubber compounds and similar materials to a reference standard system. A reference or standard set of compounds is used to calculate relative abrasion resistance.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1349 Practice for Rubber—Standard Temperatures for Testing[2]

D 3182 Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets[2]

D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[2]

3. Summary of Test Method

3.1 In this test method, a pair of tungsten carbide knives of specified geometry and sharpness is used to abrade the surface of rubber. The knives are lowered onto a circular test specimen, or button, which is rotated under controlled conditions of speed, time, and force on the knives. A dusting powder is used at the interface between the knives and the specimen to engulf the abraded rubber particles, and to maintain the knives relatively free from oils, resins, etc., which might be present in the specimen. These oils, resins, etc., interfere with the abrasion assessment. A series of five calibration compounds is used to determine that the sharpness of the knives is within specified limits and as reference standards to which the volume loss of any experimental material may be compared.

4. Significance and Use

4.1 The test method may be used to estimate the relative abrasion resistance of different rubber compounds. No correlation between this accelerated test and service performance is given or implied, due in part to the widely varying nature of service conditions.

5. Interference

5.1 This test method is conducted under controlled conditions except for the sharpness of the abrasion knives. Different rubbers behave differently with respect to the sharpness of the knives.[3] For the most uniform test results, the knives must be maintained within the specifications of 9.5.

6. Apparatus

6.1 *Pico Tester*— An overall view of the apparatus is illustrated in Fig. 1. The pico tester itself is illustrated in Fig. 2.

6.1.1 *Turntable*, on which the test specimen is mounted and rotated.

6.1.2 *Instrument Frame*, with armature assembly that holds and lifts the knives. Mounted on top of the assembly is a "dead-weight load box in which masses (weights) may be placed to regulate the force on the knives. The assembly moves freely in a bearing housing that permits vertical motion but counteracts the reaction torque on the knives, thus preventing rotation. Vertical travel, once knives have been lowered onto the test specimen, is restricted by an arm lock.

6.1.3 *Drive Motor*, with forward, reverse, and stop controls to govern the operation of the turntable.

6.1.4 *Dusting Powder Reservoir* and *Feeder Tubes*, to supply a uniform flow of dusting powder to the interface of the knives and test specimen during operation.

6.1.5 *Pair of Digital Counters*, mounted diametrically opposed to one another on the turntable support.

6.2 *Grinder*, for preparing the surfaces of test specimens. The grinder shall be equipped with a magnetic plate for holding the specimen in place, a micrometer adjustment for controlling the verticle movement of the abrasive wheel, and a handwheel for traversing the specimen. The spindle rotational frequency shall be 95 ± 3 Hz (rps). The size of the abrasive wheel shall

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[1] This test method is under the jurisdiction of ASTM Committee D-11 on Rubber and is the direct responsibility of Subcommittee D11.15 on Degradation Tests.

Current edition approved April 29, 1988. Published June 1988. Originally published as D 2228 – 63 T. Last previous edition D 2228 – 83.

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] For further information, see Research Report RR: D-11-1022. A copy is available from ASTM Headquarters, 100 Barr harbor Drive, West Conshohocken, PA 19428–2959.

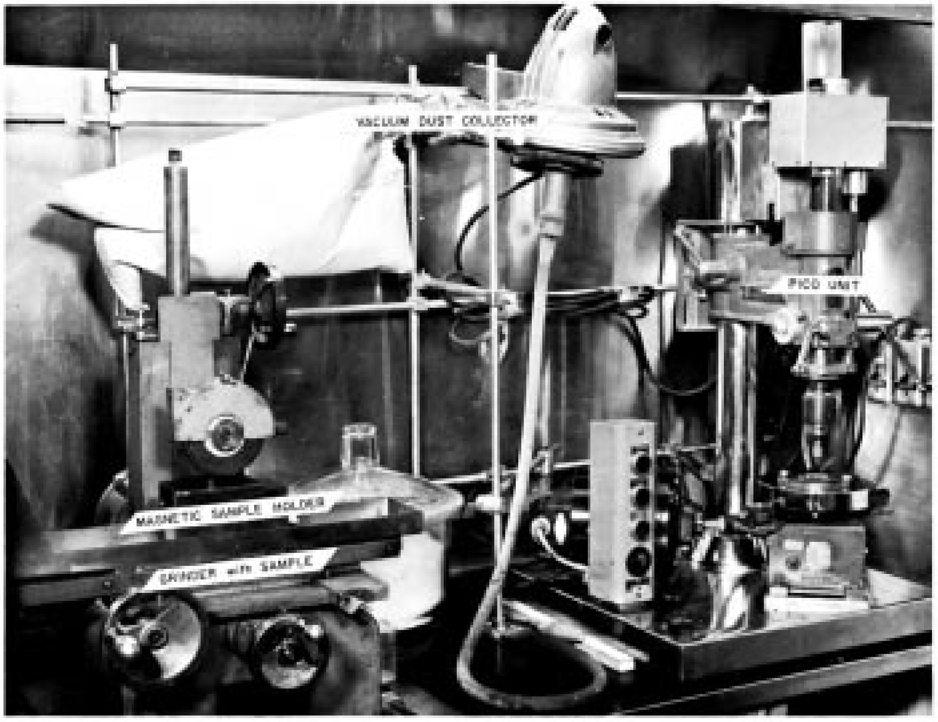

FIG. 1 Pico Tester with Auxiliary Apparatus

be about 100 mm (4 in.) in diameter and 12.5 mm (0.5 in.) in width with a center mounting hole of 12.7 mm (0.5 in.) diameter. The grit grade of the wheel shall be equivalent to Carborundum C30LB.

6.3 *Vacuum Dust Collector*, with vacuum sweeper hose of gum rubber tubing having a tapered tip to provide rapid removal of the dusting powder and engulfed particles from the specimen.

6.4 *Balance*, accurate to ±0.0001 g.

7. Auxiliary Materials

7.1 *Dusting Powder*:

7.1.1 The dusting powder used shall be a blend of equal parts by weight of aluminum oxide and diatomaceous earth. The diatomaceous earth should be passed through a No. 200 (75-µm) screen and the retained material discarded.[4,5]

7.1.2 An equal part mixture of the two powders shall be thoroughly blended, densed, and screened. For small quantities, the following procedure is satisfactory: into a sturdy ceramic wide-mouth, 4-dm^3 jar, place 100 g of each of the two pigments. Blend thoroughly by agitation. Add 1000 g of 4.76-mm (3⁄16-in.) steel balls, and place the closed jar on a roller for approximately 8 h at about 0.33 Hz (rps). Remove the steel balls. Scrape the densed dust out of the jar and pass through a No. 30 (600 µm) screen with the aid of a brush.[6]

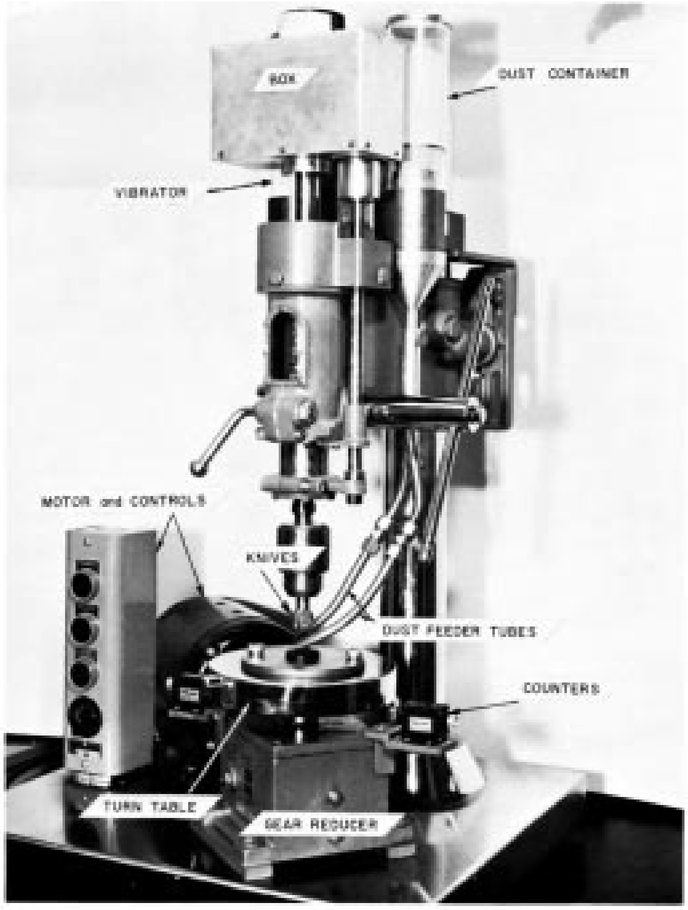

FIG. 2 Pico Tester

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[4] Alon-C undensed aluminum oxide, manufactured by the Cabot Corp., Boston, MA, has been found satisfactory.

[5] "Seneca Standard" Tripoli, Air Float Rose diatomaceous earth, manufactured by the American Tripoli Co., Seneca, MO, or Double Ground Rose, manufactured by the Harshaw Chemical Co., Cleveland, OH, has been found satisfactory.

[6] A preblend mixture of these pigments is commercially available through the Ferry Machine Co., Kent, OH 44240.

7.2 *Calibration Compounds*:

7.2.1 The formulas and the mixing and curing specifications for the five calibration compounds are given in Annex A1. A brief description of the five compounds in terms of rubber and black types is as follows:

Compound	Rubber	Black
A	Styrene-Butadiene Rubber	Industry Reference Black
B	Styrene-Butadiene Rubber	Industry Reference Black
C	Natural Rubber	Industry Reference Black
D	Styrene Butadiene/Polybutadiene Blend	Industry Reference Black
E	Styrene Butadiene/Polybutadiene Blend	Intermediate Surface Abrasion Furnace Black

7.2.2 The calibration compounds given in Annex A1 are new compounds (1982). The old calibration compounds of this method can no longer be prepared due to the unavailability of several materials. The new calibration compounds are not intended to give equivalent index results to the old reference materials. The nominal indices of the new calibration compounds, however, have been developed based on the old reference compounds and on the qualification of 5.1, and the tolerance ranges have been established based on the specification tolerances for knife sharpness as explained in 9.5.

7.2.3 The five calibration compounds are used to check the operation of the tester. If within specification tolerances, experimental materials are then tested and compared to the test results of the calibration compounds. In essence, once it has been determined that the tester is in-calibration, the calibration compounds act as reference compounds; where applicable, either of the two terms will be used.

8. Test Specimen

8.1 The standard test specimen shall be molded to give the dimensions shown in Fig. 3.

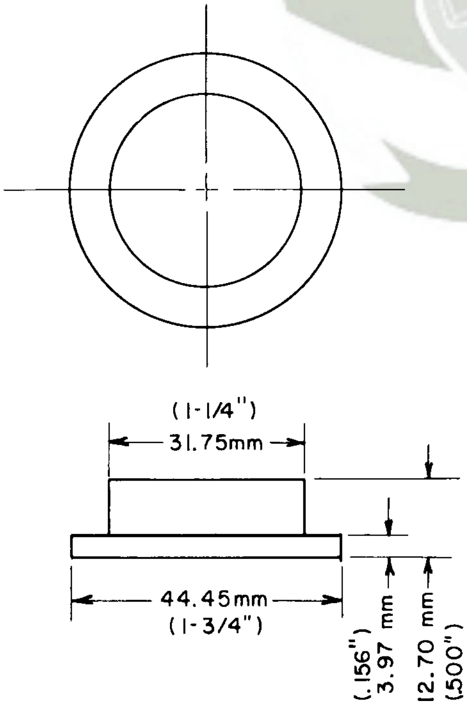


FIG. 3 Test Specimen

8.2 An alternative specimen may be used in which a disk of the test material, not less than 1.59 mm (0.062 in.) thick and of the same diameter as the standard specimen, is cemented to a previously used specimen or one that has been buffed down to accommodate the thickness of the disk. The disk may be cut from a product or from a laboratory cured sheet.

8.3 For testing conveyor belt covers, a specimen may be prepared as described in 8.2 or by cutting cylindrical specimens through the belt and cementing these to buffed down standard specimens with either the top cover or bottom cover facing up, as desired. Covers shall be at least 0.79 mm (0.032 in.) thick.

8.4 Two separately cured test specimens per material shall be tested. However, if replicate determinations are required, the specimens may be rebuffed and retested many times. Replicate determinations of the same test material are limited when thin disks are cemented to a standard specimen or when thin conveyor belt covers are tested.

9. Calibration

9.1 The tester is checked for within specification operation by testing the five calibration compounds under standard conditions. The results based on the calculation of 9.2 shall fall within the acceptance limits of Table 1.

9.2 Calculate the volume loss for each calibration compound by subtracting the final mass from the initial mass and dividing the result by the density of the rubber:

$$L_x = \frac{M_i - M_f}{D} \tag{1}$$

where:

L_x = volume loss in cm^3 of calibration compound X,
M_i = initial mass in g,
M_f = final mass in g, and
D = Density, in mg/m^3.

9.3 Multiply the volume loss for each calibration compound by its nominal index, add these products together, and divide by 500 as follows:

$$\text{Standard volume loss} = \frac{(L_A \times 76) + (L_B \times 86) + (L_C \times 106) + (L_D \times 113) + (L_E \times 128)}{5 \times 100} \tag{2}$$

where L_A, L_B, etc. = volume loss, in cm^3, for Calibration Compounds A, B, etc.

TABLE 1 Calibration Compound (Reference Compound) Specifications

NOTE 1—Industry Reference Black No. 5 was used in Compounds A through D when these nominal indices were determined; Compound E contains an ISAF Black. The most recent IRB allotment (No. 6; 1986) does not match its predecessor in physical properties performance of vulcanized compounds. The nominal indices of Compounds A through D maintain their relative values with respect to one another with the new black allotment but Compound E is forced to a higher nominal index (148).

	Compound Designation				
	A	B	C	D	E
Nominal index	76	86	106	113	128
Permissible range	69 to 83	81 to 91	95 to 117	105 to 121	116 to 140

9.4 Divide the standard volume loss resulting from the calculation of Eq 2 by the individual volume losses of each calibration compound to give the index value for each.

NOTE 1—*Example:* The following volume losses, in cm ^{3}, were obtained:

$$L_A = 0.0395 \tag{3}$$

$$L_B = 0.0337$$

$$L_C = 0.0272$$

$$L_D = 0.0254$$

$$L_E = 0.0235$$

$$\text{Standard volume loss} = \frac{(0.0395 \times 76) + (0.0337 \times 86) + (0.0272 \times 106) + (0.0254 \times 113) + (0.0235 \times 128)}{5 \times 100} = 0.0293 \tag{4}$$

$$\text{Index for calibration compound A} = (0.0293/0.0395) \times 100 = 74 \tag{5}$$

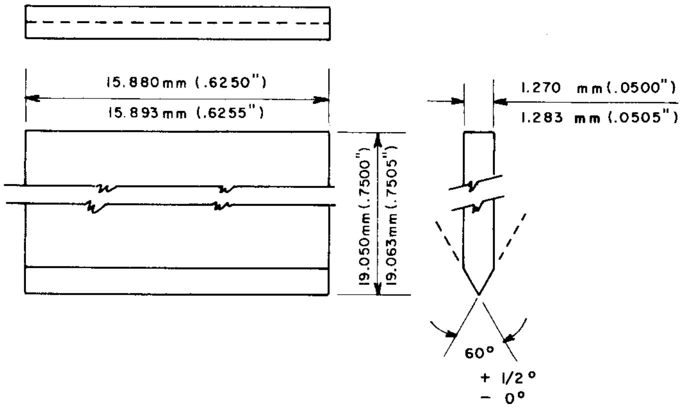
$$\text{Index for calibration compound B} = (0.0293/0.0337) \times 100 = 87$$

$$\text{Index for calibration compound C} = (0.0293/0.0272) \times 100 = 108$$

$$\text{Index for calibration compound D} = (0.0293/0.0254) \times 100 = 115$$

$$\text{Index for calibration compound E} = (0.0293/0.0235) \times 100 = 125$$

9.5 To function properly, the knives must have a "flat" of 10 to 20 µm on the abrasion edge. To produce this "flat," knives of the geometry illustrated in Fig. 4 can be dulled with a diamond dust to give a "flat" of 10 to 12 µm. Normally, with new or resharpened knives, the five calibration compounds will fall within the acceptance limits. If one or more of the calibration compounds fail to do so, it indicates that the particular compound(s) is out of specification in one respect or another and it should be remixed, recured, and retested. After continued use, the knives will wear so that the "flat" becomes too wide, that is, wider than 20 µm. When this occurs, Calibration Compounds C and E will become equivalent to Compound D and Compounds C and E will also fail to meet their acceptance limits. The knives should be returned to the supplier for resharpening (Note 2).



Material—Carboloy Grade 831 or equal.

NOTE 1—Opposite sides must be parallel.
NOTE 2—Pairs must match within 0.013 mm (0.0005 in.).
NOTE 3—Final finish on bevel is equal to No. 4 µm finish.
NOTE 4—Width of cutting edge shall be not greater than 10 µm.

FIG. 4 Cutting Knives

TABLE 2 Type 1—Precision

NOTE 1—
S_r = within laboratory standard deviation,
r = repeatability (in measurement units),
(r) = repeatability (in percent),
S_r = between laboratory standard deviation,
R = reproducibility (in measurement units), and
(R) = reproducibility (in percent)

Compound	Test Level Average	Part A—Volume Loss, cm^3 Within Laboratories			Between Laboratories		
		Sr	*r*	(*r*)	*Sr*	*R*	(*R*)
E	0.017	0.0005	0.0014	8.32	0.0037	0.0105	61.6
C	0.017	0.0006	0.0017	10.0	0.0038	0.010	63.3
D	0.019	0.0006	0.0017	8.95	0.0036	0.0102	53.6
B	0.025	0.0012	0.0034	13.6	0.0069	0.0195	78.1
A	0.036	0.0011	0.0031	8.61	0.0043	0.0122	33.8
		Part B—Abrasion Index					
A	71.4	6.37	18.0	25.3	7.61	21.5	30.1
B	96.9	5.28	14.9	15.4	4.97	14.1	14.6
C	114.2	4.26	12.1	10.6	...	...	...
D	119.3	6.70	19.0	15.9	5.03	14.2	11.9
E	140.7	6.70	19.0	13.5	14.1	39.9	28.4

NOTE 2—Scanning electron microscopy may be used to identify the width of the" flats." This procedure will eliminate any false measurements due to reflected light that may be encountered with a normal light microscope.

9.6 When the five calibration compounds are within their tolerance ranges, the tester is in calibration. The frequency for checking the calibration shall be at least once for every 30 specimens that are tested.

10. Procedure

10.1 Although it is common practice in ASTM standards to present a section on calibration before a section on procedure, the order is reversed because the calibration of test necessitates the knowledge of operation. Both procedure and calibration are required to conduct tests on experimental materials.

10.2 Prepare the test specimen by buffing the surface of the specimen on a surface grinder as specified in 6.2. Set the abrasive wheel for an abraded depth of 0.13 mm (0.005 in.) to remove the mold skin. Follow with a finishing depth of 0.025 mm (0.001 in.). Without changing the micrometer setting, give the surface of the specimen a finish grind. The dwell time per pass under the abrasive wheel should be approximately one second.

10.2.1 When successive tests are made on a previously tested specimen, buff off the abrasion pattern produced on the specimen as given in 10.2.

10.3 Brush the buffed specimen to remove all loose rubber particles.

10.4 Different volume losses will be obtained depending on the time specimens are allowed to equilibrate after buffing. To obtain consistent results, specimens, after buffing, should be allowed to condition for 24 h in an atmosphere having a temperature of 23 ± 2°C (73.4± 3.6°F) and a relative humidity of 50 ± 5 % in accordance with Practice D 1349.

10.5 Determine the mass of the specimen on a balance, recording results to the nearest 0.0001 g.

10.6 Close the power switch for the motor control unit. Let the thymatrol tubes warm up for two minutes before starting the motor. After the motor warms up, it can be started, stopped, and reversed at will (Note 3).

NOTE 3—A direct-current driven motor with SCR control may be used. If so, 10.6 can be disregarded.

10.7 Control the rotational frequency of the turntable to 1.00 ± 0.03 Hz (rps) by a rheostat on the control. Check the rotational frequency occasionally with a stopwatch (Note 4).

NOTE 4—A tachometer may be mounted permanently to the apparatus to give a direct indication of rotational frequency.

10.8 The force on the knives for standard conditions shall be 44 N (Note 5). The tare of the shaft, chuck, knife holder, knives, and box is stamped on each tester. Add a sufficient amount of lead or steel to attain 44 N.

NOTE 5—The rotational frequency of 1 Hz (rps) with a force of 44 N is a standard condition. If varying severity tests are desired, it is recommended that the following conditions be employed:

	Rotational Frequency, Hz (rps)	Force, N
Low severity	0.50	24.5
High severity	1.83	88.2

For each condition, the number of revolutions remains the same, that is, a total of 80.

10.9 Clamp the specimen onto the turntable. Start the duster and adjust so that an even flow (5 mg/s) of dusting powder is established.

10.10 Push the forward button, and at the first click of the counter, lower the knives gently onto the specimen within the first quarter revolution following the click. On the twentieth click, stop the tester within one quarter of a revolution. Stop the duster and lift the knives from the specimen. Vacuum the dusting powder and the abraded rubber particles from the specimen. Restart the duster and repeat these operations, reversing the direction of rotation for three more increments of 20 revolutions, to a total of 80 revolutions, 40 revolutions in each direction.

10.11 A cylindrical receptacle may be placed around the test specimen and filled with a sufficient supply of dusting powder so that the knives do not have to be lifted upon change of rotational direction. Volume losses obtained by this method will not be as great, but as long as all test specimens and calibration compounds are tested similarly, similar index results will be attained. If this procedure is used, some form of electronically automated control is permissible.

10.12 Remove the specimen, brush away all loose powder and abraded rubber with a stiff brush and determine the mass on a balance, recording the result to the nearest 0.0001 g.

11. Calculation

11.1 Calculate the volume loss from the mass loss and density of the tested material. As done in 9.2, 9.3, and 9.4, express the result as an index number obtained by dividing the standard volume loss of the reference compounds, tested in the same series, by the volume loss of the tested material and multiplying the quotient by 100.

11.2 Calculate the index of the tested material against any one of the reference compounds as described in 11.1. This test method is particularly useful when employing nonstandard severity conditions.

12. Report

12.1 The report shall include the following:
12.1.1 Identification of the tested specimens,
12.1.2 Cure time and temperature,
12.1.3 Density,
12.1.4 Force on knives used,
12.1.5 Rotational frequency used,
12.1.6 Initial specimen mass,
12.1.7 Final specimen mass,
12.1.8 Specimen mass loss,
12.1.9 Specimen volume loss, and
12.1.10 Abrasion index with the test method used to calculate the index as described in 11.1 or 11.2.

13. Precision and Bias [7]

13.1 These precision statements have been prepared in accordance with Practice D 4483. Please refer to this practice for terminology and other testing and statistical concept explanations.

13.2 *Type 1*—Precision data have been compiled which excludes the compounding variation among laboratories.

13.3 The statements were developed from interlaboratory testing of the five new Calibration Compounds (A–E). These five compounds were mixed in a B Banbury internal mixer with curatives added on a mill. All specimens of the same compound were cured from the same mix.

13.4 The precision statements are based on the testing of five samples by six laboratories on two days.

13.5 A test result is defined to be the average of two separately cured specimens.

13.6 Precision statements were prepared for both volume loss and abrasion index. Volume loss is the measure of the physical differences among the interlaboratory testers and index is a measure of the test method in general.

13.7 The precision of this test method may be expressed in the format of the following statements that use an appropriate value of *r*, *R*, *(r)*, or (*R*), that is, that value to be used in decisions about test results (obtained with this test method). The *appropriate value* is that value of *r* or *R* associated with a mean level in the precision table closest to the mean level under consideration (at any given time, for any given material) in routine testing operations.

13.8 *Repeatability*— The repeatability *r*, of this test method has been established as the *appropriate value* tabulated in the precision tables. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

13.9 *Reproducibility*— The reproducibility *R*, of this test method has been established as the *appropriate value* tabulated in the precision tables. Two single test results obtained in two different laboratories, under normal test method procedures,

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[7] Supporting data are available from ASTM Headquarters. Request RR: D11–1022.

that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or non-identical sample populations.

13.10 Repeatability and reproducibility expressed as a percentage of the mean level, (*r*) and (*R*), have equivalent application statements as 13.8 and 13.9 for *r* and *R*. For the (*r*) and (*R*) statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

13.11 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by the test method. Bias, therefore, cannot be determined.

14. Keywords

14.1 knife abrasion; rubber articles; rubber products

ANNEX

(Mandatory Information)

A1. FORMULAS AND MIXING AND CURING SPECIFICATIONS FOR THE CALIBRATION COMPOUNDS

A1.1 Calibration Compounds

A1.1.1 The formulas for the calibration compounds are given in Table A1.1.

A1.2 Methods of Mixing

A1.2.1 The compounds are mixed in a B Banbury internal mixer in accordance with Practice D 3182. Initial temperature of the mixing chamber is 50°C (120°F). Batch size is 70 % of total chamber volume capacity. The curatives are added on a mixing mill having rolls between 250 and 258-mm (9.8 to 10.2-in.) outside diameter and an operating temperature of 65°C (150°F).

NOTE A1.1—The standard mill has rolls between 150 and 155-mm (5.9 to 6.1-in.) outside diameter. If this mill is used to add curatives, the batch may be divided into three equal portions. The mixing cycle may have to be adjusted to obtain comparable results.

A1.2.2 The mixing cycles for the calibration compounds are given in Table A1.2. Mixing is accomplished by following the time specifications. No provisions are made for preconditioning of the carbon black.

TABLE A1.1 Formulas for Calibration Compounds

	NBS Standard	Designation				
		A	B	C	D	E
Natural rubber	385			100.0		
CB 441					68.75	68.75
SBR 1502			100.0			
SBR 1712		137.5			68.75	68.75
Stearic acid	372	1.5	1.5	2.0	1.5	1.5
Zinc oxide	370	5.0	5.0	5.0	5.0	5.0
IRB[A]		60.0	40.0	45.0	80.0	
ISAF black[B]						80.0
Process oil[C]		5.0	5.0	5.0	8.75	8.75
Dimethyl butylphenyl phenylenediamine						
Trimethyldihydro-quinoline		1.5	1.5	1.0	1.5	1.5
TBBS[D]		1.5	1.5	1.5	1.5	1.5
Sulfur	384	1.0	1.0	0.6	1.2	1.2
Specific gravity	371	2.0	2.0	2.5	2.0	2.0
		1.13	1.12	1.13	1.16	1.16

[A] Industry Reference Black is available in 22.68 kg (50 lb) bags from carbon black suppliers.

[B] N234, or its equivalent.

[C] Sundex 7260T, or its equivalent.

[D] N- *tert*-butyl-2-benzothiazole sulfenamide.

TABLE A1.2 Mixing Cycles for Calibration Compounds

Step	Compound, min				
	A	B	C	D	E
B Banbury:					
Add rubber	0:00	0:00	0:00	0:00	0:00
Add fillers	0:30	0:30	0:30	0:30	0:30
Ram sweep	2:00	1:45	2:10	2:00	2:00
Add oil	2:30	2:10	2:55	2:25	2:30
Ram scrape	3:10	3:00	3:50	3:15	3:15
Dump	4:15	3:50	5:05	4:00	4:15
Probe temperature at dump, °C, (°F)	143 (290)	152 (305)	160 (320)	138 (280)	138 (280)
Mill:					
Band material	0:00	0:00	0:00	0:00	0:00
Add curatives	0:30	0:40	0:45	0:40	0:40
End pass	2:30	2:15	3:00	2:15	2:00
Take off	6:15	6:30	6:15	5:30	5:30

A1.2.3 Sheet the compound off the mill at an approximate thickness of 2.1 mm (0.08 in.) and cool on a flat dry clean metal surface.

A1.2.4 Die cut disks of the required diameter and stack the disks to the required height.

A1.3 Recommended Cures

A1.3.1 Cures for the calibration compounds, in the form of the molded specimens required for the test, are given in Table A1.3.

A1.3.2 The size of the molded specimen is such that a lag time or incubation time of approximately five minutes is involved in the cure. It is recommended that cures of experimental materials be increased by this amount over the cure that is established for sheets approximately 2 mm (0.08 in.) thick.

TABLE A1.3 Recommended Cures for Calibration Compounds

Compound	Time, min	Temperature,° C (°F)
A	65	150 (302)
B	65	150 (302)
C	60	140 (284)
D	65	150 (302)
E	65	150 (302)

Designation: D 2229 – 99

Standard Test Method for
Adhesion Between Steel Tire Cords and Rubber[1]

This standard is issued under the fixed designation D 2229; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the force required to pull a steel cord from a block of vulcanized rubber.

1.2 Although designed primarily for steel cord, this test method may be applied with modifications to wire used in rubber products.

1.3 This test method can also be used for evaluating rubber compound performance with respect to adhesion to steel cord.

1.4 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 76 Specification for Tensile Testing Machines for Textiles[2]
D 123 Terminology Relating to Textiles[2]
D 1566 Terminology Relating to Rubber[3]
D 2904 Practice for Interlaboratory Testing of a Textile Test Method that Produces Normally Distributed Data[2]
E 105 Practice for Probability Sampling of Materials[4]
E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

3. Terminology

3.1 *Definitions*

3.1.1 *adhesion, n—in tire fabrics*, the force required to separate a textile material from rubber or other elastomer by a definite prescribed method.

3.1.2 *rubber compound, n—as used in the manufacture of rubber articles*, an intimate mixture of elastomer(s) with all materials necessary for the finished article.

3.1.3 *steel cord, n*—a formed structure made of two or more steel filaments when used as an end product or a combination of strands or filaments and strands.

3.1.4 For definitions of other textile or rubber terms used in this test method refer to Terminology D 123 or Terminology D 1566.

4. Summary of Test Method

4.1 The steel cords are vulcanized into a block of rubber and the force necessary to pull the cords linearly out of the rubber is measured.

5. Significance and Use

5.1 This test method is considered satisfactory for the acceptance testing of commercial shipments of steel tire cord because current estimates of between-laboratory precision for single materials are considered acceptable and the method has been used extensively in the trade for acceptance testing.

5.1.1 If there are differences or practical significances between reported test results for two laboratories (or more), comparative tests should be performed to determine if there is a statistical bias between them, using competent statistical assistance. As a minimum, the test samples should be used that are as homogenous as possible, that are drawn from the material from which the disparate test results were obtained, and that are randomly assigned in equal numbers to each laboratory for testing. Other materials with established test values may be used for this purpose. The test results from the two laboratories should be compared using a statistical test for unpaired data, at a probability level chosen prior to the testing series. If a bias is found, either its cause must be found and corrected, or future test results must be adjusted in consideration of the known bias.

5.2 The mold described in this test method is primarily designed for quality acceptance testing for steel cord where the sample size for each cord is 4 or a multiple thereof, but any mold/cavity combination which will provide the required test block dimensions (Figs. 1 and 2) is acceptable.

5.3 Appendix X1 contains suggested ranges of environmental conditions for aging tests.

5.4 The property measured by this test method indicates whether the adhesion of the steel cord to the rubber is greater than the cohesion of the rubber, that is, complete rubber coverage of the steel cord, or less than the cohesion of the rubber, that is, lack of rubber coverage.

6. Apparatus

6.1 *Mold* (Figs. 2 and 3)—The mold is designed to produce

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[1] This test method is under the jurisdiction of ASTM Committee D-13 on Textiles and is the direct responsibility of Subcommittee D13.19 on Tire Cord and Fabrics.

Current edition approved Nov. 10, 1999. Published January 2000. Originally published as D 2229 –63 T. Last previous edition D 2229 – 98.

[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 09.01.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

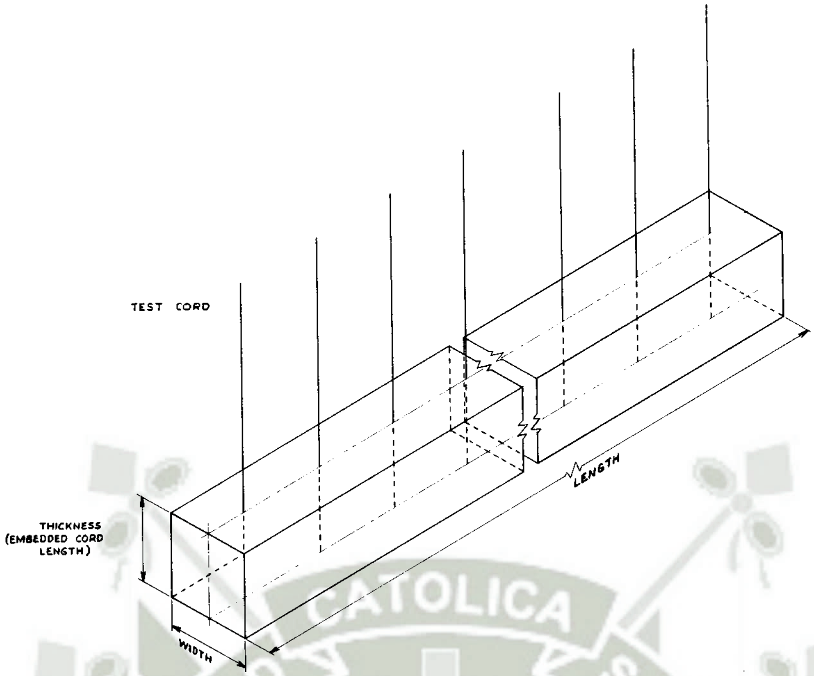

FIG. 1 Definition of Test Block Dimensions

four test blocks with the preferred dimensions, each containing 15 steel cords. The blocks are 200 mm long and 12.5 mm thick (embedded cord length). When testing cords equal to or less than 1.7-mm diameter, the mold in Fig. 2 and Fig. 3 should be used to produce blocks, and when testing cords with a diameter greater than 1.7 mm, the mold should be suitably modified. Molds designed to produce any other number of test blocks of the required dimensions are acceptable, and molds designed to produce blocks with different embedded cord length are permitted.

6.2 If more than one third of the cords break at the 12.5-mm embedment, it may be advisable to reduce the embedment by use of a suitable mold insert.

6.3 *Testing Machine*:

6.3.1 A constant-rate-of-extension (CRE) type tensile testing machine conforming to the requirements of Specification D 76 for textiles shall be used for measuring the pull-out force. The rate of travel of the power actuated grip shall be 50 mm/min. Other rates of travel up to 150 mm/min may be used as agreed upon by the purchaser and the supplier.

6.3.2 The top grip shall apply force to the cord during testing that is normal to the face of the test block.

6.3.3 The bottom grip (Fig. 4) shall be a special holder made for the vulcanized test block.

6.4 *Press*—A curing press, large enough to take the mold, and capable of a minimum pressure of 3.5 MPa over the total area of the mold plate. Electrical or steam heat for the top and bottom platens shall be provided, of sufficient capacity for maintaining the mold components at the temperatures required for the rubber compound being used.

6.5 *Desiccator*.

7. Materials and Reagents

7.1 *Solvent*—A solvent may be used to freshen the surface of the rubber when necessary, provided such solvent treatment does not affect adhesion of the cord in the vulcanized block. A suitable solvent has been found to be a special lead-free gasoline (normal heptane), with a distillation range from 40 to 141°C and a maximum recovery of 97 %.

7.2 *Rubber Compound*—The rubber compound shall be furnished by the user of the cord, together with pertinent information of the temperature and time for the vulcanization of the particular rubber, as well as the conditioning period between vulcanization and testing. Because the performance of the rubber stock is affected by its age and storage conditions, the user of the cord shall also specify storage conditions and any time limits for storage of a particular rubber, or approve the storage conditions utilized by the producer. The rubber shall be provided in sheet form at least 215 mm wide and either 7 − 0, + 1 mm thick or 3.5 − 0, + 0.5 mm thick, sheeted onto nonhygroscopic backing, such as a plasticizer-free plastic material.

7.3 *Mold Release Lubricant*—A suitable mold release lubricant may be applied to the empty mold to facilitate test block removal. Excess lubricant shall be wiped from the mold and particularly from the slots provided for the cords. The lubricant should not be applied when exposed cord is in the area, and should only be used when absolutely necessary. Use of a mold release lubricant should be recorded on the test report.

NOTE 1—The use of mold release lubricant is not recommended. The mold should be permanently coated with Teflon® or preferably, with a stainless steel reinforced nonstick coating, such as Excalibur®.[5]

8. Hazards

8.1 Refer to the maufacturer's material safety data sheets (MSDS) for information on handling, use, storage, and disposal of chemicals used in this test.

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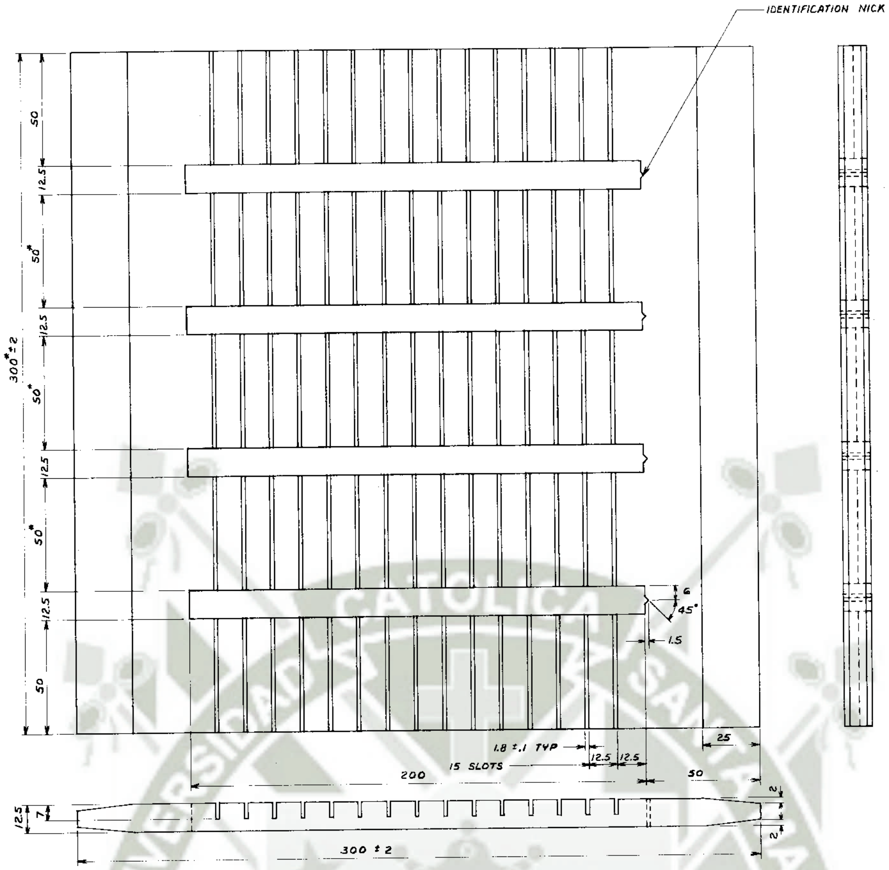
[5] Excalibur® is a registered trademark of the Whitford Corporation, West Chester, PA.



TOLERANCES
All dimensions ±0.2
Angular ±2°
Except where noted

NOTE 1—All dimensions in millimetres except where noted.

NOTE 2—Material—Mild steel.

NOTE 3—Mold should be coated permanently with a polytetrafluoro-ethylene, such as Teflon®, or preferably, with a stainless steel reinforced polytetrafluoro-ethylene with a polyamid binder, such as Excalibur®.[5]

NOTE 4—Dimensions with "*" may be altered to accommodate test grips.

FIG. 2 Four-Cavity Steel Cord Adhesion Mold

8.2 Wear heat resistant gloves when working at the hot press and handling hot forms.

9. Sampling and Specimen Preparation

9.1 Obtain lot and laboratory samples in accordance with Practices E 105 and E 122.

9.2 Cut specimens from each laboratory sampling unit into lengths that are greater than the total mold length. To eliminate flare, use procedures in 9.2.1 or 9.2.2. Choose the number of specimen to achieve the desired level of test result precision. The relationship between the sample size and test precision is shown in Table 2.

9.2.1 Simultaneously cut and fuse the cut ends using a small portable welding device.

9.2.2 Tape the samples at the ends of the required specimen length and cut through the sample where it has been taped leacing the new ends of both sample and specimen taped.

9.3 Handle samples and specimens with care to prevent changes in surgace conditions of the steel cord. Wear clean gloves when handling samples and specimens. if the tests blocks cannot be constructed within 8 h store the cords in a dessicator at 23 ± 2°.

10. Procedure

10.1 *Test Block Construction*:

10.1.1 Construct the test blocks in a cold mold or form having the same dimensions as the mold in the following manner.

10.1.2 Lay out specimens on a clean dry surface. Touch the specimens only at their ends. Steel cord is normally tested in the "as-received" condition; therefore, it is generally not cleaned nor dried prior to building the test block.

10.1.3 Cut pieces the rubber compound to the size of the mold cavity. If a thickness of 3.5 mm is supplied, it should be laminated to a 7 mm thickness before cutting to size. If the rubber surface appears dry or contaminated, it may be freshened with clean solvent described in 7.1 and allowed to dry at least 3 min. This will facilitate handling the test blocks prior to vulcanization.

10.2 *Test Block Assembly*:

TOLERANCES
All dimensions ±2
Except where noted

NOTE 1—Material—Mild steel.
NOTE 2—Number required—2.
NOTE 3—All dimensions in millimetres except where noted.
NOTE 4—Dimensions with "*" may be altered to accommodate the mold.

FIG. 3 Top and Bottom Plates for Adhesion Mold

10.2.1 Place one piece of rubber in each cavity with the protected side up and remove the protective film.

10.2.2 Place the specimen in individual slots with approximately equal lengths extending beyond either end of the form. Do not press the cords into the cavities with fingers. Make note of the location of the specimens for 10.2.4.

10.2.3 Remove the protective film from pieces of rubber compound and place one in each cavity with the freshly exposed surface against the cords. Press firmly in place using a wooden dowel or flat faced stitching tool.

10.2.4 Write the identification on each pad using a silver pen or marking pencil.

10.2.5 Carefully remove the four blocks from the form by pressing uniformly from the back side. Store at a temperature of 23 ± 2°C until vulcanization. Blocks should be vulcanized within a maximum of 12 h.

10.3 *Vulcanizing*:

10.3.1 Preheat the complete mold assembly to the required temperature.

10.3.2 Remove the mold assembly from the press and remove the top plate.

10.3.3 Place the preconstructed blocks in the mold. Take care to ensure that the blocks are seated in the mold cavities and all specimens are in the proper slots.

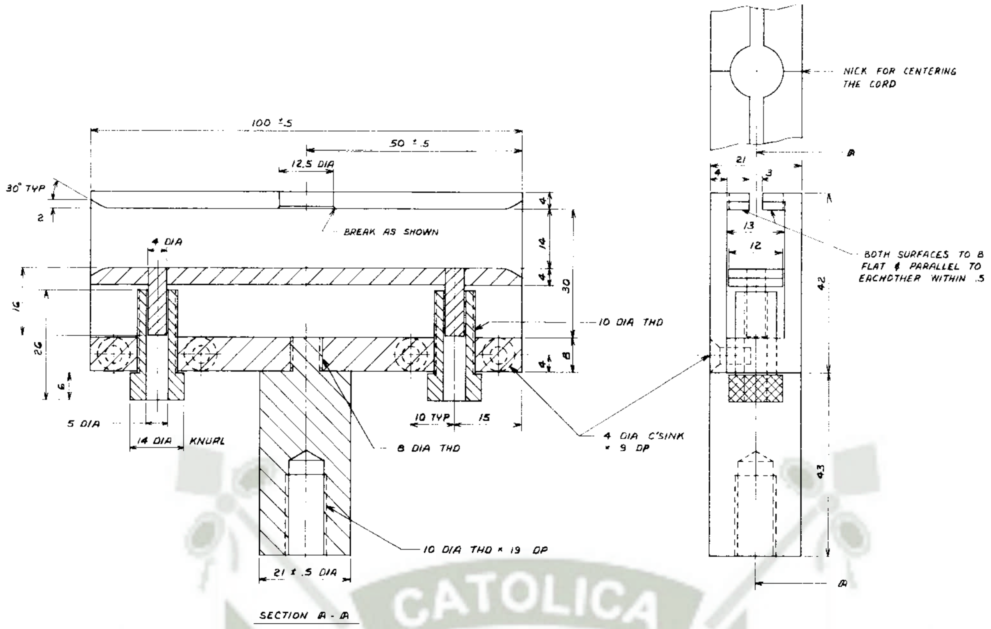
10.3.4 Place the top plate on the mold and place the mold assembly in the press. Close the press and apply a minimum pressure of 3.5 MPa on the mold surface.

10.3.5 At the end of the cycle, open the press remove the mold assembly. Remove the top and bottom plates, and push the blocks out with uniform pressure. Take care to minimize block deformation when removing from the mold.

10.4 *Conditioning of Test Blocks*:

10.4.1 Allow the blocks to rest at room temperature for a minimum of 16 h before testing.

10.4.2 Cut the blocks apart by clipping the cords flush with one side of each block. Trim any "flash" with a razor blade or suitable clippers, taking care not to damage the cord or cut into the body of the test block.



TOLERANCES
All dimensions ±0.2
Angular ±½°
Except where noted

NOTE 1—Material—Steel.
NOTE 2—Break all sharp corners.
NOTE 3—All dimensions in millimetres except where noted.

FIG. 4 Bottom Grip

10.5 *Testing*:

10.5.1 Test at 24 ± 2°C unless otherwise agreed upon.

10.5.2 Push the block into the appropriate lower fixture and adjust the bottom plate of the fixture so that the block can be moved through the fixture but yet undergo minimum deformation during testing. Do not force the bottom plate against the test block.

10.5.3 Center each cord in succession in the 12.5-mm hole and clamp the cord in the upper grip.

10.5.4 Start the cross head.

10.5.5 Record, to the nearest 5 N, the maximum pull-out force required to extract the cord. Retain the specimens, properly identified, for visual evaluation if required.

10.5.6 Rate the rubber coverage of the pulled specimens visually from 1 to 5 or percent coverage using Table 1. The appearance can be evaluated with 0.5 point precision if using the 1 through 5 rating scale. Record visual ratings.

10.5.6.1 The precision and bias statement was developed using the percent rubber coverage system.

TABLE 1 Critical Differences for Conditions Noted, 95 % Probability Level

Name of Property	Number of Observations	Single Operator Precision	Within-Laboratory Precision	Between-Laboratory Precision
Pull-out force, N		(Single-Material Comparisons)		
	4	49	52	85
	8	34	39	77
	16	24	31	74
		(Multi-Material Comparisons)		
	4	49	52	120
	8	34	39	115
	16	24	31	112
Rubber coverage, %		(Single-Material Comparisons)		
	4	7	7	19
	8	5	5	18
	16	4	4	18
		(Multi-Material Comparisons)		
	4	11	11	28
	8	10	10	28
	16	9	9	28

11. Calculation

11.1 Calculate the average pull-out force to the nearest 5 N using the values from the test blocks for each laboratory sampling unit and for the lot.

11.2 Calculate the average rubber coverage visual rating to the nearest 0.5 rating or percent using the values from the specimens pulled from the test blocks for each laboratory sampling unit and for the lot.

12. Report

12.1 State that the specimens were tested as directed in Test Method D 2229. Describe the material sampled and the method of sampling.

12.2 Report the following information:

12.2.1 Identification of rubber compounds.

12.2.2 Number of specimens per laboratory sampling unit and the number of laboratory sampling units per block.

12.2.3 Number of blocks per laboratory sampling unit where a laboratory sampling unit has been tested in more than one block.

12.2.4 The average pull-out force (newtons) for each laboratory sampling unit tested and the lot.

12.2.5 Date of test.

12.2.6 Rate of extension, if not standard.

12.2.7 Vulcanization time and temperature.

12.2.8 Visual evaluation, if required.

12.2.9 Any modifications to the test.

13. Precision and Bias

13.1 *Summary*—In comparing two averages of four observations, the difference between averages should not exceed the following amounts in 95 out of 100 cases when all of the observations are taken by the same well-trained operator using the same piece of equipment and specimens are randomly drawn from the same sample of material:

Pull-out force, 50 N
Rubber coverage, 10 %

13.1.1 Because the pull-out force is affected significantly by the thickness of the steel tire cord, larger or smaller differences are likely to occur when testing steel tire cords with thicknesses outside the range of the specimens used in the interlaboratory evaluation that generated these data.

13.2 *Interlaboratory Test Data*—An interlaboratory evaluation was conducted in 1990 in which randomly drawn samples of two constructions of steel tire cord and two different rubber compounds were tested in the four possible combinations in 10 laboratories in accordance with Practice D 2904. Each laboratory used two operators, each of whom tested the four materials on two separate days. Initial analysis of the data indicated that the results from two of the laboratories were statistical outliers, and upon investigation the cause for this condition was determined to be failure to follow the test method properly. The data from the two laboratories was deleted prior to further analysis.

13.2.1 The steel tire cords used in the laboratory evaluation were of the following construction and nominal thickness:

Cord 1	1 × 2 + 7 × 0.22 mm	0.81 mm
Cord 2	(1 × 3 × 0.20 mm) + 6 × 0.35 mm	1.13 mm

The details of the formulation of the rubber compounds are contained in a research report.[6]

13.3 *Precision*—Two test results should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences listed in Table 2. For the purposes of the interlaboratory evaluation, each combination of steel tire cord and rubber compound was considered as a different material; therefore, caution should be exercised when referring to the critical differences for multi-material comparisons.

13.4 *Bias*—The procedures in this test method produce test values that can be defined only in terms of a test method. There is no independent referee method by which bias may be determined. This test method has no known bias.

NOTE 2—The tabulated values of the critical differences should be considered to be a general statement, particularly with respect to between-laboratory precision. Before a meaningful statement can be made about two specific laboratories, the amount of statistical bias, if any, between them must be established, with each comparison being based on recent data obtained on specimens taken from a lot of material of the type being evaluated so as to be as nearly homogeneous as possible and then randomly assigned in equal numbers to each of the laboratories (see 5.1.1).

14. Keywords

14.1 adhesion; rubber; steel; tire cord

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[6] Supporting data is available from ASTM Headquarters. Request RR: D13-1054.

APPENDIX

(Nonmandatory Information)

X1. SUGGESTED RANGES OF CONDITIONS FOR ACCELERATED AGING OF STEEL CORD ADHESION BLOCKS

TABLE X1.1 Ranges of Conditions for Accelerated Aging of Steel Cord Adhesion Blocks

Uncured humidity	90–95 % RH, 35–40°C
Cured humidity	90–95 % RH, 35–40°C or 95–100 % RH, 70–80°C
Oxygen	70–80°C
Steam	120–130°C
Thermal	100–120°C

Designation: D 2240 – 02

Standard Test Method for Rubber Property—Durometer Hardness[1]

This standard is issued under the fixed designation D 2240; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes eight types of rubber hardness measurement devices known as durometers: types A, B, C, D, DO, O, OO and M. The procedure for determining indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, and some plastics is also described.

1.2 This test method is not equivalent to other indentation hardness methods and instrument types, specifically those described in Test Method D 1415.

1.3 This test method is not applicable to the testing of coated fabrics.

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only. Many of the stated dimensions in SI are direct conversions from the U. S. Customary System to accommodate the instrumentation, practices and procedures that existed prior to the Metric Conversion Act of 1975.

1.5 All materials, instruments, or equipment used for the determination of mass, force or dimension shall have traceability to the National Institute for Standards and Technology, or other internationally recognized organization parallel in nature.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 374 Test Methods for Thickness of Solid Electrical Insulation[2]
D 618 Practice for Conditioning Plastics for Testing[3]
D 785 Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials[3]
D 1349 Practice for Rubber—Standard Temperatures For Testing[4]
D 1415 Test Method for Rubber Property—International Hardness[4]
D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[4]
F 1957 Test Method for Composite Foam Hardness-Durometer Hardness[5]

3. Summary of Test Method

3.1 This test method permits hardness measurements based on either initial indentation or indentation after a specified period of time, or both. Durometers with maximum reading indicators used to determine maximum hardness values of a material may yield lower hardness when the maximum indicator is used.

3.2 The procedures for Type M, or micro hardness durometers, accommodate specimens that are, by their dimensions or configuration, ordinarily unable to have their durometer hardness determined by the other durometer types described. Type M durometers are intended for the testing of specimens having a thickness or cross sectional diameter of 1.25 mm (0.050 in.) or greater, although specimens of lesser dimensions may be successfully accommodated under the conditions specified in Section 6, and have a Type M durometer hardness range of between 20 and 90. Those specimens which have a durometer hardness range other than specified shall use another suitable procedure for determining durometer hardness.

4. Significance and Use

4.1 This test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. *The geometry of the indentor and the applied force influence the measurements such that no simple relationship exists between the measurements obtained with one type of durometer and those obtained with another type of durometer or other instruments used for measuring hardness*. This test method is an empirical test

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[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved Jan 10, 2002. Published March 2002. Originally published as D 2240 – 64 T. Last previous edition D 2240 – 00.

[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 08.01.

[4] *Annual Book of ASTM Standards*, Vol 09.01.

[5] *Annual Book of ASTM Standards*, Vol 15.07.

intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this test method and any fundamental property of the material tested. For specification purposes it is recommended that Test Method D 785 be used for materials other than those described in 1.1.

5. Apparatus

5.1 Hardness measuring apparatus, or durometer, and an operating stand, Type 1, Type 2, or Type 3, refer to 5.1.2, consisting of the following components:

5.1.1 *Durometer*:

5.1.1.1 *Presser Foot*, with an orifice (to allow for the protrusion of the indentor) having a diameter as specified in Fig. 1a, Fig. 1b, or Fig. 1c, with the center a minimum of 6.0 mm (0.24 in.) from any edge of the foot.

5.1.1.2 *Presser Foot, Type M*, with an orifice (to allow for the protrusion of the indentor) having a diameter as specified in Fig. 1d, with the center a minimum of 1.60 mm (0.063 in.) from any edge of the flat circular presser foot.

5.1.1.3 *Indentor*, formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1a, Fig. 1b, or Fig. 1c, polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 2.50 ± 0.04 mm (0.098 ± 0.002 in.).

5.1.1.4 *Indentor, Type M*, formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1d, polished over the contact area so that no flaws are visible under 50× magnification, with an indentor extension of 1.25 ± 0.02 mm (0.049 ± 0.001 in.).

5.1.1.5 *Indentor Extension Indicator*, (analog or digital electronic), having a display that is an inverse function of the indentor extension. The display shall indicate from 0 to 100 with equal divisions throughout the range at a rate of one hardness point for each 0.025 mm (0.001 in.) of indentor movement, for Type M durometers, the display shall indicate from 0 to 100 with no less than 100 equal divisions at a rate of one hardness point for each 0.0125 mm (0.0005 in.) of indentor movement.

5.1.1.6 *Timing Device (optional)*, capable of being set to a desired elapsed time, signaling the operator or holding the hardness reading when the desired elapsed time has been reached. The timer shall be automatically activated when the

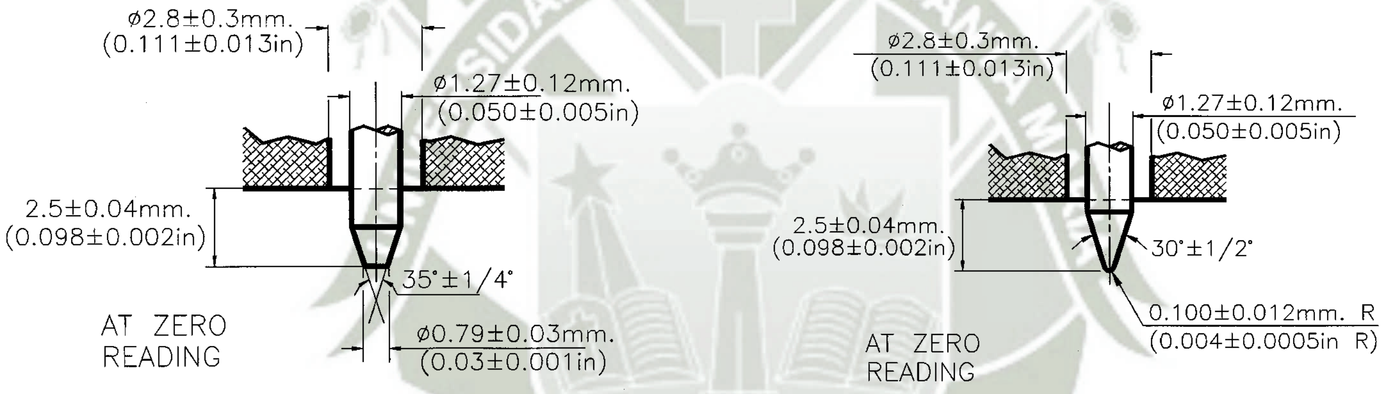

Figure 1a Type A and C Indentor

Figure 1b Type B and D Indentor

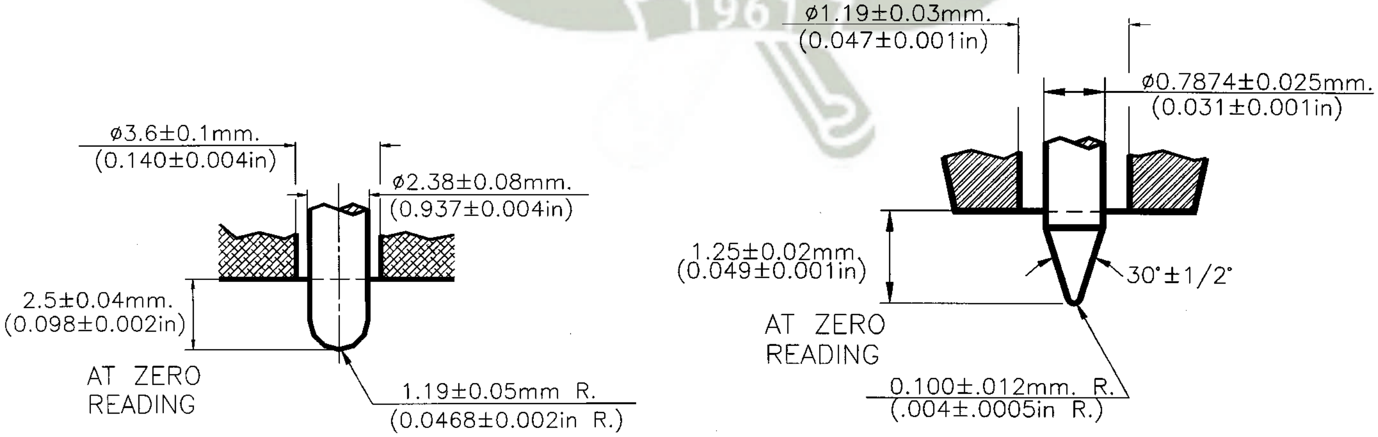

Figure 1c O, DO, and oo Indentor

Figure 1d Type M Indentor

FIG. 1 Durometers

presser foot is in contact with the specimen being tested, for example, the initial indentor travel has ceased. Digital electronic durometers may be equipped with electronic timing devices that shall not affect the indicated reading or determinations attained by more than one half the calibration tolerance stated in Table 1.

5.1.1.7 *Maximum indicators (optional)*, maximum indicating pointers are auxiliary analog indicating hands designed to remain at the maximum hardness value attained until reset by the operator. Electronic maximum indicators are digital displays electronically indicating and maintaining the maximum value hardness value achieved, until reset by the operator.

5.1.1.8 Analog maximum indicating pointers have been shown to have a nominal effect on the values attained, however this effect is greater on durometers of lesser total mainspring loads, for example, the effect of a maximum indicating pointer on Type D durometer determinations will be less than those determinations achieved using a Type A durometer. Analog style durometers may be equipped with maximum indicating pointers. The effect of a maximum indicating pointer shall be noted at the time of calibration in the calibration report, refer to 10.1.4, and when reporting hardness determinations, refer to 10.2.4. Analog Type M durometers shall not be equipped with maximum indicating pointers.

5.1.1.9 Digital electronic durometers may be equipped with electronic maximum indicators that shall not affect the indicated reading or determinations attained by more than one half of the spring calibration tolerance stated in Table 1.

5.1.1.10 *Calibrated Spring*, for applying force to the indentor, in accordance with Fig. 1a through Fig. 1d and capable of applying the forces as specified in Table 1.

5.1.2 *Operating Stand*:

5.1.2.1 Type 1, Type 2, and Type 3, shall be capable of supporting the durometer presser foot surface parallel to the specimen support table (Fig. 2) throughout the travel of each. The durometer presser foot to specimen support table parallelism shall be verified each time the test specimen support table is adjusted to accommodate specimens of varying dimensions. This may be accomplished by applying the durometer presser foot to the point of contact with the specimen support table and making adjustments by way of the durometer mounting assembly or as specified by the manufacturer.

5.1.2.2 *Operating Stand, Type 1* (specimen to indentor type), shall be capable of applying the specimen to the indentor in a manner that minimizes shock.

TABLE 1 Durometer Spring Force Calibration All Values are in N

Indicated Value	Type M	Type A, B, O	Type C, D, DO	Type OO
0	0.324	0.55		0.203
10	0.368	1.3	4.445	0.294
20	0.412	2.05	8.89	0.385
30	0.456	2.8	13.335	0.476
40	0.5	3.55	17.78	0.566
50	0.544	4.3	22.225	0.657
60	0.589	5.05	26.67	0.748
70	0.633	5.8	31.115	0.839
80	0.677	6.55	35.56	0.93
90	0.721	7.3	40.005	1.02
100	0.765	8.05	44.45	1.111
N/durometer unit	0.0044	0.075	0.4445	0.00908
Spring Calibration Tolerance	±0.0176 N	±0.075 N	±0.4445 N	±0.0182 N

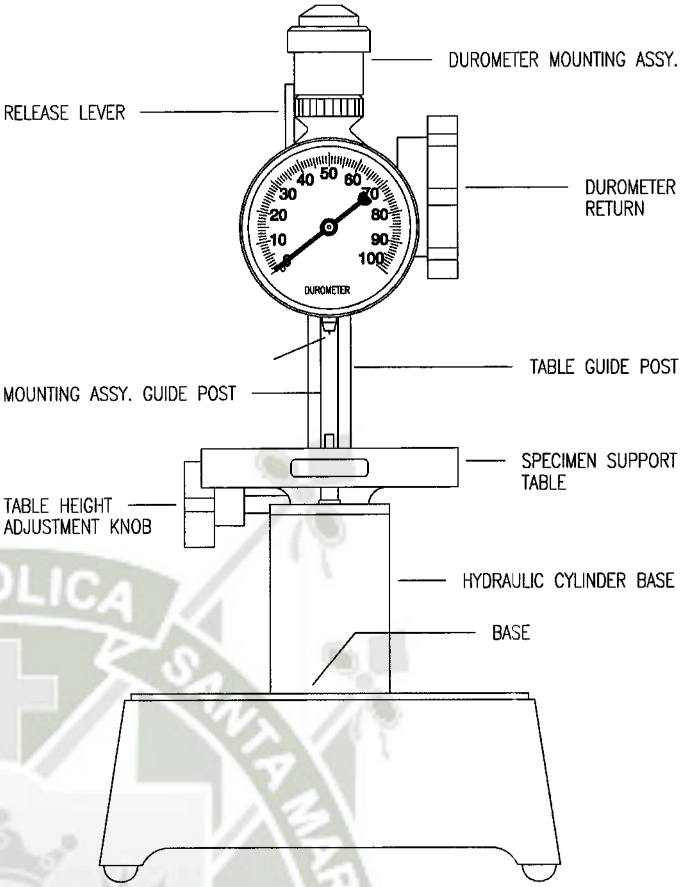

FIG. 2 Durometer Operating Stand

5.1.2.3 *Operating Stand, Type 2* (indentor to specimen type), shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.20 mm/s (0.125 in/s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1.

5.1.2.4 *Operating Stand, Type 3* (indentor to specimen type), hydraulic dampening, pneumatic dampening or electromechanical (required for the operation of Type M durometers) shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.2 mm/s (0.125 in/s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1. Manual application, Type 1 or Type 2 operating stands are not acceptable for Type M durometer operation.

5.1.2.5 The entire instrument should be plumb and level, and resting on a surface that will minimize vibration. Operating the instrument under adverse conditions will negatively affect the determinations attained.

5.1.2.6 *Specimen Support Table*, (Fig. 2) integral to the operating stand, and having a solid flat surface. The specimen support platform may have orifices designed to accept various inserts or support fixtures (Fig. 3) to provide for the support of irregularly configured specimens. When inserts are used to support test specimens, care must be taken to align the indentor to the center of the insert, or the point at which the indentor is to contact the specimen. Care should be exercised to assure that the indentor does not abruptly contact the specimen support

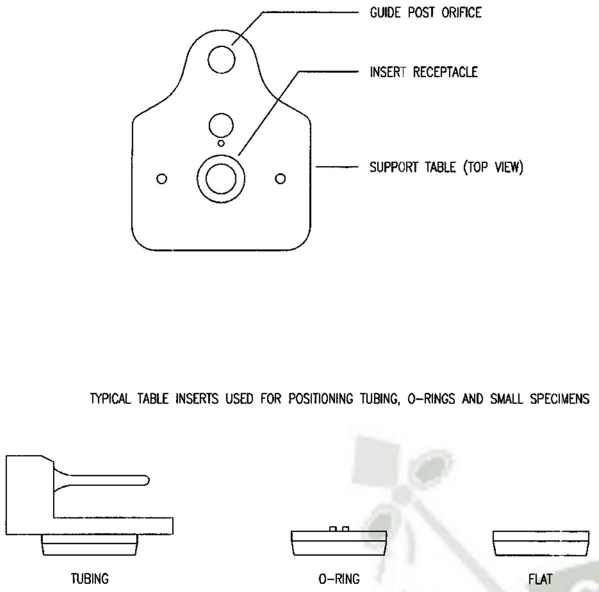

FIG. 3 Small Specimen Support Table

table as damage to the indentor may result.

6. Test Specimen

6.1 The test specimen, herein referred to as "specimen" or "test specimen" interchangeably, shall be at least 6.0 mm (0.24 in.) in thickness unless it is known that results equivalent to the 6.0 mm (0.24 in.) values are obtained with a thinner specimen.

6.1.1 A specimen may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens as the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen shall be sufficient to permit measurements at least 12.0 mm (0.48 in.) from any edge unless it is known that identical results are obtained when measurements are made at a lesser distance from an edge.

6.1.2 The surfaces of the specimen shall be flat and parallel over an area to permit the presser foot to contact the specimen over an area having a radius of at least 6.0 mm (0.24 in.) from the indentor point. The specimen shall be suitably supported to provide for positioning and stability. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

6.2 Type M test specimens should be at least 1.25 mm (0.05 in.) in thickness unless it is known that results equivalent to the 1.25 mm (0.05 in.) values are obtained with a thinner specimen.

6.2.1 A Type M specimen that is not of a configuration described in 6.2.2 may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens because the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen should be sufficient to permit measurements at least 2.50 mm (0.10 in.) from any edge unless it is known that identical results are obtained when measurements are made at lesser distance from an edge. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

6.2.2 The Type M specimen, when configured as an o-ring, circular band, or other irregular shape shall be at least 1.25 mm (0.05 in.) in cross sectional diameter, unless it is known that results equivalent to the 1.25 mm (0.05 in.) values are obtained with a thinner specimen. The specimen shall be suitably supported in a fixture (Fig. 3) to provide for positioning and stability.

6.3 The minimum requirement for the thickness of the specimen is dependent on the extent of penetration of the indentor into the specimen; for example, thinner specimens may be used for materials having higher hardness values. The minimum distance from the edge at which measurements may be made likewise decreases as the hardness increases.

7. Calibration

7.1 *Indentor Extension Adjustment Procedure*:

7.1.1 Place precision ground dimensional blocks (Grade B or better) on the support table and beneath the durometer presser foot and indentor. Arrange the blocks so that the durometer presser foot contacts the larger block(s) and the indentor tip just contacts the smaller block (Fig. 4). It is necessary to observe the arrangement of the blocks and the presser foot/indentor under a minimum of 20× magnification to assure proper alignment.

7.1.2 Indentor extension and shape must be in accordance with 5.1.1.3 or 5.1.1.4 respective to durometer type (Fig. 1a through Fig. 1d). Examination of the indentor under 20× magnification, 50× for Type M indentors, is required to examine the indentor condition. Misshapen or damaged indentors shall be replaced.

7.1.3 A combination of dimensional gage blocks shall be used to achieve a difference of 2.54 mm +0.00 –0.0254 mm (0.100 in +0.00 –0.001 in.) between them. For Type M durometers the gage block dimensions are 1.27 mm +0.0 –0.0127 mm (0.050 in +0.00 –0.0005 in.) between them (Fig. 4).

7.1.4 Carefully lower the durometer presser foot until it contacts the largest dimensional block(s), the indentor tip should just contact the smaller block, verifying full indentor extension.

7.1.5 Adjust the indentor extension to 2.50 ± 0.04 mm (0.098 ± 0.002 in.). For Type M durometers, adjust the indentor extension to 1.25 ± 0.02 mm (0.049 ± 0.001 in.), following the manufacturer's recommended procedure.

7.1.5.1 When performing the procedures in 7.1, care should be used so as not to cause damage to the indentor tip. Fig. 4

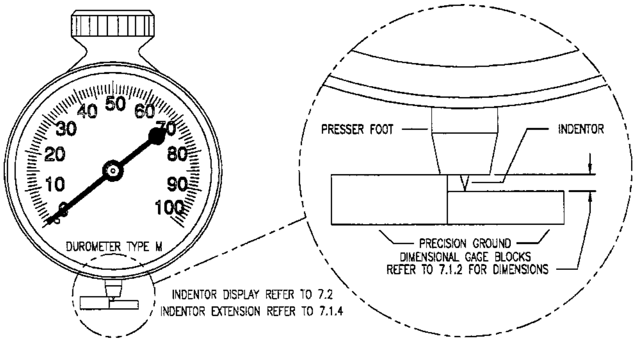

FIG. 4 Detail of Indentor Extension & Display Adjustment

depicts a suitable arrangement for gauging indentor extension.

7.1.6 Parallelism of the durometer presser foot to the support surface, and hence the dimensional gage blocks, at the time of instrument calibration shall be in accordance with Test Method D 374, Machinist's Micrometers. The application of this parallel tolerance is not practical during routine use as described in 5.1.2.1.

7.2 *Indentor Display Adjustment*:

7.2.1 After adjusting the indentor extension as indicated in 7.1, use a similar arrangement of dimensional gage blocks to verify the linear relationship between indentor travel and indicated display at two points: 0 and 100. Following the manufacturer's recommendations, make adjustments so that:

7.2.2 The indicator displays a value equal to the indentor travel measured to within:

–0.0 +1.0 durometer units measured at 0;

±0.50 durometer units measured at 100;

±1 durometer units at all other points delineated in 7.4.

7.2.3 Each durometer point indicated is equal to 0.025 mm (0.001 in.) of indentor travel, for Type M Durometers each indicated point is equal to 0.0125 mm (0.0005 in.).

7.2.4 The indicator shall not display a value greater than 100 or less than 0 at the time of calibration.

7.2.5 Other means of determining indentor extension or indentor travel, such as optical or laser measurement methods, are acceptable. The instrumentation used shall have traceability as described in 1.5.

7.2.6 The durometer shall be supported in a suitable fashion when performing the procedures described in 7.1 and 7.2.

7.3 *Calibration device*:

7.3.1 The durometer spring shall be calibrated by supporting the durometer in a calibrating device, refer to Fig. 5, in a vertical position and applying a measurable force to the indentor tip. The force may be measured by means of a balance as depicted in Fig. 5, or an electronic force cell. The calibrating device shall be capable of measuring applied force to within 0.5 % of the maximum spring force necessary to achieve 100 durometer units.

7.3.2 Care should be taken to ensure that the force is applied vertically to the indentor tip, as lateral force will cause errors in calibration. Refer to 7.1.5.1 and 7.1.6.

7.4 *Spring Calibration*—The durometer spring shall be calibrated at displayed readings of 10, 20, 30, 40, 50, 60, 70, 80, and 90. The measured force (9.8× mass in kilograms) shall be within the spring calibration tolerance specified in Table 1. Table 1 identifies the measured force applied to the indentor for the entire range of the instrument, although it is necessary only to verify the spring calibration at points listed herein.

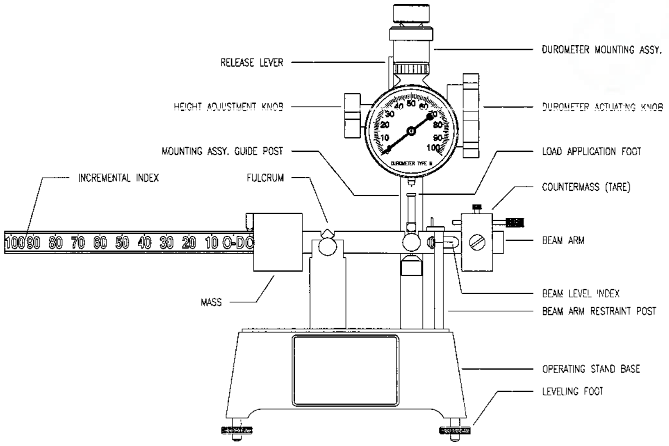

FIG. 5 Example of Durometer Calibration Apparatus

7.5 *Spring Calibration Procedure*:

7.5.1 Ensure that the indentor extension has been adjusted in accordance with 7.1 and the linear relationship between indentor travel and display is as specified in 7.2.

7.5.2 Place the durometer in the calibration device as depicted in Fig. 5. Apply the forces indicated in Table 1 so that forces applied are aligned with the centerline of the indentor in a fashion that eliminates shock or vibration and adjust the durometer according to manufacturers' recommendations so that:

7.5.3 At the points enumerated in 7.4, the display shall indicate a value equal to 0.025 mm (0.001 in.) of indentor travel, for Type M Durometers the display shall indicate a value equal to 0.0125 mm (0.0005 in.) of indentor travel within the spring calibration tolerances specified in 7.6.

7.6 Spring calibration tolerances are ±1.0 durometer units for Types A, B, C, D, O and DO, ±2.0 durometer units for Type OO, and ±4.0 durometer units for Type M, while not indicating below 0 or above 100 at the time of calibration, refer to Table 1.

7.7 *Spring Force combinations*:

For Type M Durometers:

Force, N = 0.324 + 0.0044 HM

Where HM = hardness reading on Type M durometers.

For Type A, B, and O Durometers:

Force, N = 0.55 + 0.075 HA

Where HA = hardness reading on Type A, B, and O durometer.s

For Type C, D, and DO Durometers:

Force, N = 0.4445 HD

Where HD = hardness reading on Type C, D, and DO durometers.

For Type OO Durometers:

Force, N = 0.203 + 0.00908 HOO

Where HOO = hardness reading on Type OO durometers.

7.8 The rubber, or metal, reference block(s) provided for checking durometer operation and state of calibration are not to be relied upon as calibration standards. The calibration procedures outlined in Section 7 are the only valid calibration procedures.

8. Laboratory Atmosphere and Test Specimen Conditioning

8.1 Tests shall be conducted in the standard laboratory atmosphere, as defined in Practice D 618, Section 4.2.

8.2 The instrument shall be maintained in the standard laboratory atmosphere, as defined in Practice D 618, Section 4.1, for 12 h prior to performing a test.

8.3 The specimen shall be conditioned in accordance with condition 40/23 exclusive of humidity control, as described in Practice D 618, Section 8.1, Procedure A and tested under the same conditions, exclusive of humidity control.

8.4 These procedures may be modified if agreed upon between laboratories or between supplier and user and are in accordance with alternative procedures identified in Practice D 618.

8.5 No conclusive evaluation has been made on durometers at temperatures other than 23.0 ± 2.0°C (73.4 ± 3.6°F). Conditioning at temperatures other than the above may show changes in calibration. Durometer use at temperatures other than the above should be decided locally (see Practice D 1349).

9. Procedure

9.1 *Operating Stand Operation (Type 3 Operating Stand Required for Type M)*:

9.1.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.1.2 Adjust the presser foot to support table parallelism as described in 5.1.2.1. It is necessary to make this adjustment each time the support table is moved to accommodate specimens of varying dimensions.

9.1.3 Prior to conducting a test, adjust the vertical distance from the presser foot to the contact surface of the test specimen to 25.4 ± 2.5 mm (01.00 ± 0.100 in.), unless it is known that identical results are obtained with presser foot at a greater or lesser vertical distance from the test specimen contact surface, or if otherwise stipulated by the manufacturer.

9.1.4 Place the specimen on the specimen support table, in a manner that the contact point of the indentor is in accordance with Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance from the edge of the test specimen.

9.1.5 Actuate the release lever (Fig. 2) of the operating stand or activate the electromechanical device, allowing the durometer to descend at a controlled rate and apply the presser foot to the specimen in accordance with 5.1.2. In the case of "specimen to indentor" type operating stands, operate the lever or other mechanism to apply the specimen to the indentor in a manner that assures parallel contact of the specimen to the durometer presser foot without shock and with just sufficient force to overcome the calibrated spring force as shown in Table 1.

9.1.6 An operating stand that applies the mass at a controlled rate of descent, without shock is mandatory for Type M durometers. Hand held application or the use of a Type 1 or Type 2 operating stands for the Type M durometer is not an acceptable practice, refer to 5.1.2.4.

9.1.7 For any material covered in 1.1, once the presser foot is in contact with the specimen, for example, the initial indentor travel has ceased, the indicated reading shall be recorded within 1 ± 0.1 s, or after any period of time agreed upon among laboratories or between supplier and user. If the durometer is equipped with a maximum indicator, the maximum indicated reading shall be recorded within 1 ± 0.1 s of the cessation of indentor travel. The indicated hardness reading may change with time.

9.1.8 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart, 0.80 mm (0.030 in.) apart for Type M; and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to 10.2.8

9.2 *Manual (Hand Held) Operation of Durometer*:

9.2.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.2.2 Place the specimen on a flat, hard, horizontal surface. Hold the durometer in a vertical position with the indentor tip at a distance from any edge of the specimen as described in Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance.

9.2.3 Apply the presser foot to the specimen, maintaining it in a vertical position keeping the presser foot parallel to the specimen, with a firm smooth downward action that will avoid shock, rolling of the presser foot over the specimen, or the application of lateral force. Apply sufficient pressure to assure firm contact between the presser foot and the specimen.

9.2.4 For any material covered in 1.1, after the presser foot is in contact with the specimen, the indicated reading shall be recorded within 1 ± 0.1 s, or after any period of time agreed upon among laboratories or between supplier and user. If the durometer is equipped with a maximum indicator, the maximum indicated reading shall be recorded within 1 ± 0.1 s of the cessation of initial indentor travel. The indicated hardness reading may change with time.

9.2.5 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to Section 10.2.8.

9.3 It is acknowledged that durometer readings below 20 or above 90 are not considered reliable. It is suggested that readings in these ranges not be recorded.

9.4 Manual operation (hand held) of a durometer will cause variations in the results attained. Improved repeatability may be obtained by using a mass, securely affixed to the durometer and centered on the axis of the indentor. Recommended masses are 1 kg for Type A, B and O durometers, 5 kg for Type C, D and DO durometers, and 400 g for Type OO durometers. Further improvement may be achieved by the use of a durometer operating stand which controls the rate of descent of the durometer presser foot to the test specimen and incorporates the masses described above.

10. Report

10.1 *Instrument Calibration Report (Durometer or Operating Stand)*:

10.1.1 Date of calibration.

10.1.2 Date of last calibration.

10.1.3 Manufacturer, type, model, and serial number of the instrument, and a notation when a maximum indicator or timing device is present.

10.1.4 Values obtained (pre- and post calibration results), including a notation of the affect of a maximum indicator, if present. The method of reporting the calibrated value shall be by attaining the arithmetic mean of the determinations.

10.1.5 Ambient temperature.

TABLE 2 Type 1 Precision—Type M Durometer Method

Material		Within Laboratories			Between Laboratories		
	MEAN	*Sr*[A]	*r*[B]	(*r*)[C]	*SR*[D]	*R*[E]	(*R*)[F]
1	31.8	1.26	3.58	11.24	3.76	10.63	33.41
2	40.8	1.14	3.23	7.90	2.47	7.00	17.13
3	54.0	0.975	2.76	5.11	2.38	6.73	12.46
4	62.8	0.782	2.21	3.52	2.24	6.34	10.10
5	70.9	0.709	2.01	2.83	0.974	2.76	3.89
6	80.6	1.686	4.77	5.92	1.61	4.56	5.65
7	87.7	1.15	3.25	3.71	2.63	7.45	8.50
8	32.4	0.947	2.68	8.26	3.64	10.29	31.73
9	41.8	0.797	2.26	5.40	2.23	6.31	15.11
10	53.3	0.669	1.89	3.55	2.29	6.49	12.17
11	63.2	0.485	1.37	2.17	2.19	6.20	9.80
12	69.6	0.737	2.09	3.00	0.99	2.80	4.02
13	78.3	0.784	2.22	2.84	1.04	2.94	3.75
14	87.6	1.121	3.17	3.62	2.65	7.49	8.55
15	34.1	0.85	2.40	7.05	1.84	5.20	15.25
16	42.3	0.635	1.80	4.25	1.20	3.39	8.01
17	54.6	0.56	1.59	2.90	2.15	6.09	11.15
18	62.9	1.12	3.17	5.04	1.47	4.16	6.61
19	70.3	0.689	1.95	2.77	0.944	2.67	3.80
20	81.7	0.483	1.37	1.67	1.10	3.10	3.80
21	87.9	0.879	2.49	2.83	2.07	5.86	6.67
AVERAGE	61.4						
POOLED VALUES		0.924	2.62	4.26	2.146	6.07	9.89

[A] *Sr* = repeatability standard deviation, measurement units.
[B] *r* = repeatability = 2.83 × *Sr*, measurement units.
[C] (*r*) = repeatability, relative, (that is, in percent).
[D] *SR* = reproducibility standard deviation, measurement units.
[E] *R* = reproducibility = 2.83 × *SR*, measurement units.
[F] (*R*) = reproducibility, relative, (that is, in percent).

TABLE 3 Type 1 Precision—Type A Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		Sr[A]	*r*[B]	(*r*)[C]	*SR*[D]	*R*[E]	(*R*)[F]
1	51.4	0.646	1.83	3.56	1.56	4.41	8.59
2	65.3	0.878	2.48	3.81	2.21	6.06	9.27
3	68.0	0.433	1.23	1.80	2.28	6.45	9.49
Pooled	61.6	0.677	1.92	3.11	2.018	5.72	9.28

[A] *Sr* = repeatability standard deviation, measurement units.
[B] *r* = repeatability = 2.83 × *Sr*, measurement units.
[C] (*r*) = repeatability, relative, (that is, in percent).
[D] *SR* = reproducibility standard deviation, measurement units.
[E] *R* = reproducibility = 2.83 × *SR*, measurement units.
[F] (*R*) = reproducibility, relative, (that is, in percent).

TABLE 4 Type 1 Precision—Type D Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		Sr[A]	*r*[B]	(*r*)[C]	*SR*[D]	*R*[E]	(*R*)[F]
1	42.6	0.316	0.894	2.10	2.82	7.98	18.7
2	54.5	0.791	2.24	4.11	3.54	10.0	18.4
3	82.3	1.01	2.86	3.47	3.54	10.0	12.2
Pooled	59.8	0.762	2.16	3.61	3.32	9.40	15.7

[A] *Sr* = repeatability standard deviation, measurement units.
[B] *r* = repeatability = 2.83 × *Sr*, measurement units.
[C] (*r*) = repeatability, relative, (that is, in percent).
[D] *SR* = reproducibility standard deviation, measurement units.
[E] *R* = reproducibility = 2.83 × *SR*, measurement units.
[F] (*R*) = reproducibility, relative, (that is, in percent).

10.1.6 Relative humidity.

10.1.7 Technician identification.

10.1.8 Applicable standards to which the instrument is calibrated.

10.1.9 Calibrating instrument information to include type, serial number, manufacturer, date of last calibration, and a statement of traceability of standards used to NIST or other acceptable organization. See 1.5.

10.2 *Hardness Measurement Report*:

10.2.1 Date of test.

10.2.2 Relative humidity.

10.2.3 Ambient temperature.

10.2.4 Manufacturer, type and serial number of the durometer or operating stand, or both, including a notation when a maximum indicator or timing device is present, and date of last calibration.

10.2.5 Means of testing, whether manual (hand held), Type 1 operating stand (specimen to indentor), Type 2 operating stand (indentor to specimen type), or Type 3 operating stand (electromechanical or hydraulically dampened).

10.2.6 Description of test specimen, including thickness, number of pieces plied if less than the thickness indicated in Section 6, including the vulcanization date.

10.2.7 Complete identification of material tested.

10.2.8 Hardness value obtained and method of calculation, either arithmetic mean or alternatively, the median.

10.2.9 Indentation hardness time interval at which determination was made. Readings may be reported in the form: M/60/1 where M is the type of durometer, 60 the reading, and 1 the time in seconds that the presser foot is in contact with the specimen or from an electronic timing device.

11. Precision and Bias

11.1 These precision and bias statements have been prepared in accordance with Practice D 4483. Refer to this Practice for terminology and other testing and statistical concepts.

11.2 The Type 1 precision for the Type M method was determined from an interlaboratory program with 21 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for the Type M testing program. All materials were supplied from a single source, being those commonly supplied as reference materials with the instruments from the manufacturer.

11.3 The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers) used in the particular interlaboratory program as described above. The precision parameters should not be used for acceptance or rejection testing, or both, of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols that include this test method.

11.4 The Type 1 precision for both Type A and D methods was determined from an interlaboratory program with 3 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for both A and D testing programs. All materials were supplied from a single source.

11.5 A test result for hardness, for Types A, D, and M, was the median of five individual hardness readings on each day in each laboratory.

11.6 Table 2 shows the precision results for Type M method[6], Table 3 shows the precision results for Type A

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[6] Supporting data are available from ASTM International Headquarters. Request RR: D11-1091.

method[7], and Table 4 gives the precision results for Type D method[7].

11.7 *Precision*—The precision of this test method may be expressed in the format of the following statements which use as appropriate value *r*, *R*, *(r)*, or *(R)*, that is, that value to be used in decisions about test results (obtained with the test method). The appropriate value is that value of *r* or *R* associated with a mean level in Table 1 closest to the mean level under consideration (at any given time, for any given material) in routine testing operations.

11.7.1 *Repeatability*—The repeatability, *r*, of these test methods has been established as the appropriate value tabulated in Tables 2-4. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

11.7.2 *Reproducibility*—The reproducibility, *R*, of these test methods has been established as the appropriate value tabulated in Tables 2-4. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or non-identical sample populations.

11.7.3 Repeatability and reproducibility are expressed as a percentage of the mean level, *(r)* and *(R)*, have equivalent application statements as above for *r* and *R*. For the*(r)* and *(R)* statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

11.8 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by this test method. Bias, therefore cannot be determined.

12. Keywords

12.1 durometer; durometer hardness; hardness; indentation hardness; micro durometer hardness

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[7] Supporting data are available from ASTM International Headquarters. Request RR: D11-1029.

APPENDIXES

(Nonmandatory Information)

X1. DUROMETER SELECTION GUIDE

X1.1 The durometer selection guide is designed to assist in the selection of the proper durometer type for various applications.

X1.2 It is generally recognized that durometer hardness determination below 20 and above 90 are unreliable. It is recommended that the next lower or higher type (scale) be used in these situations.

X1.3 It is also recommended that, whenever possible, an operating stand be employed in performing durometer hardness tests.

TABLE X1.1 Durometer Selection: Typical Uses

Type (Scale)	Typical Examples of Materials Tested	Durometer Hardness (Typical Uses)
A	Soft vulcanized rubber, natural rubber, nitriles, thermoplastic elastomers, flexible polyacrylics and thermosets, wax, felt, and leathers	20–90 A
B	Moderately hard rubber, thermoplastic elastomers, paper products, and fibrous materials	Above 90 A Below 20 D
C	Medium-hard rubber, thermoplastic elastomers, medium-hard plastics and thermoplastics	Above 90 B Below 20 D
D	Hard rubber, thermoplastic elastomers, harder plastics, and rigid thermoplastics	Above 90 A
DO	Moderately hard rubber, thermoplastic elastomers, and very dense textile windings	Above 90 C Below 20 D
M	Thin, irregularly shaped rubber, thermoplastic elastomer, and plastic specimens	20–85 A
O	Soft rubber, thermoplastic elastomers, very soft plastics and thermoplastics, medium-density textile windings	Below 20 DO
OO	Extremely soft rubber, thermoplastic elastomers, sponge, extremely soft plastics and thermoplastics, foams, low-density textile windings, human and animal tissue	Below 20 O
CF	Composite foam materials such as amusement ride safety cushions, vehicle seats, dashboards, headrests, armrests, and door panels	See Test Method F 1957

X2. RELATED TEST METHODS

C 367 Test Methods for Strength Properties of Prefabricated Architectural Acoustical Tile or Lay-In Ceiling Panels[8]

C 473 Test Methods for Physical Testing of Gypsum Panel Product[9]

C 581 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service[10]

C 661 Test Method for Indentation Hardness of Elastomeric-Type Sealants by Means of a Durometer[11]

C 836 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course[11]

D 461 Test Methods for Felt[12]

D 531 Test Method for Rubber Property—Pusey and Jones Indentation[4]

D 619 Test Methods for Vulcanized Fibre Used for Electrical Insulation[2]

D 1037 Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials[13]

D 1054 Test Method for Rubber Property—Resilience Using a Rebound Pendulum[4]

D 1414 Test Methods for Rubber O-Rings[14]

D 1474 Test Methods for Indentation Hardness of Organic Coatings[15]

D 2134 Test Method for Determining the Hardness of Organic Coatings with a Sward-Type Hardness Rocker[15]

D 2287 Specification for Nonrigid Vinyl Chloride Polymer and Copolymer Molding and Extrusion Compounds[3]

D 2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor[16]

D 2632 Test Method for Rubber Property—Resilience by Vertical Rebound[4]

D 4289 Test Method for Elastomer Compatibility of Lubricating Greases and Fluids[17]

D 5672 Test Method for Testing Flexible Cellular Materials Measurement of Indentation Force Deflection Using a 25 mm (1 in.) Deflection Technique[18]

D 6546 Test Methods for and Suggested Limits for Determining Compatibility of Elastomer Seals for Industrial Hydraulic Fluid Applications[19]

F 1151 Test Method for Determining Variations in Hardness of Film Ribbon Pancakes[20]

NOTE X2.1—The hardness testing of other nonmetallic materials may be under the jurisdiction of one or more ASTM committees; the respective committee should be contacted for specific information.

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[8] *Annual Book of ASTM Standards*, Vol 04.06.

[9] *Annual Book of ASTM Standards*, Vol 04.01.

[10] *Annual Book of ASTM Standards*, Vol 08.04.

[11] *Annual Book of ASTM Standards*, Vol 04.07.

[12] *Annual Book of ASTM Standards*, Vol 07.01.

[13] *Annual Book of ASTM Standards*, Vol 04.10.

[14] *Annual Book of ASTM Standards*, Vol 09.02.

[15] *Annual Book of ASTM Standards*, Vol 06.01.

[16] *Annual Book of ASTM Standards*, Vol 08.02.

[17] *Annual Book of ASTM Standards*, Vol 05.02.

[18] *Annual Book of ASTM Standards*, Vol 08.03.

[19] *Annual Book of ASTM Standards*, Vol 05.04.

[20] *Annual Book of ASTM Standards*, Vol 15.09.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

Designation: D 3182 – 89 (Reapproved 1994)

Standard Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets[1]

This standard is issued under the fixed designation D 3182; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice provides a listing of reference compounding materials required to prepare the rubber test compounds listed in succeeding methods and contains procedures for weighing. It also specifies the mixing equipment, general mixing procedures, vulcanization equipment and procedures.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precaution statements, see 5.5.

2. Referenced Documents

2.1 *ASTM Standards:*

D 88 Test Method for Saybolt Viscosity[2]

D 1646 Test Method for Rubber—Viscosity, Stress Relaxation, and Pre-Vulcanization Characteristics (Mooney Viscometer)[3]

D 2084 Test Method for Rubber Property—Vulcanization Using Oscillating Disk Cure Meter[3]

D 2161 Practice for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity[4]

D 2226 Classification for Various Types of Petroleum Oils for Rubber Compounding Use[3]

D 2501 Test Method for Calculation of Viscosity-Gravity Constant (VGC) of Petroleum Oils[4]

D 4678 Practice for Rubber—Preparation, Testing, Acceptance, Documentation, and Use of Reference Materials[3]

E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens[5]

3. Significance and Use

3.1 This practice shall be used for specific procedures used in preparing rubber compounds for quality control of production, for research and development purposes, and for comparison of different materials.

4. Standard Materials

4.1 *Standard Reference Materials*:

4.1.1 The materials required for standard rubber test formulas shall be National Institute of Standards and Technology (NIST) Reference Materials or materials that are known to have properties similar to these standard materials. However, in case of dispute, the following actual standard materials from the NIST of the United States shall be used:

4.1.2 An Industry Reference Material (IRM) is a standard reference from a designated supplier and has been certified in accordance with Practice D 4678.[6,7]

NIST Standard Reference Material or IRM	Standard Reference Material No.	Industry Reference Material No.
Zinc oxide	370	
Sulfur	371	
Stearic acid	372	
Benzothiazyl disulfide[6]		2
Tetramethylthiuram disulfide[6,7]		1
Magnesium oxide	376	
Oil furnace carbon black—HAF	378	
Gas furnace carbon black—SRF	382	
Mercaptobenzothiazole	383	
N-tert-butyl-2-benzothiazolesulfenamide	384	
SBR-1500	386	
Natural rubber[8]	201	

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[1] This practice is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.20 on Compounding Materials and Procedures.

Current edition approved Mar. 31, 1989. Published May 1989. Originally published as D 3182 – 73. Last previous edition D 3182 – 87.

[2] *Annual Book of ASTM Standards*, Vol 04.04.

[3] *Annual Book of ASTM Standards*, Vol 09.01.

[4] *Annual Book of ASTM Standards*, Vol 05.01.

[5] *Annual Book of ASTM Standards*, Vol 14.04.

[6] NIST has discontinued supply of SRM 373, 374, and 385. A substitute material is available as IRM 2, 1, and 201 respectively from Forcoven Products, Inc., P.O. Box 1556, Humble, TX 77338 for IRM 1 and 2. IRM 201 is available from Akron Chemical Co., 255 Fountain St., Akron, OH 44304. Request RR: D11-1034 from ASTM Headquarters, 1916 Race St., Philadelphia, PA 19103.

[7] Supporting data are available from ASTM Headquarters. Request RR: D11-1026.

4.2 Other standard or industry reference materials are as follows: Industry Reference Black Current Lot in use at time of testing ASTM Oil Type 103[8]

5. Weighing of Materials

5.1 The standard batch mass (in grams) for the laboratory mill shall be three times the formula mass in parts per hundred grams of rubber, unless otherwise specified.

5.2 The batch mass (in grams) for an internal mixer shall be the nominal capacity (1170 ± 40 cm^3) multiplied by the density of the rubber compound.

5.3 The batch mass (in grams) for a miniature internal mixer (MIM) shall be 75 % of the nominal capacity (85 ± 1 cm^3) multiplied by the density of the rubber compound.

5.4 The rubber and carbon black shall be weighed to within a tolerance of ±1 g for mill and internal mixer compounds and with a tolerance of ±0.1 g for miniature internal mixer compounds. All other materials shall be weighed with a ±0.1-g accuracy or less for mill and internal mixer compounds and with ±0.01-g accuracy for the miniature internal mixer compounds.

5.5 Compounding materials other than rubber, carbon black, and oil may be added to miniature internal mixer batches more precisely and with greater ease if they are previously blended in proportion to the mass required by the recipe. Such blend may be made in a mortar and pestle, by mixing for 10 min in a biconical blender with intensifier bar turning, or by mixing in a blender[9] for five 3-s periods and scraping the inside of the mixer to dislodge materials stuck to the sides after each 3-s mix. **Caution:** If mixed longer than 3 s, the stearic acid may melt and prevent good dispersion.

5.6 Unless otherwise specified, carbon black shall be conditioned by heating for 1 h at 125 ± 3°C (257 ± 5°F) in a 1 B oven or equivalent, in accordance with Specification E 145.

5.6.1 Place the carbon black in an open vessel of suitable dimensions so that the depth of the black is no more than 10 mm (0.4 in.) during conditioning. Store the conditioned carbon black in a closed moisture-proof container until cool and then use for weighing and mixing.

6. Equipment for Mixing

6.1 *Standard Mill*:

6.1.1 The standard mill shall have rolls between 150 and 155 mm (5.9 and 6.1 in.) in diameter. The mill shall be equipped with retaining guides, with a distance between the guides at the nip of 250 to 280 mm (10 to 11 in.).

NOTE 1—If mills of other sizes are used, adjustments to batch masses and mixing cycles may be required to obtain equivalent results.

6.1.2 The speed of the slow roll shall be 0.4 ± 0.50 rad/s (24 ± 0.5 rpm) and the ratio between slow and fast roll shall be 1:1.4. Other ratios may be used, but modifications in mixing procedure may be required to obtain equivalent results. The use of other than a standard mill shall be recorded with the reported data.

6.1.3 Means shall be provided for controlling the mill roll temperatures to the specified temperature ±5°C (±9°F).

6.1.4 The clearance between rolls shall be adjustable from 0.2 to 8.0 mm (0.008 to 0.31 in.) as a minimum range of adjustment. Roll clearance shall be determined by means of two lead strips 10 ± 3 mm (0.4 ± 0.1 in.) wide, at least 50 mm (2 in.) long, and 0.25 to 0.50 mm (0.01 to 0.02 in.) thicker than the roll clearance to be measured. The lead strips shall be inserted, one at each end of the rolls approximately 25 mm (1 in.) from the guides, while a piece of compounded rubber, with Mooney viscosity in excess of 50 ML 1 + 4 at 100°C (212°F), approximately 75 by 75 by 6 mm (3 by 3 by 0.25 in.) is passing through the center portion of the rolls. The rolls shall be at the temperature specified for mixing. After the lead strips have passed through the rolls, measure the thickness of the strips to the nearest 0.02 mm (0.001 in.). Tolerance on a roll clearance shall be ±10 % or 0.05 mm (0.002 in.), whichever is larger.

6.2 *Standard Internal Mixer*—The standard internal mixer shall have a chamber of 1575 ± 50 cm^3 volume and two rotors with approximately 400-cm^3 displacement volume, resulting in 1170 ± 40-cm^3 loading capacity. The slow rotor speed shall be 8.16 rad/s (77 rpm) and the gear ratio shall be 1:1.125. The rotor wing tip to side clearance shall be 2.4 + 0.3, − 0.1 mm (0.094 + 0.010, − 0.005 in.). The mixer shall be equipped with a thermocouple for measuring and recording batch mixing temperatures. The thermocouple shall be installed through the end frame and shall protrude into the mixing chamber 25 ± 2.5 mm (1 ± 0.1 in.) measured along the top side of the thermocouple probe. A ram that is 56 ± 3 mm by 140 ± 8 mm (2.2 ± 0.1 in. by 5.5 ± 0.3 in.) shall exert a force of 1.27 ± 0.06 kN (285 ± 14 lbf) on the batch in the chamber. The sides shall be hinged to swing open, made of cast stainless steel and jacketed for controlling temperature by means of a circulating liquid or steam. The end frames shall be of ductile iron that has a 0.20 ± 0.02-mm (0.008 ± 0.001-in.) thick chrome plating on the working surfaces. Rotors are of stainless steel, nitrided, drilled, and equipped with rotary unions for controlling the rotor temperature by means of a circulating liquid or steam.

NOTE 2—If internal mixers of other sizes are used, adjustments of batch masses and rotor speeds or mixing cycles will be required to obtain equivalent results.

6.3 *Standard Miniature Internal Mixer (MIM)*:

6.3.1 The standard miniature internal mixer shall be equipped with a stainless steel mixer head having a bowl of 120-cm^3 volume and stainless steel cam-style mixer rotors (removable or fixed) of 34 to 35-cm^3 displacement, thus resulting in a 85 ± 1-cm^3 volume. The recommended loading is 75 % (64 cm^3). The fast or driving rotor (left) shall turn at 6.28 + 3.14 rad/s (60 + 3, − 0 rpm) and the gear ratio (drive to driven) shall be 1.5:1. The mixer shall be equipped with a thermocouple installed through the ridge in the bowl for measuring and recording the batch temperatures. The mixing chamber shall be closed during the mixing cycle by means of a lever or ram. The head and the backplate shall be maintained

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[8] Defined by Classification D 2226. A lot of oil conforming to the basic description in Classification D 2226 and more specifically, to the values listed below, can be obtained from Sun Refining and Marketing Co., Process Materials Group, 10 Penn Center, 1801 Market St., Philadelphia, PA 19103 (available in 1 and 5-gal quantities): Kinematic Viscosity (Test Method D 88) and (Practice D 2161) 16.8 ± 1.2 mm^2/s at 100°F, Viscosity-Gravity Constant (Test Method D 2501) 0.889± 0.002.

[9] A Waring Blender has been used in this practice. Results cannot be guaranteed using another brand.

at the required temperature either electrically or by means of a thermal liquid medium.

NOTE 3—If miniature internal mixers equipped with Banbury-style mixer head and rotors or heads of other sizes are used, adjustments of batch masses, rotor speeds, or mixing cycles will be required to obtain equivalent results.

6.3.2 The miniature internal mixer may be equipped with a torque-measuring instrument and recorder, which are not essential for the mixing operation. If used, it must be calibrated occasionally and after each overhaul of the miniature internal mixer using the manufacturer's instructions.

7. General Mixing Procedures

7.1 *Mill Mixing Procedure*:

7.1.1 Mix compounds with the rubber banded on the slow roll, unless otherwise specified.

7.1.2 Measure the temperature of the surfaces of the rolls at a point approximately equidistant from the ends during the mixing operation either continuously on a recorder or with a manual device having an accuracy of at least ±1°C (± 2°F), frequently enough to maintain the desired temperature. The batch may be removed momentarily from the mill to measure the surface temperature of the slow roll.

7.1.3 Whenever ¾cuts are specified, cut the batch ¾of the distance across the roll and hold the knife at this position until the bank just disappears. Make successive ¾ cuts from alternate ends of the roll, allowing 20 s between each cut unless otherwise specified.

7.1.4 Do not cut any batch while free materials are evident in the bank or on the milling surface.

7.1.5 Add carbon black evenly across the mill at a uniform rate. Add all other dry materials slowly and evenly in prescribed times. Oil, if required, may be added alternately with carbon black. Carefully collect materials falling through the nip from the tray and return to the mix.

7.1.6 Conclude the mixing cycle by passing the rolled batch endwise through the mill six times with an opening of 0.8 mm (0.031 in.), to improve the dispersion.

7.1.7 Pass the batch four times through the mill at a setting of 6 mm (.25 in.), folding it back on itself each time.

7.1.8 Weigh the batch, remove the test specimens for Mooney viscosity in accordance with Test Method D 1646 or cure meter in accordance with Test Method D 2084, or both, and sheet out the remainder to 2.2 to 2.4-mm (0.087 to 0.094-in.) thickness after shrinkage has taken place.

7.2 *Internal Mixer Mixing Procedure*:

7.2.1 The compound is usually prepared in two stages: the first one always in the internal mixer and the second either in the internal mixer or on the standard mill.

7.2.2 The initial internal mixer temperature will be either indicated or be such that the required discharge temperature is reached.

7.2.3 The rotor speed shall be 8.16 rad/s (77 rpm), unless otherwise specified.

7.2.4 Cut the rubber into pieces suitable for fast feeding.

7.2.5 Prepare the mix according to specified instructions regarding the order and time of material addition.

7.2.6 Consolidate the discharge on a standard mill, weigh, and allow to cool on a flat metal surface before proceeding with the second-stage mix.

7.2.7 If the second stage mix is prepared in the internal mixer, cut the batch from stage 1 into strips for easier feeding, and follow by the addition of the materials according to the specific instructions. The batch should then be discharged at the prescribed time or temperature. If the second-stage mix is prepared on the standard mill, add materials in prescribed order and time. The batch size may be reduced to better accommodate the mill and to result in better dispersion of compounding materials.

7.2.8 Conclude the mixing by passing the rolled batch endwise through the standard mill six times with an opening of 0.8 mm (0.031 in.), to improve the dispersion.

7.2.9 Pass the batch four times through the mill at a setting of 6 mm (0.24 in.), folding it back on itself each time.

7.2.10 After weighing and removal of test specimens, sheet out the batch to 2.2 to 2.4-mm (0.087 to 0.094-in.) thickness after shrinkage has taken place.

7.3 *Miniature Internal Mixer Procedure*:

7.3.1 Maintain the mixer head temperature for at least 5 min before mixing.

7.3.2 The unloaded rotor speed shall be 1.0 + 0.05, − 0 rev/s (60 + 3, − 0 rpm), unless otherwise specified. It should be frequently checked if a variable speed model is used.

7.3.3 Prepare the compound according to instructions specified for the rubber.

7.3.4 Immediately pass the discharge from the mixer twice through a standard mill maintained at specified temperature with roll separation of 0.5 mm (0.020 in.) once, then twice at a separation of 3 mm (0.12 in.), in order to dissipate the heat, and weigh.

7.3.5 After the removal of a curemeter specimen, if a compound viscosity or tension specimen, or both are required, pass the batch endwise through the mill six times with an opening of 0.8 mm (0.031 in.) to enhance the dispersion.

7.3.6 After removing the compound viscosity specimen, if a tension specimen is required, pass the batch four times through a standard mill at specified temperature. Fold it lengthwise after each pass and pass always in the same direction to obtain the effect of mill direction. The roll opening should be such that it will produce a 2.2 to 2.4-mm (0.087 to 0.094-in.) thick sheet after shrinkage.

8. Preparation of Standard Vulcanized Sheets

8.1 *Preparation of Sheets*:

8.1.1 Unless otherwise specified, condition the sheeted compound for 1 to 24 h at 23 ± 3°C (73.4 ± 5.4°F) at a relative humidity not greater than 55 %. For maximum precision, condition for 1 to 24 h in a closed container to prevent absorption of moisture from the air, or in an area controlled at 35 ± 5 % relative humidity.

8.1.2 Place the sheeted compound on a flat, dry, clean metal surface and cut pieces that are 4.5 ± 1.5 mm (0.18 ± 0.06 in.) shorter in width and length than the corresponding dimensions of the mold cavity. Mark the direction of the milling on each piece.

8.1.3 The mass of a 150 by 150-mm (6 by 6-in.) sheet or a 150 by 75-mm (6 by 3-in.) sheet to be vulcanized in the molds described in 8.2.2 shall be as shown below:

Density of Compound	Mass of Unvulcanized Sheet, g 150 by 150 mm (6 by 6 in.)	 150 by 75 mm (6 by 3.0 in.)
0.94	52 ± 3	26± 1.5
0.96	53	27
0.98	54	27
1.00	55	28
1.02	56	28
1.04	57	29
1.06	58	29
1.08	59	30
1.10	60	30
1.12	61	31
1.14	62	31
1.16	63	32
1.18	64	32
1.20	65	33
1.22	66	33
1.24	67	34
1.26	68	34
1.28	69	35
1.30	70	35

8.1.4 A film of suitable material, such as a nonlubricated aluminum foil 0.1 mm (0.004 in.) thick, may be placed above and below the sheet in the mold to prevent contamination with materials remaining in the mold from previous cures. The mass of the unvulcanized sheet shall be reduced to compensate for the thickness of the foil.

8.2 *Vulcanization Equipment*:

8.2.1 *Press*—The press shall be capable of exerting a pressure of not less than 3.5 MPa (500 psi) on the total cross-sectional area of the cavities of the mold during the entire period of vulcanization. It shall have heated platens of sufficient size so that no portion of the rubber will be nearer than 75 mm (3 in.) to the edge of the platen during vulcanization. The platen shall preferably be made of rolled steel, machined for steam heating or for electrical elements for heating electrically. When steam heat is used, place either a self-bleeding trap or a small vent in the exit stream line to allow steam to flow continuously through the platens. If chamber-type platens are used, place the steam outlet slightly below the steam chamber so that good drainage is assured. Reduce conduction of heat from the hot platens to the press cross-head as much as practicable by means of a steel grid between them, or by other means. Platens should be suitably shielded from drafts. The pressing surfaces of the platen shall be plane parallel to within 0.25 mm/m (0.003 in./ft) when the platens are at 150°C (302°F) and closed under full pressure with a grid of soft solder or lead between them. With either type of platen, the temperature over the mold area shall be uniform. The maximum deviation from the temperature at the center of the platen shall not exceed ±0.5°C (1°F). Between adjacent platens the temperature difference between corresponding points on the two platens shall not exceed 0.5°C (1°F).

8.2.2 *Molds*:

8.2.2.1 The mold for 150 by 150 by 2-mm (6 by 6 by 0.08-in.) sheets shall have cavity sections similar in dimensions to that shown in Fig. 1. The cavities to within 6.3 mm (0.25 in.) of the edges shall be between 1.9 and 2.0 mm (0.075 and 0.079 in.) deep. The corners of the cavities may be rounded with a radius not greater than 6.3 mm (0.25 in.). An alternative type of

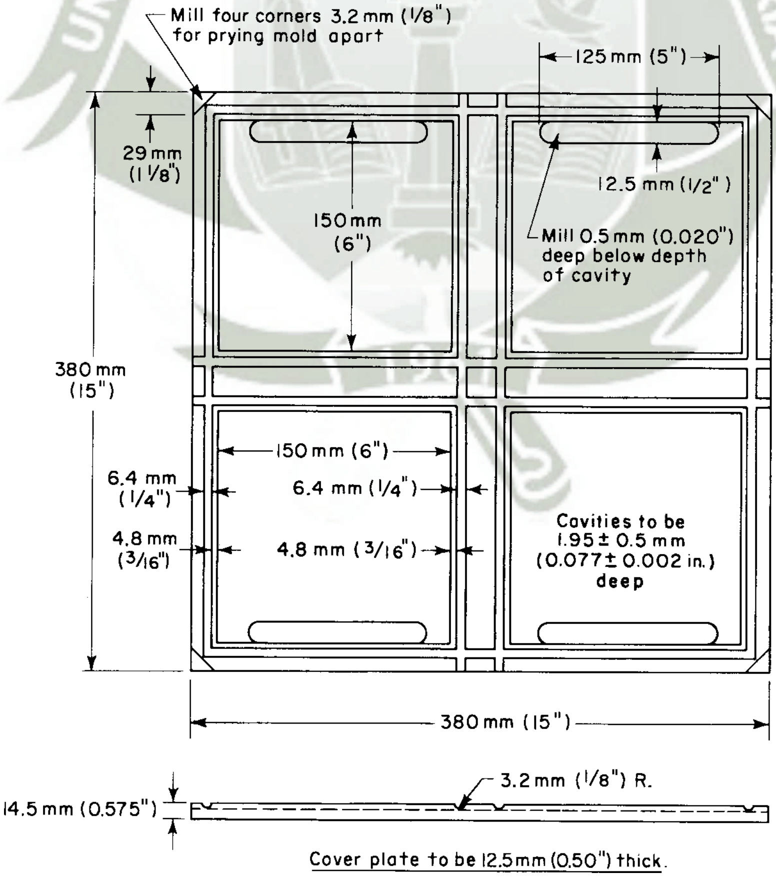


FIG. 1 Design of Four-Cavity Mold

test sheet mold, made by the cut-off bar method with a lower plate thickness of about 20 mm (0.75 in.), is shown in Fig. 2.

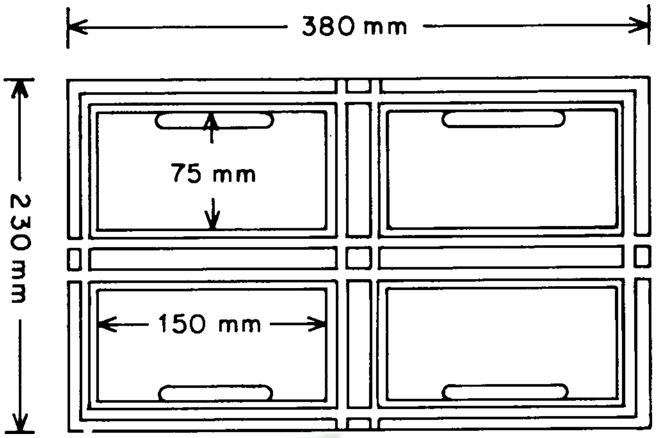
8.2.2.2 The mold for 150 by 75 by 2-mm (6 by 3.0 by 0.08-in.) sheets shall have cavity sections similar in dimensions to that shown in Fig. 3 or Fig. 4. The cavities of this mold shall meet the requirements described in 8.2.2.1.

8.2.2.3 The molding surfaces shall be cleaned, highly polished, and hard chromium-plated. Molds constructed of hardened steel are preferred, but chrome-plated mild steel and stainless steel are also acceptable. The cover of the mold shall be a flat plate at least 10 mm (0.4 in.) in thickness and preferably hinged to the cavity section to minimize scratching of the mold surfaces. Instead of a separate mold and cover, the cavities may be cut directly into the platen of the press. Unless required, do not use a mold lubricant on the mold surfaces. When a mold lubricant is required, use only a residual-type lubricant, which does not affect the vulcanized sheet, and remove the excess lubricant by vulcanizing and discarding at least one set of sheets. A silicone-type lubricant or mild soap solution has been found satisfactory.

8.3 *Vulcanization Procedure*:

8.3.1 Bring the mold to curing temperature within ±0.5°C (1°F) in the closed press, and hold at this temperature for at least 20 min before the unvulcanized pieces are inserted. Verify the temperature of the mold by means of a thermocouple or other suitable temperature measuring device inserted in one of the overflow grooves and in intimate contact with the mold.

8.3.2 Open the press, insert the unvulcanized pieces into the mold, and close the press in the minimum time possible. When the mold is removed from the press to insert the pieces, take precautions to prevent excessive cooling of the mold by contact with cool metal surfaces or by exposure to air drafts.



NOTE 1—All other dimensions as in Fig. 1.

FIG. 3 Design for Four Cavity Small Tensile Sheet Mold

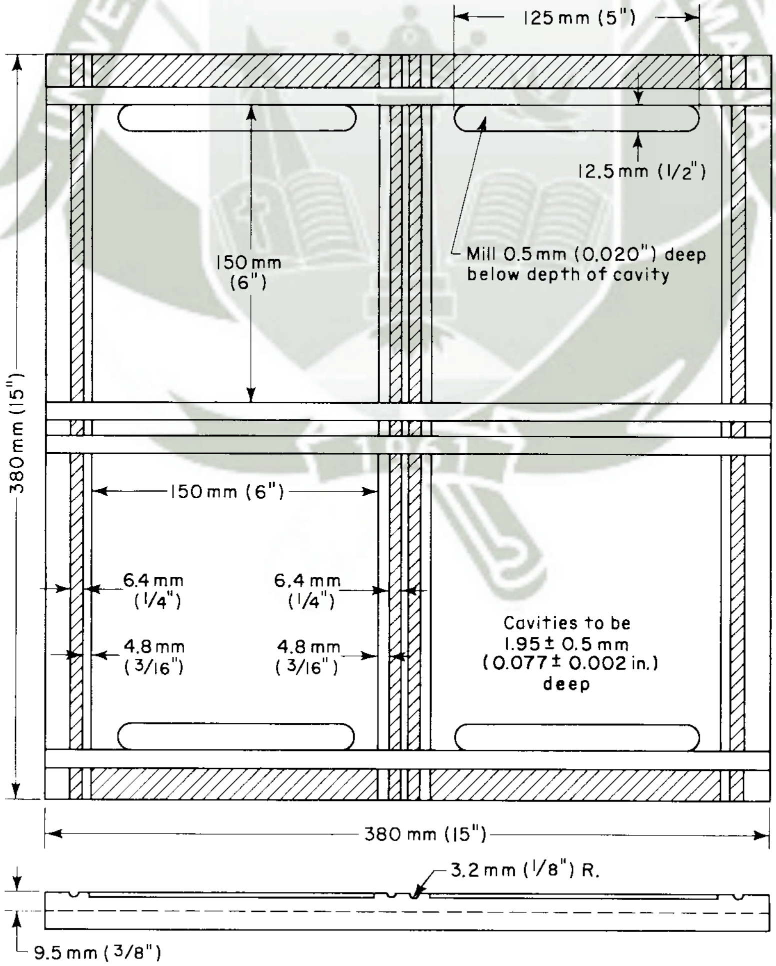


FIG. 2 Cutoff Bar Type of Test of Slab Mold

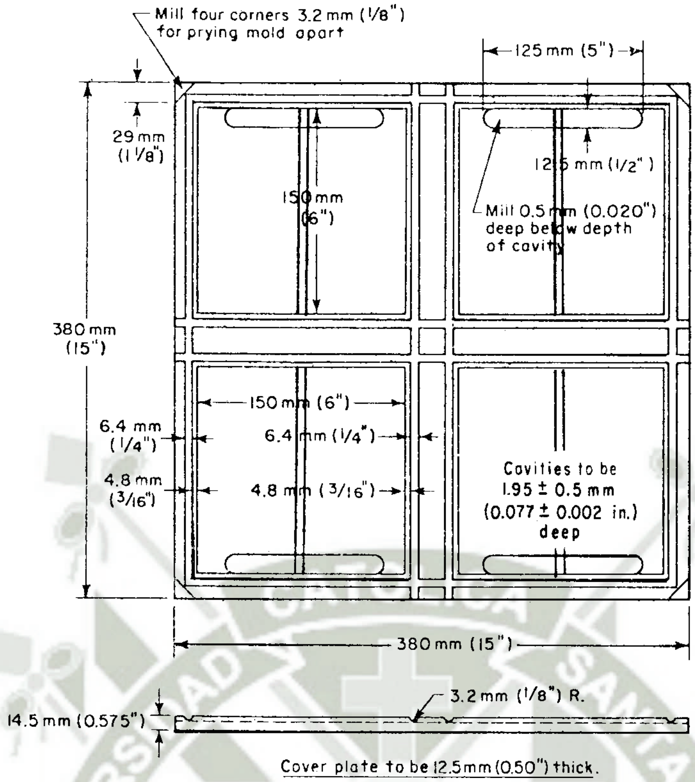


FIG. 4 Design of Eight Cavity Mold, for Small Tensile Sheets Made by Modifying the Mold Shown in Fig. 1

8.3.3 Consider the time of vulcanization to be the period between the instant the pressure is applied fully and the instant the pressure is released. Hold the mold under a minimum pressure of 3.5 MPa (500 psi) on the cavity areas during vulcanization. As soon as the press is opened, remove the vulcanized sheets from the mold and cool in water (room temperature or lower) or on a metal surface (for items used for electrical measurements) for 10 to 15 min. Designate in the report the type of cooling used.

8.3.4 Condition vulcanizates of compounds at a temperature of 23 ± 2°C (73 ± 3.6°F) for at least 16 h (Note 4) and for not more than 96 h before preparing and testing, unless otherwise specified.

NOTE 4—Quality control of rubber production may require testing within 1 to 6 h to provide close surveillance of the plant operation; however, slightly different results may be obtained.

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Designation: D 3574 – 95

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Standard Test Methods for Flexible Cellular Materials—Slab, Bonded, and Molded Urethane Foams[1]

This standard is issued under the fixed designation D 3574; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods apply to slab, bonded, and molded flexible cellular products known as urethane foams. Urethane foam may be generally defined as an expanded cellular product produced by the interaction of active hydrogen compounds, water, and isocyanates.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 *This standard should be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire hazard assessment or a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 412 Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers— Tension[2]

D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[2]

E 162 Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source[3]

NOTE 1—The specific dated edition of Practice D 4483 that prevails in this document is referenced in the Precision and Bias section.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bonded foam*—a product produced by the adhesion of small pieces of urethane foam to each other with a suitable bonding agent.

3.1.2 *core*—the internal portion of a molded part, free of skin.

3.1.3 *flexible cellular product*—a cellular organic polymeric material that will not rupture when a specimen 200 by 25 by 25 mm is bent around a 25-mm diameter mandrel at a uniform rate of 1 lap in 5 s at a temperature between 18 and 29°C.

3.1.4 *molded foam*—a cellular product having the shape of the enclosed chamber in which it is produced by foaming.

3.1.5 *skin*—the smooth surface layer of a molded foam product, formed by contact with the mold or surfaces.

3.1.6 *slab*—a section of foam that is cut from the internal portion of a large bun.

3.1.7 *urethane foam*—a flexible cellular product produced by the interaction of active hydrogen compounds, water, and isocyanates.

4. Summary of Test Methods

4.1 Unless specifically stated otherwise between the supplier and the purchaser, all tests shall be made in accordance with the methods specified in Sections 9-124 which include test procedures for the following:

Tests:		Sections
Test A	Density Test	9-15
Test B_1	Indentation Force Deflection Test—Specified Deflection	16-22
Test B_2	Indentation Force Deflection Test—Specified Force	23-29
Test C	Compression Force Deflection Test	30-36
Test D	Constant Deflection Compression Set Test	37-44
Test E	Tension Test	45-52
Test F	Tear Resistance Test	53-60
Test G	Air Flow Test	61-67
Test H	Resilience (Ball Rebound) Test	68-75
Test I_1	Static Force Loss Test at Constant Deflection	77-85
Test I_2	Dynamic Fatigue Test by the Roller Shear at Constant Force,	86-94
Test I_3	Dynamic Fatigue Test by Constant Force Pounding	95-103
Test I_4	Dynamic Fatigue Test for Carpet Cushion	104-112
Test J	Steam Autoclave Aging	113-118
Test K	Dry Heat Aging	119-124

Appendixes:

X1. Suggested Method for Specifying Flexible Urethane Foams

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[1] These test methods are under the jurisdiction of ASTM Committee D-20 on Plastics and are the direct responsibility of Subcommittee D20.22 on Cellular Plastics.

Current edition approved Feb. 15, 1995. Published May 1995. Originally published as D 3574 – 77. Last previous edition D 3574 – 91.

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] *Annual Book of ASTM Standards*, Vol 04.07.

X2. Suggested Method of Construction for a Roller Shear Dynamic Flex Fatigue Apparatus
X3. Definitions of Terms Used to Describe the Force-Deflection Curve of Flexible Urethane Foam
X4. Suggested Tests for Determining Combustibility of Flexible Urethane Foam. (The combustion tests are given for informational purposes only and are not part of the standard.)
X5. Suggested Method for Verification of an Inclined Oil Manometer

5. Significance and Use

5.1 The test procedures provide a standard method of obtaining data for research and development, quality control, acceptance and rejection under specifications, and special purposes.

5.2 The data obtained by these test methods are applicable to the material under conditions of the particular test and are not necessarily the same as obtained in other environments in use.

6. General Test Conditions

6.1 Tests shall be conducted under known conditions of temperature and humidity or as specified in the individual test procedure. The product shall be conditioned undeflected, and undistorted at the temperature and humidity of test for at least 12 h before being tested. In cases of dispute, the tests shall be made at a temperature of 23 ± 2°C and in an atmosphere of 50 ± 5 % relative humidity.

6.2 It is recommended for referee purposes that all tests shall be performed 7 days or more after the foam has been manufactured.

6.3 All foams shall be preflexed twice 75 to 80 % of their nominal thickness or as specified by the purchaser.

7. Sampling

7.1 When possible, the completed manufactured product shall be used for the test specified. Representative samples of the lot being examined shall be selected at random as required.

7.2 When it is necessary or advisable to obtain specimens from the articles, as in those cases where the entire sample is not required or adaptable for testing, the method of cutting and the exact position from which specimens are to be taken shall be specified. The density and the state of cure may vary in different parts of the finished product, especially if the article is of complicated shape or of varying thickness, and these factors affect the physical properties of the specimens. Also, the density is affected by the number of cut surfaces on the specimen. If a test specimen is die cut, sufficient time should be allowed for complete recovery of the thickness across the full width of the specimen.

7.3 When the finished molded product does not lend itself to testing or to the taking of specimens because of complicated shape, small size, metal or fabric inserts, adhesion to metal, or other reasons, molded test slabs as agreed upon between the supplier and the purchaser shall be prepared.

7.4 When differences in test results arise due to the difficulty in obtaining suitable specimens from the finished parts, the supplier and the purchaser may agree upon an acceptable location to take the specimen.

8. Measurement of Test Specimens

8.1 Measure the length and width with a scale or tape. Take care not to distort the foam.

8.2 Measure thickness up to and including 25 mm using a dial-type gage with a minimum foot area of 650 mm^2. Hold the pressure of the dial foot to 170 ± 35 Pa (Note 2). Thicknesses over 25 mm may be measured with a dial gage, a sliding caliper gage, or as specified in 8.1. When a sliding caliper gage is employed, make the gage setting with the gage out of contact with the foam. Pass the specimen through the previously set gage: the proper setting shall be the one when the measuring faces of the gage contact the surfaces of the specimen without compressing it.

NOTE 2—For soft foams having compression force deflection values less than 1.65 kPa, the pressure on the dial foot shall not exceed 70 Pa.

8.3 The scale, tape, or gage shall be graduated so as to permit measurements within ±1 % of the dimensions to be measured.

8.4 Results reported shall be the median of a minimum of three measurements.

TEST A—DENSITY TEST

9. Scope

9.1 This test method covers determination of the density of uncored foam by calculation from the mass and volume of the specimen. The density value thus obtained applies only to the immediate area from which the specimen has been taken. It does not necessarily relate to the bulk density of the entire molded pad.

10. Test Specimen

10.1 *Interior Density*—A representative specimen of regular shape, circular or square without skins or densification lines, not less than 1000 mm^3 in volume, shall be cut from a portion free of voids and defects and as near as possible to the section from which the tension and tear specimens were taken.

10.2 *Section Density*—A representative specimen with skins on the top and bottom surface measuring at least 0.1 m^2 in area by full-part thickness shall be cut from an area free of voids and defects and as near as possible to the location from which the tension and tear specimens were taken. When these dimensions are not possible, the largest representative portion as agreed upon between the supplier and the purchaser shall be used.

11. Number of Specimens

11.1 One specimen shall be tested.

12. Procedure

12.1 Determine the mass of the specimen within 1 %.

12.2 Determine the dimensions of the specimen in accordance with Section 8, and calculate the volume.

13. Calculation

13.1 Calculate the density in kilograms per cubic metre as follows:

$$\text{Density} = M/V \tag{1}$$

where:

M = mass of specimen, kg, and
V = volume of specimen, m^3.

14. Report

14.1 Report the following information:

14.1.1 Density to the nearest 1 kg/m^3, and

14.1.2 Type of specimen.

15. Precision and Bias

15.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST B_1 —INDENTATION FORCE DEFLECTION TEST—SPECIFIED DEFLECTION

16. Summary of Test Method

16.1 This will be known as the indentation force deflection test and the results as the IFD values. This test consists of measuring the force necessary to produce 25 and 65 % or other designated indentations in the foam product (Appendix X3).

17. Apparatus

17.1 An apparatus having a flat circular indentor foot 323 cm^2 in area connected by means of a swivel joint capable of accommodating the angle of the sample to a force-measuring device and mounted in such a manner that the product or specimen can be deflected at a speed of 0.4 to 6.3 mm/s. The apparatus shall be arranged to support the specimen on a level horizontal plate which is perforated with approximately 6.5-mm holes on approximately 20-mm centers to allow for rapid escape of air during the test. Special support for contoured molded pads shall be perforated and agreed upon between the supplier and the purchaser. Pads longer than the base plate shall be supported from distortion at the 4.5-N contact force.

18. Test Specimen

18.1 The test specimen shall consist of the entire product sample or a suitable portion of it, except that in no case shall the specimen have dimensions less than 380 by 380 by 20 mm. Specimens less than 20 mm thick shall be plied up, without the use of cement, to a minimum of 20 mm.

18.2 The IFD values for molded products are dependent on the specimen dimensions. Higher values are generally obtained for specimens that retain all molded surfaces.

19. Number of Specimens

19.1 One specimen shall be tested.

20. Procedure

20.1 Place the test specimen in position on the supporting plate of the apparatus. If the product has one side cored or honey-combed, this face shall rest on the perforated plate. The specimen position shall be such that whenever practicable the indentation will be made at the center of all articles, except where another location is agreed upon by the supplier and the purchaser.

20.2 Preflex the area to be tested by twice lowering the indentor foot to a total deflection of 75 to 80 % of the full-part thickness at a rate of 4 ± 0.4 mm/s. Mark the location of the test area with a pen by circumscribing the indentor foot while under a 4.5-N force. Allow the specimen to rest 6 ± 1 min after the preflex.

20.3 Bring the indentor foot into contact with the specimen and determine the thickness after applying a contact force of 4.5 N (Note 3) to the indentor foot. Indent the specimen at 0.83 ± 0.08 mm/s 25 % of this thickness and observe the force in newtons after 60 ± 3 s. Without removing the specimen increase the deflection to 65 % deflection, allowing the force to drift while maintaining the 65 % deflection, and again observe the force in newtons after 60 ± 3 s.

NOTE 3—For super-soft foam, foam with a 25 % IFD less than 40 N, a reduction of pressure on the indentor foot shall be allowed. Sufficient pressure to make contact is normal.

21. Report

21.1 Report the force in newtons required for 25 and 65 % indentation (Note 4). These figures are known as the 25 % and 65 % IFD values, respectively. Report also length, width, and thickness of the specimen and the ratio (comfort factor Appendix X3) of 65 % to 25 % IFD values.

NOTE 4—Indentation deflection tests, other than 25 and 65 %, as well as a 25 % return value, may be specified as agreed upon between the supplier and the purchaser.

22. Precision and Bias

22.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST B_2 —INDENTATION FORCE DEFLECTION TEST—SPECIFIED FORCE

23. Summary of Test Method

23.1 Cellular foam products have been traditionally checked for force deflection by determining the force required to effect a 5 % deflection. In seating, on the other hand, the interest is in determining how thick the padding is under the average person. Two measurements are called for to meet the requirements of this test method. The force deflection is determined by measuring the thickness of the pad under a fixed force of 4.5 N, 110 N, and 220 N, on a 323-cm^2 circular indentor foot.

23.2 This determination shall be known as the Indentation Residual Deflection Force and the measurements as the IRDF values.

24. Apparatus

24.1 An apparatus having a flat circular indentor foot 323 cm^2 in area and equipped with a swivel joint for applying forces of 4.5 N, 110 N, and 220 N shall be mounted over a level horizontal platform that is perforated with approximately 6.5-mm holes on approximately 20-mm centers to allow for rapid escape of air during the test. The distance between the indentor foot and the platform shall be variable to indent the specimen at a speed of 0.83 ± 0.08 to 3.3 ± 0.3 mm/s for deflection measurements. The apparatus shall be equipped with a device for measuring the distance between plates.

24.2 Special support for contoured molded pads shall be perforated and agreed upon between the supplier and the purchaser. Pads longer than the base plate shall be supported from distortion at the 4.5-N contact force.

25. Test Conditions

25.1 When possible the completed manufactured product shall be used. In the case of tapered cushions, the location of the area for measurement is to be agreed upon between the supplier and the purchaser. In the case a finished part is not feasible for test, 380 by 380-mm specimens of an average thickness are to be cut from the cushion.

25.2 The IRDF values for molded products are dependent on the specimen dimensions. Difference values are generally obtained for specimens that retain all molded surfaces.

26. Number of Specimens

26.1 One specimen shall be tested.

27. Procedure

27.1 Test the whole test specimen or a minimum area of 380 by 380 mm. Preflex twice to a 10-kPa pressure. This corresponds to 330 N on a 320-cm^2 indentor foot at 3.3 mm/s. Allow to rest 6 ± 1 min. Position in the test apparatus with any coring, honeycombing, or slotting resting on the perforated bottom plate.

27.2 Bring the indentor foot into contact and determine the thickness of the specimen with the 4.5-N load on the indentor foot.

27.3 Apply the 110-N force at 0.83 ± 0.08 mm/s to the indentor foot and indent the specimen until the force is carried by the specimen. Determine the thickness at 110 N after maintaining the force for 60 ± 3 s.

27.4 Without removing the specimen apply the 220-N force to the indentor foot and further indent the pad until this load is carried. After 60 ± 3 s under load, observe the thickness of the pad.

28. Report

28.1 Report the specimen thickness after 60 ± 3 s at 4.5 N, 110 N, and 220 N. These figures are known as the IRDF values, respectively. Report also the length, width, and thickness of the specimen.

29. Precision and Bias

29.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST C—COMPRESSION FORCE DEFLECTION TEST

30. Summary of Test Method

30.1 This test consists of measuring the force necessary to produce a 50 % compression over the entire top area of the foam specimen.

NOTE 5—Compression deflection tests other than at 50 % may be specified as agreed upon between the supplier and the purchaser.

31. Apparatus

31.1 An apparatus having a flat compression foot, larger than the specimen to be tested connected to a force-measuring device and mounted in a manner such that the product or specimen can be deflected at a speed of 0.4 to 6.3 mm/s. The apparatus shall be arranged to support the specimen on a level horizontal plate that is perforated with approximately 6.5-mm holes on approximately 20-mm centers to allow for rapid escape of air during the test.

32. Test Specimens

32.1 The slab test specimen shall have parallel top and bottom surfaces and essentially vertical sides. The thickness shall be no greater than 75 % of the minimum top dimension.

32.2 Specimens from uncored slab stock shall be a minimum of 2500 mm^2 in area and a minimum thickness of 20 mm. Specimens less than 20 mm thick shall be plied up, without the use of cement, to a minimum of 20 mm.

32.3 Specimens from cored slab stock shall be of such size that the coring does not appreciably affect the compression value.

32.4 The test specimen from molded parts shall have parallel top and bottom surfaces and perpendicular sides. Preferably the specimen should include both top and bottom molded skins. If a test specimen with parallel top and bottom surfaces including both molded skins cannot be obtained because of the shape of the molded part, at least one of the molded skin surfaces should be retained. Both surface skins should be removed only in cases where the shape of the original sample makes this absolutely necessary.

32.5 Maximum molded specimen thickness shall be no greater than the minimum top dimensions. Specimens from uncored stock shall have a minimum length of 50 mm, a minimum width of 50 mm, and a minimum thickness of 20 mm. Specimens less than 20 mm thick shall be plied up, without the use of cement, to a minimum of 20 mm.

33. Number of Specimens

33.1 Three specimens per sample shall be tested. The value reported shall be the median of those observed. If any value deviates more than 20 % from this median, two additional specimens shall be tested and the median for all five values shall be reported.

34. Procedure

34.1 Preflex the specimen twice, 75 to 80 % of its original thickness at 4 ± 0.4 mm/s. Then allow the specimen to rest for a period of 6 ± 1 min.

34.2 Place the specimen centered in the line of the axial load on the supporting plate of the apparatus. If the product has one side cored or honeycombed, rest this face on the perforated plates.

34.3 Bring the compression foot into contact with the specimen and determine the thickness after applying a contact load of 140 Pa to the specimen area (Note 2). Compress the specimen 50 % of this thickness at 0.83 ± 0.08 mm/s and observe the final load after 60 ± 3 s.

35. Report

35.1 Report the thickness after contact load, and the 50 % compression deflection value in pascals.

36. Precision and Bias

36.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST D—CONSTANT DEFLECTION COMPRESSION SET TEST

37. Summary of Test Method

37.1 This test method consists of deflecting the foam specimen under specified conditions of time and temperature and noting the effect on the thickness of the specimen.

38. Apparatus

38.1 *Compression Device*, consisting of two or more flat plates arranged so the plates are held parallel to each other by bolts or clamps and the space between the plates is adjustable to the required deflection thickness by means of spacers.

39. Test Specimens

39.1 The test specimens shall have parallel top and bottom surfaces and essentially perpendicular sides.

39.2 Specimens from uncored slab stock shall be 50 by 50 by 25 mm unless otherwise specified. Specimens less than 25 mm in thickness shall be plied up, without the use of cement, to a 25-mm thickness.

39.3 Specimens from cored slab stock shall be of such size that the coring does not appreciably affect the test result. They shall have a minimum top surface area of 100 cm^2. The thickness shall be no greater than 75 % of the minimum top dimension.

39.4 Specimens from uncored molded products 75 mm or less in thickness shall be 50 by 50 mm by full-part thickness and shall contain the top and bottom skin.

39.5 Specimens greater than 50 mm in thickness shall be cut to 50 mm thickness and the sample containing the top skin used for testing.

39.6 Specimens from cored molded products shall be of such size that the coring does not appreciably affect the test results. They shall have a minimum top surface area of at least 100 cm^2. The thickness shall be no greater than 75 mm and shall include the top molded surface. Specimens from molded products may be tested without skins by agreement between the customer and the supplier.

40. Number of Specimens

40.1 Three specimens per sample shall be tested. The value reported shall be the median of those observed. If any value deviates more than 20 % from this median, two additional specimens shall be tested and the median for all five values shall be reported.

41. Procedure

41.1 Perform the entire test procedure under the following conditions: Conduct all measurements, conditioning, and recovery of the specimen at 23 ± 2°C and in an atmosphere of 50 ± 2 % relative humidity. The oven conditions shall be 70 ± 2°C and 5± 1 % relative humidity.

NOTE 6—This condition of relative humidity may be achieved by placing an oven at 70 ± 2°C in an atmosphere maintained at 23 ± 2°C and 50 ± 2 % relative humidity.

41.2 Measure the test specimen in accordance with the procedure described in Section 8.

41.3 Place the test specimen in the apparatus and deflect it to either 50 ± 1, 75 ± 1, or 90 ± 1 % of its thickness, or any other deflection depending on the value agreed upon between the supplier and the purchaser.

41.4 Within 15 min, place the deflected specimen and the apparatus in the mechanically convected air oven for a period of 22 h; then remove the apparatus.

41.5 Remove the specimen immediately from the apparatus and measure it in accordance with the procedure described in Section 8 after 30 to 40 min recovery.

42. Calculation

42.1 Calculate two compression set values as follows:

42.1.1 Calculate the constant deflection compression set, expressed as a percentage of the original thickness, as follows:

$$C_t = [(t_o - t_f)/t_o] \times 100 \tag{2}$$

where:

C_t = compression set expressed as a percentage of the original thickness,
t_o = original thickness of test specimen, and
t_f = final thickness of test specimen 30 min + 10 or − 0 min after removal from the apparatus.

42.1.2 Calculate the constant deflection compression set, expressed as a percentage of the original deflection, as follows:

$$C_d = [(t_o - t_f)/(t_o - t_s)] \times 100 \tag{3}$$

where:

C_d = compression set expressed as a percent of the original deflection,
t_o = original thickness of test specimen,
t_s = thickness of spacer bar used, and
t_f = final thickness of test specimen 30 min +10 or −0 min after removal from the apparatus.

NOTE 7—Approximate conversion of C_d to C_t can be calculated by multiplying the 50 % C_t by 2, the 75 % C_t by 1.33, and the 90 % C_t by 1.11.

43. Report

43.1 Report compression set as C_t or C_d, and deflection used.

44. Precision and Bias

44.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST E—TENSION TEST

45. Scope

45.1 This test method determines the effect of the application of a tensile force to foam. Measurements are made for tensile stress, tensile strength, and ultimate elongation.

46. Apparatus

46.1 *Dies*—The specimen for tension tests shall be stamped out with a die of the shape and dimensions shown in Fig. 1, or

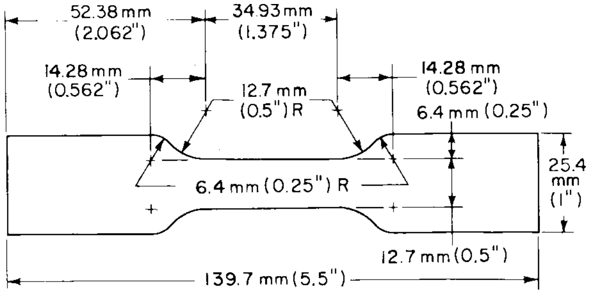

FIG. 1 Die for Stamping Tension Specimens

Die A of Test Methods D 412. The die shall be sharp and free of nicks in order to prevent leaving ragged edges on the specimen.

46.2 *Bench Marker*—The marker shall have two parallel marking edges 1.6 mm in thickness and spaced 20 or 25 mm apart on centers.

46.3 *Measurements*—The dimensions of the test specimen shall be determined with a suitable gage in accordance with Section 8.

46.4 Machine—Tension tests shall be made on a power-driven machine complying with the following requirements:

46.4.1 The machine shall be of such capacity as to allow the specimen to break at practically three fourths of machine full-scale force. It shall be equipped with a dial or scale indicator that will remain at the point of maximum load after rupture of the specimen and will measure the applied tension at that point. Rate of travel of a power-actuated grip shall be 8.3 ± 0.8 mm/s and shall be uniform at all times.

46.4.2 The machine may be equipped with a device graduated to 2.5 mm for measuring the elongation. For testing dumbbell specimens, the machine shall have either screw-type flat plate grips or a type of grip that tightens automatically and exerts a uniform pressure across the gripping surfaces, increasing as the tension increases to prevent slipping.

47. Test Specimens

47.1 The test specimens shall be cut from flat sheet material 12.5 ± 1.5 mm thick. The top and bottom surfaces shall be parallel and free of skin. The cut edges shall be perpendicular to the top surface and be free of ragged edges. The specimens shall be die cut either parallel to or across the direction of rise of the foam and shall be so specified. The length of the tabs may be adjusted to fit machine conditions provided that all other requirements remain constant.

48. Number of Specimens

48.1 Three specimens per sample shall be tested. The value reported shall be the median of those observed. If any value deviates more than 20 % from this median, two additional specimens shall be tested, and the median for all five values shall be reported.

49. Procedure

49.1 Set the grip separation at 65.3 mm minimum. Place the dumbbell tabs in the grips of the testing machine, using care to adjust them symmetrically, in order that the tension will be distributed uniformly over the cross section. Start the machine and note continuously the distance between the two bench marks. Record the stress at the corresponding elongation or if an automatic recording device is used, it will record the data continuously. At rupture, measure or record elongation to the nearest 10 %.

50. Calculation

50.1 Calculate the tensile strength by dividing the breaking force by the original cross-sectional area of the specimen.

50.2 Calculate the stress by dividing the force at a predetermined elongation by the original cross-sectional area of the specimen.

50.3 Calculate the ultimate elongation, *A*, by subtracting the original distance between the bench marks from the total distance between the bench marks at the time of rupture and expressing the difference as a percentage of the original distance, as follows, or use the grip separations in a similar calculation.

$$A, \% = [(d_f - d_o)/d_o] \times 100 \tag{4}$$

where:

d_o = original distance between bench marks, and

d_f = distance between bench marks at the break point.

50.4 The value reported shall be the median value of all specimens tested.

51. Report

51.1 Report the following information:

51.1.1 Tensile strength in kilopascals,

51.1.2 Stress in kilopascals at a predetermined elongation, and

51.1.3 Ultimate elongation, in percent, and whether the distance between bench marks or grip separations were used in the calculations.

52. Precision and Bias

52.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST F—TEAR RESISTANCE TEST

53. Scope

53.1 This test method covers determination of the tear resistance of foam. The block method, as described, measures the tear resistance under the conditions of this particular test.

54. Apparatus

54.1 Tear resistance shall be measured on a power-driven apparatus which will indicate the final load at which rupture of the specimen takes place. An automatic machine may be used which draws the actual curve, or, a style or scale shall be used having an indicator that remains at the point of maximum force after rupture.

55. Test Specimens

55.1 The test specimens shall be a block shape free of skin, voids, and densification lines, as shown in Fig. 2. They may be cut on a saw or die cut from sheet material so that the sides are parallel and perpendicular to each other. A40-mm cut shall be

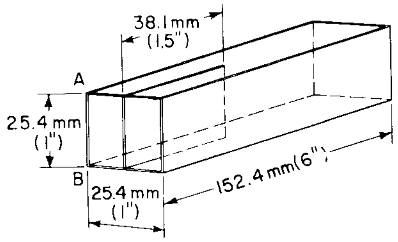

FIG. 2 Tear Resistance Test Specimens

placed in one side as shown in Fig. 2. Dimension *A-B* can be reduced to the pad thickness. The thickness shall be determined in accordance with Section 8.

56. Number of Specimens

56.1 Three specimens per sample shall be tested. The values reported shall be the median of those tested. If any value deviates more than 20 % from this median, two additional specimens shall be tested and the median for all five values shall be reported.

57. Procedure

57.1 Clamp the test specimen in the jaws of the testing machine, taking care that the jaws grip the specimen properly. Spread the block so that each tab is held in the jaw to pull across the specimen. Apply the force with a jaw speed of 0.75 to 9 mm/s. Aid the cut in the specimen with a razor blade or knife, so as to keep it in the center of the block. After the rupture of the specimen, or after at least a 50-mm length is torn, record in newtons the maximum on the dial or scale, and note also the thickness of the specimen (direction *A-B*).

58. Calculation

58.1 Calculate the tear strength from the maximum force registered on the testing machine and the average thickness of the specimen (direction *A-B*), as follows:

$$\text{Tear strength, N/m} = F/T \tag{5}$$

where:

F = force, N, and
T = thickness, m.

59. Report

59.1 Report the following information:

59.1.1 Tear strength in newtons per metre,
59.1.2 Orientation of specimen, and
59.1.3 Crosshead speed.

60. Precision and Bias

60.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST G—AIR FLOW TEST

61. Scope

61.1 The air flow test measures the ease with which air passes through a cellular structure. Air flow values may be used as an indirect measurement of certain cell structure characteristics. The test consists of placing a flexible foam core specimen in a cavity over a chamber and creating a specified constant air-pressure differential. The rate of flow of air required to maintain this pressure differential is the air flow value.

NOTE 8—A surface porosity test will be developed when required for a molded skin surface. This test is normally for slab products.

62. Terminology

62.1 *Definitions of Terms Specific to This Standard:*

62.1.1 *air flow value*—the volume of air per second at standard temperature and pressure required to maintain a constant pressure differential of 125 Pa across a flexible foam specimen approximately 50 by 50 by 25 mm.

62.1.2 *air flow parallel to foam rise*—the air flow value obtained when the air enters and leaves the mounted specimen parallel to foam rise.

62.1.3 *air flow perpendicular to foam rise*—the air flow value obtained when the air enters and leaves the specimen perpendicular to foam rise.

63. Apparatus

63.1 A schematic drawing of the apparatus including the specimen mounting chamber, manometer, air flowmeters, blowmeters, blower, and voltage control is shown in Fig. 3.[4]

63.2 *Chamber*, consisting of a pot approximately 130 mm in diameter and 150 mm high with provision for mounting the foam specimen and fittings for the manometer and air exhaust. The specimen mount cavity shall be either 50.0 ± 0.05 by 50.0 ± 0.05 by 25.0 ± 0.05 mm in size. Four foam support vanes approximately 1 mm thick and 12.5 mm high shall be placed under the opening to prevent the foam from being pulled into the vacuum chamber. The vanes shall be spaced 12.5 mm on center from each other and also centered relative to the bottom of the cavity opening. The manometer fitting shall enter a 1-mm hole midway along the side of the chamber. A 25-mm pipe fitting shall be used as the exhaust outlet from the center of the bottom of the chamber.

63.3 *Manometer*, calibrated from 0 to 250 Pa and having an accuracy of ±2 %, is required. An inclined oil manometer with graduations of 2 Pa is recommended. A level mounted on the manometer shall be used to ensure that the proper degree of inclination from the horizontal is maintained. Traps shall be provided to prevent indicating fluid from being accidentally drawn into the chamber. Appendix X5. describes a suggested method for the verification of the inclined oil manometer, the manometer can alternatively be replaced with a O-250 Pa magnehelic gage with graduations in 5 Pa.

63.4 *Flowmeters and Blower*—Low-pressure-drop air flowmeters accurate to ±2 % shall be used for air-flow measurements. A given flowmeter should not be used for values less than 10 % of full scale. Air flowmeters with at least 250-mm scales are recommended. Since the flowmeter calibration is temperature-and pressure-dependent, the use of the apparatus under ambient conditions can result in erroneous readings. In cases of dispute, the apparatus should be used under standard

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[4] An electronic instrument that has proven to be effective for measuring air flow is available from Fluid Data, 2512 N. Velasco, Angleton, TX 77515.

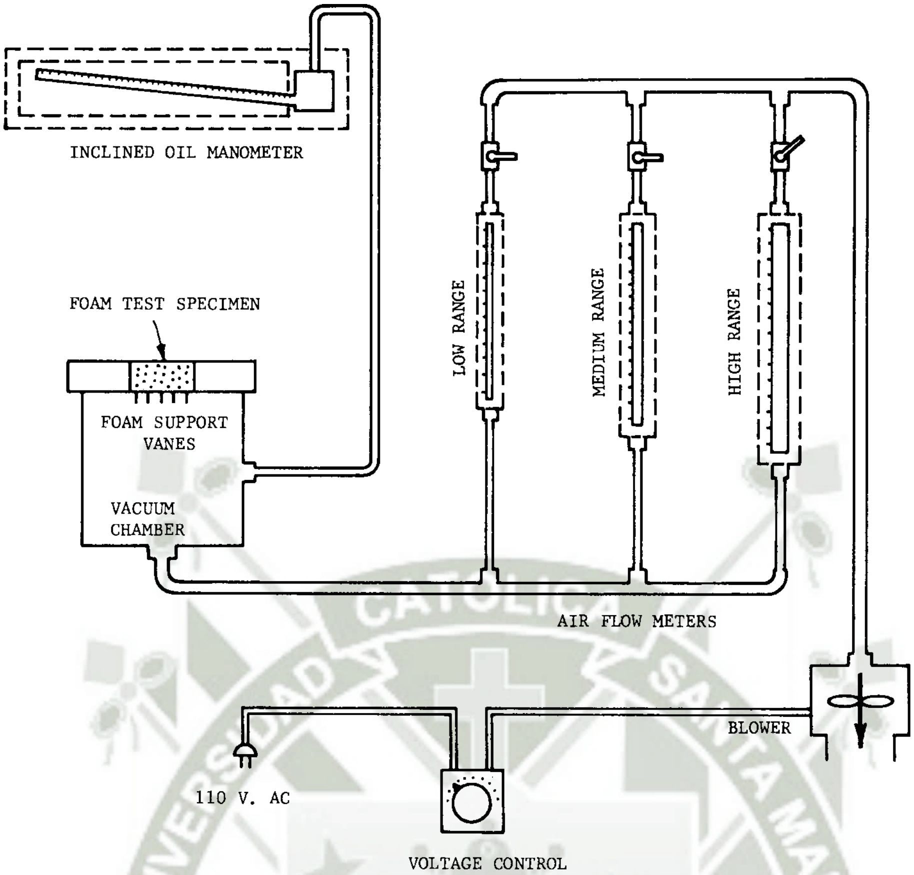

FIG. 3 Air Flow Apparatus Schematic Diagram

conditions of 23°C and 100 kPa (1 atm pressure) or else a suitable calibration correction applied. Flowmeters that range from 0 to 0.01 m^3 /s will cover a wide range of foam cell structures but a lesser range may be used. Actual flow is adjusted by a combination of valve restriction and blower speed. The two-way valves shall be mounted on the output side of the flowmeter to maintain the pressure drop across the flowmeter constant at any given flow level. A vacuum cleaner type unit shall be used for an exhaust blower.

63.5 *Leak Test*—To check the apparatus for leaks, the specimen mount cavity shall be sealed with masking tape. With all valves closed, turn on the exhaust blower to approximately ⅓ power and observe any movement of the manometer. The manometer reading, if any, should not exceed 1 Pa after a 30-s waiting period. Next, open the valve very slightly for the lowest range flowmeter reading. The flow should be essentially zero as evidenced by less than 3-mm movement of the air flowmeter float from its static position. For the equipment to perform satisfactorily over its entire range the requirements for both parts of the leak test must be met.

64. Test Specimens

64.1 The test specimens shall be parallel-piped cut to fit the mount cavity of the apparatus. A cavity 50 by 50 mm requires a specimen 51.0 ± 0.3 by 51.0 ± 0.3 by 25.0 ± 0.5 mm in size. A band saw with a movable table and a double-bevel knife-edge blade is recommended for cutting the specimens.

64.2 Three specimens per sample for each location and orientation to be tested shall be cut. The values reported shall be the mean of those observed for each location and orientation.

65. Procedure

65.1 Measure each specimen in accordance with the procedure described in Section 8 to verify the specimen size.

65.2 Impress the specimen into the test cavity. Make sure that a good air seal is obtained along all edges. The top of the specimen should be flush with the top of the test chamber.

65.3 With all valves closed, adjust the voltage control of the apparatus to 30 %.

65.4 Open one flow-control valve slowly until a pressure differential to 100 to 150 Pa is obtained. Adjust the voltage control carefully to obtain a pressure differential of 125 ± 1 Pa.

65.5 After this pressure differential has been maintained for at least 10 s, read the scale of the flowmeter.

65.6 If this reading is off-scale or less than 10 % of full scale, close that flow-control valve and open a more appropriate one. Repeat this process until the proper manometer reading and air flow is achieved.

65.7 The air flow valve may be obtained from the flowmeter scale directly, estimated from a calibration chart, or calculated with a factor depending on the calibration system.

66. Report

66.1 Report the following information:

66.1.1 Location and orientation of each specimen with respect to foam rise in the section of foam that was sampled,

66.1.2 Mean air flow value in cubic decimetres per second for each location and orientation,

66.1.3 Dimensions of the specimen, and

66.1.4 Dimension of the mount cavity of the apparatus.

67. Precision and Bias

67.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST H—RESILIENCE (BALL REBOUND) TEST

68. Scope

68.1 This test consists of dropping a steel ball on a foam specimen and noting the height of rebound.

69. Apparatus

69.1 The ball rebound tester shall consist of a 38-mm inside diameter vertical clear plastic tube, such as acrylic, into which a 16-mm diameter (16.3-g) steel ball is released by a magnet or other device. The steel ball must be released so that it falls without rotation. Centering of the ball is assured by a recess at the base of the magnet. The height of drop shall be 500 mm. Since it is most convenient to note the position of the top of the ball on rebound, the top of the ball shall be 516 mm above the surface of the foam. Thus, “zero” rebound shall be 16 mm (diameter of ball) above the specimen surface. The scale on the back of the tube shall be calibrated directly in percent as follows. Every 5 % a complete circle shall be scribed and every 1 % a 120° arc shall be scribed. The complete circles are an essential part of the apparatus, since they are used to eliminate parallax error.

70. Test Specimens

70.1 The test specimens shall have parallel top and bottom surfaces.

70.2 The test specimens shall consist of the entire product sample or a suitable portion of it, except that in no case shall the thickness be less than 50 mm, or the area less than 100 by 100 mm. Specimens less than 50 mm thick should be plied up, without the use of cement, to a minimum of 50 mm. For molded products the top skin should be removed.

71. Number of Specimens

71.1 Three specimens per sample shall be tested. The three specimens may be obtained by using separate items or different locations on a given item.

72. Procedure

72.1 Center the specimen at the base of the tube and adjust the height of the tube so that zero rebound is 16 mm above the surface of the foam specimen.

72.2 Mount the steel ball on the release mechanism; then drop it and note the maximum rebound height. If the ball strikes the tube on the drop or rebound, the value obtained is invalid. This condition is usually due to the tube not being vertical or irregularities on the specimen surface. In order to minimize parallax error, the circles on the tube in the region where the percent rebound is read must appear as lines.

72.3 Make an additional two drops on the same specimen.

73. Calculation

73.1 Calculate the median of the three rebound values. If any value deviates more than 20 % from this median, make two additional drops and calculate the median for all five drops.

74. Report

74.1 Report the median of the three specimen medians as the ball rebound resilience value of the sample in percent.

75. Precision and Bias

75.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST I—FATIGUE TESTS

76. Scope

76.1 The fatigue tests consist of four methods:

76.1.1 Static Force Loss Test at Constant Deflection,

76.1.2 Dynamic Fatigue by the Roller Shear at Constant Force,

76.1.3 Dynamic Fatigue Test by Constant Force Pounding, and

76.1.4 Dynamic Fatigue Test for Carpet Cushion.

TEST I_1 —STATIC FORCE LOSS TEST AT CONSTANT DEFLECTION

77. Scope

77.1 The purpose of this static force loss test is to determine: (*1*) a loss of force support, (*2*) a loss of thickness, and (*3*) structural breakdown by visual examination.

77.2 This procedure tests the specimen statistically at a 75 % constant deflection.

78. Apparatus

78.1 The apparatus shall consist of two parallel plates (wood or metal) which can produce a uniform, constant deflection of the specimen. The plates shall be 500 by 500 mm square, and spacer bars shall be available to produce 75 % deflection.

79. Test Specimen

79.1 The test specimen shall be 380 by 380 mm by the desired thickness. One specimen shall be tested.

80. Initial Measurements

80.1 Measure the 25 and 65 % IFD of the test specimen in accordance with Sections 16 to 22 except preflex six times instead of twice and allow to rest 5 min ± 15 s rather than 6 ± 1 min. Measure the original thickness with 4.5-N contact force after preflexing.

81. Procedure

81.1 Place the specimen between the plates with the spacer bars to provide a 75 % deflection. Clamp the plates and hold at 75 % deflection for 22 h at 23 ± 2°C and 50 ± 2 % relative humidity.

82. Final Measurements

82.1 For the final force reading 30 min after the fatigue test is completed, repeat 80.1 using six preflexes and the original thickness to determine the deflection for the final force reading.

82.2 If the loss in thickness is above 10 %, the force loss would be indeterminate and only the thickness loss should be reported.

82.3 For a measurement of more permanent fatigue, repeat 82.1, except allow 24 h of recovery time rather than 30 min.

83. Calculation

83.1 Check the specimen for physical breakdown of the cellular structure by visual examination and comparison with unflexed specimens.

83.2 Calculate the percentage loss of thickness as follows:

$$F_t = \frac{t_o - t_f}{t_o} \times 100 \tag{6}$$

where:

F_t = loss in thickness, %,
t_o = original specimen thickness, and
t_f = final specimen thickness.

83.3 Calculate the percentage loss of force deflection, as follows:

$$F_L = \frac{L_o - L_f}{L_o} \times 100 \tag{7}$$

where:

F_L = loss of indentation force deflection, %,
L_o = original indentation force deflection value, and
L_f = final indentation force deflection value.

84. Report

84.1 Report the following information:

84.1.1 Percentage loss of thickness and the percentage loss of 25 and 65 % IFD if the thickness loss is less than 10 %, and

84.1.2 Results of visual examination.

84.1.3 Recovery time whether 30 min. or 24 h.

85. Precision and Bias

85.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST I_2 —DYNAMIC FATIGUE TEST BY THE ROLLER SHEAR AT CONSTANT FORCE

86. Scope

86.1 This procedure fatigues the specimen dynamically at a constant force, deflecting the material both vertically and laterally.

86.2 The fatigue test may be conducted by either Procedure A or Procedure B. Both test procedures are the same and differ only in the number of cycles used. Procedure A shall use 8000 cycles (approximately 5 h) and Procedure B shall use 20 000 cycles (approximately 12 h).

NOTE 9—The mass of the roller and the number of cycles may be changed as agreed upon between the supplier and the purchaser.

87. Apparatus (Appendix X2)

87.1 *Perforated-Base Platen*, approximately 500 by 500 by 10 mm with a finished ground-top surface and with perforation of approximately 6.5-mm centers covering the center 360 by 360-mm portion.

87.2 *Roller*, 450-mm minimum length and 76.0 ± 1.3 mm-diameter made from stainless steel or chrome-plated metal having a minimum surface finish of 1 µm. The roller shall be mounted in an offset position (15 ± 3°) with suitable means of adjustment for a specified loading of the test specimen. The force imparted by the roller assembly shall not exceed 110 N.

87.3 The test is conducted at a frequency of 0.45 ± 0.5 Hz. A cycle is a complete forward and reverse stroke. The length of the stroke shall be 300 ± 10 mm.

87.4 Any suitable method for holding the test specimen securely on the roller base platen is acceptable as long as the test specimen remains stationary during the rolling flex cycles. An acceptable method for retaining the specimen on the base platen is described as follows: Four pieces of cotton sheeting or paper masking tape 50 to 75 mm wide at least 50 mm longer than each side of the test specimen shall be required. Bond the cotton strips (with a solvent or water-emulsion-type of adhesive) or the masking tape along the edges of the base surface of the test specimen. Allow 25 to 50 mm of each strip to extend beyond the edges of the test specimen so that the test specimen can be securely clamped to the base platen through the use of suitable metal retainer straps.

88. Test Specimen

88.1 A specimen 380 mm long by 300 mm wide by the desired thickness is used. The thickness of specimens tested should be at least 25 mm and no greater than 125 mm. Normally full-part thickness is used where the top and bottom surfaces are essentially parallel and fall within the thickness limits. Where part thickness exceeds 125 mm or the bottom surface is contoured so that the surfaces are not essentially parallel, the bottom surface shall be sliced to provide a flat surface essentially parallel to the top surfaces (see Section 7).

88.2 The length and width dimensions shall be held to ± 6.5 mm and shall be saw cut or die cut; if die cut, sufficient time must be allowed for complete edge recovery (usually 2 h minimum).

88.3 One specimen shall be tested.

89. Initial Measurements

89.1 Bond the masking tape or suitable hold-down cloth to the bottom edges of the specimen so the specimen can be secured to the perforated base platen of the fatigue tester.

89.2 Condition the specimen as in Section 6. The test should also be run under the same conditions.

89.3 Determine the IRDF in accordance with Sections 23-29 except preflex the test specimen six times.

90. Procedure

90.1 Adjust the roller to obtain a constant force of 130 ± 2 N on the foam specimen. This critical measurement may be made by fashioning a lightweight fabric sling around the roller at its center and measuring the force downward while holding the weighing scale vertically over the roller and maintaining the roller axis in a horizontal plane with the pivot axis.

NOTE 10—Forces greater than 130 N may be used as agreed upon between the supplier and the purchaser.

90.2 Set the vertical adjustment of the roller or the mounting base by placing the specimen in position and lowering the roller so it is supported by the specimen. Observe the pivot axis and roller axis relationship and adjust the vertical height so that the axes lie in an essentially horizontal plane at the start of the test.

90.3 Mount the test specimen on the base platen with the long dimension parallel to the stroke of the dynamic fatigue machine and secure by means of the tape and metal-retainer strips. When mounting cored pieces, coring is to be against the platen. Set the counter to zero, start the machine, and fatigue test the sample for either 8000 cycles (Procedure A) or 20 000 cycles (Procedure B).

91. Final Measurements

91.1 Within 60 ± 5 min after the fatigue test is completed, measure the final thickness in accordance with Sections 23-29, preflexing the specimen six times.

91.2 For a measurement of more permanent fatigue repeat 91.1, except allow 24 h of recovery rather than 60 min.

92. Calculation and Inspection

92.1 Check the specimen for physical breakdown of cellular structure by visual examination and comparison with unflexed similar specimens.

92.2 Calculate and report the percent loss in thickness as follows:

$$\text{Thickness loss, \%} = \frac{100(A - B)}{A} \quad (8)$$

where:

A = original thickness under compression forces of 4.5 N, 110 N, and 220 N, and

B = final thickness under the same compression forces.

92.3 Calculate the total loss number as follows:

$$\text{Total loss number} = \text{sum of \% losses at each load} \quad (9)$$

Sample Calculation:
Percent thickness loss at 4.5 N = 2.0
Percent thickness loss at 110 N = 18.0
Percent thickness loss at 220 N = 27.0
Total loss number 47.0

93. Report

93.1 Report the following information:

93.1.1 Percentage loss of thickness and the percentage loss of compressed thickness under the force if the thickness loss is less than 10 %,

93.1.2 Method used for load deflection,

93.1.3 Total loss number, and

93.1.4 Results of visual examination.

93.1.5 Recovery time whether 60 min. or 24 h.

94. Precision and Bias

94.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST I_3 —DYNAMIC FATIGUE TEST BY CONSTANT FORCE POUNDING

95. Scope

95.1 The purpose of the fatigue test is to determine: (*1*) the loss of force support at 40 % IFD (indentation force deflection), (*2*) a loss in thickness, and (*3*) structural breakdown as assessed by visual inspection.

NOTE 11—Deflection other than 40 % may be used as agreed upon between supplier and purchaser.

95.2 This procedure describes tests that evaluate the specimen by repeatedly deflecting the material by a flat-horizontal indention exerting a vertical force of 750 ± 20 N on the test specimen.

95.3 This fatigue test may be conducted by either Procedure A or Procedure B. The test procedures differ only in the number of cycles used. Procedure A shall use 8000 cycles (approximately 2 h) and Procedure B shall use 80 000 cycles (approximately 19 h).

96. Apparatus

96.1 *Perforated Base Platen*, approximately 500 by 300 by 10 mm, with finished ground-top surface and with perforation of approximately 6.5-mm diameter holes on 20-mm centers, over a minimum central area of 350 by 350 mm.

96.2 A flat circular indentor that exerts a force of 750 ± 20 N on the test specimen at maximum indentation. The indentor shall have an overall diameter of 250 ± 1 mm with a 25 ± 1-mm radius at the lower edge, to prevent cutting hard foam.

96.3 By means of a crank or other suitable mechanism, the machine shall be capable of oscillating either the platen carrying the test specimen or the indentor support mounting towards each other in a vertical direction at a frequency of 70 ± 5 cycles per minute.

96.4 The indentor shall be free to be lifted in its mounting to prevent overloading of the test specimen.[5]

97. Test Specimen

97.1 The test specimen shall be 380 by 380 by 50 mm. One specimen shall be tested.

98. Initial Measurement

98.1 The specimen shall be conditioned for at least 12 h and also fatigued at 23 ± 2°C and 50 ± 5 % relative humidity.

98.2 Measure the 40 % IFD of the test specimen in accordance with Sections 16-22 except preflex six times instead of twice. Measure the original thickness with 4.5-N contact force after preflexing. (See Note 10).

99. Procedure

99.1 Mount the specimen on the base platen. Set the counter to zero, start the machine, and fatigue the test specimen for either 8000 cycles (Procedure A) or 80 000 cycles (Procedure B).

100. Final Measurement

100.1 Within 60 ± 5 min after the fatigue test is completed, repeat 98.2 using six preflexes and the original thickness to determine the deflection for the final force reading.

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[5] Detailed drawings are available from ASTM Headquarters. Request Adjunct No. 12-435740-20.

100.2 For a measurement of more permanent fatigue repeat 100.1, except allow 24 h of recovery rather than 60 min.

100.3 If the loss in thickness is above 10 %, the force loss would be indeterminate and only the thickness loss should be reported.

101. Calculation

101.1 Check the specimen for physical breakdown of the cellular structure by visual examination and comparison with unflexed specimens.

101.2 Calculate the percent loss of thickness as follows:

$$F_t = \frac{t_o - t_f}{t_o} \times 100 \tag{10}$$

where:

F_t = loss in thickness, %,
t_o = original specimen thickness, and
t_f = final specimen thickness.

101.3 Calculate the percent loss of force deflection, as follows:

$$F_L = \frac{L_o - L_f}{L_o} \times 100 \tag{11}$$

where:

F_L = loss of 40 % indentation force deflection, %,
L_o = original 40 % indentation force deflection value, and
L_f = final indentation force deflection value.

102. Report

102.1 Report the following information:

102.1.1 Percent loss in thickness and the percent loss of 40 % IFD if the thickness loss is less than 10 %, and

102.1.2 Results of visual examination.

102.1.3 Recovery time whether 60 min. or 24 h.

103. Precision and Bias

103.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST I_4 —DYNAMIC FATIGUE TEST FOR CARPET CUSHION

104. Scope

104.1 The purpose of this test is to determine: (*1*) retention of force support at 65 % CFD (compression force deflection), (*2*) a loss in thickness, and (*3*) structural breakdown as addressed by visual inspection.

104.2 This procedure describes tests that evaluate the specimen by repeatedly deflecting the carpet cushion by a 152 mm diameter and 152 mm wide rubber covered roller exerting a force of 266 ± 5N on the test specimens.

104.3 This fatigue test may be conducted by either Procedure A or Procedure B. The test procedures differ only in the number of cycles used. Procedure A shall use 8000 cycles (approximately 5 h) and Procedure B shall use 20 000 cycles (approximately 12 h).

NOTE 12—CFD at other than 65 % deflection may be used upon agreement between customer and supplier.

105. Apparatus (Appendix X2)

105.1 The apparatus is identical to that described in Section 87 with the following changes. The roller described in 104.2 replaces the longer roller and is attached perpendicularly. The base platen is replaced or covered with a 19 mm thick plywood for mounting the sample. The sample is secured with floor tacks or staples. The carpet is likewise attached with floor tacks or staples. (See Fig. 4 for test apparatus.)

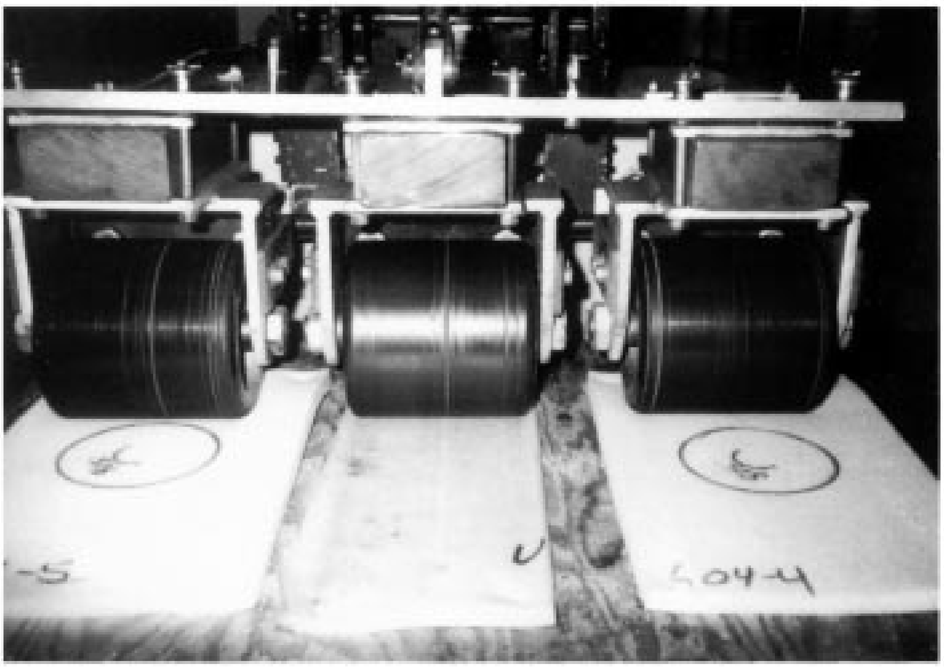

FIG. 4 Three-station Carpet Cushion Fatigue Tester

106. Test Specimens

106.1 The specimen is 380 mm long and 230 mm wide, die cut with two 100 mm diameter discs on the center line about 20 to 30 mm apart. Secure the sample to the plywood base.

107. Initial Measurements

107.1 Condition the specimens as in Section 6. The test should be run under the same conditions, if possible. Preflex the specimens 6 times 75 % of the nominal thickness. After a 6 ± 1 min rest, measure the original thickness, t_o, according to Section 8 and determine the original 65 % CFD, L_o, according to Sections 30-36.

108. Procedure

108.1 Place the disc specimens in the sample with the slip coat up and cover with carpet, securing the free end of the carpet to the plywood base. The type of carpet used shall be agreed upon by the purchaser and supplier. Lab studies have determined that the carpet can be used up to 5 tests (100 000 cycles) and be replaced without affecting the foam fatigue.

108.2 If needed, adjust the vertical height of the roller or base so that the axis lies in an essentially horizontal plane at the start of the test.

108.3 Set the counter to zero, start the machine, and fatigue the sample for either 8000 cycles (Procedure A) or 20 000 cycles (Procedure B).

109. Final Measurements

109.1 Within 60 ± 5 min after the fatigue test is completed measure the final thickness, t_f, according to Section 8 and the final 65 % CFD, L_f, according to Sections 30-36 except preflex 6 times and use the original thickness, t_o, to determine the deflection.

109.2 For a measurement of more permanent fatigue repeat 109.1, except allow 24 h of recovery rather than 60 min.

110. Calculation and Inspection

110.1 Check the specimen and the carpet backing for physical breakdown by visual examination.

110.2 Calculate and report the percentage loss in thickness as follows:

$$F_l = \frac{t_o - t_f}{t_o} \times 100 \qquad (12)$$

where:

F_l = loss in thickness, %,
t_o = original specimen thickness, and
t_f = final specimen thickness.

110.3 Calculate the percentage retain of force deflection as follows:

$$R = 100 - \frac{(L_o - L_f \times 100)}{(L_o)} \qquad (13)$$

where:

R = retain CFD, %,
L_o = original CFD force, and
L_f = final CFD force.

111. Report

111.1 Report the following information:

111.1.1 Percentage loss in thickness and percentage retain of 65 % compression force deflection,

111.1.2 Result of visual examination of both the carpet and carpet backing, and

111.1.3 Description of the carpet.

111.1.4 Recovery time whether 60 min. or 24 h.

112. Precision and Bias

112.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST J—STEAM AUTOCLAVE AGING

113. Summary of Test Method

113.1 This test consists of treating the foam specimen in a low-pressure steam autoclave and observing the effects on the properties of the foam specimen. Use either of the following procedures, J_1 or J_2 :

113.1.1 Procedure J_1, 3 h at 105 ± 3°C.

113.1.2 Procedure J_2, 5 h at 125 + 0, −5°C.

114. Apparatus

114.1 *Steam Autoclave*, or similar vessel, that is thermostatically controlled to ±2°C and capable of withstanding gage pressures of up to 140 kPa.

115. Procedure

115.1 Fill the autoclave with fresh-distilled water to a level 50 mm above the bottom of the autoclave. Set the thermostat control at the desired procedures of test, which is between 105 ± 3°C and 125 + 0, −5°C. Allow the autoclave to heat until the water boils. Place the specimen on edge on a rack in the inside container so that one specimen does not touch another or any metal except at the supporting surface. Place the container inside the autoclave and close and tighten the top. Leave the safety valve open until all the air is out of the autoclave. This is apparent when steam begins blowing out of the ports on the safety valve. Close the valve 2 min after the appearance of steam, and take the zero time of the heat at this point.

115.2 After the exposed period, turn off the heat, release the steam pressure, and remove the specimens without delay. Dry the specimens for 3 h for each 25 mm of thickness at 100 ± 5°C in a mechanically convected dry-air oven. Allow them to come to temperature equilibrium, after removal from the oven, for at least 2 and no more than 24 h at 23 ± 2°C and 50 ± 5 % relative humidity.

115.3 Test each specimen for the prescribed property in accordance with the appropriate sections.

NOTE 13—A drying temperature of 70°C may be used where 100°C adversely affects the final properties upon agreement by customer and supplier.

116. Calculation

116.1 Calculate the present change in physical property as follows:

$$\text{Physical property change, \%} = \frac{(P_o - P_f)}{P_o} \times 100 \qquad (14)$$

where:
P_o = mean property of the unexposed specimen, and
P_f = mean property of the exposed specimen.

117. Report

117.1 Report the following information:

117.1.1 Percent change in physical property,

117.1.2 Original and steam aged results for other properties, and

117.1.3 Test procedure J_1 or J_2.

118. Precision and Bias

118.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

TEST K—DRY HEAT AGING

119. Summary of Test Method

119.1 This test consists of exposing foam specimens in an air-circulating oven and observing the effect on the properties of the foam.

120. Apparatus

120.1 *Air-Circulating Oven*, capable of maintaining 140 ± 1.2°C for exposing the specimens. A device for sensing and recording the temperature of the oven at least every 2 h shall be attached.

121. Procedure

121.1 Expose the specimens for 22 h. Obtain and record the oven temperature near the specimen at least every 2 h.

121.2 Remove the specimens from the oven and condition for not less than 12 h at 23 ± 2°C and 50 ± 5 % relative humidity.

122. Calculation

122.1 Calculate the percent change in physical property as follows:

$$\text{Physical property change, } \% = \frac{(P_o - P_f)}{P_o} \times 100 \qquad (15)$$

where:
P_o = mean property of the unexpected specimen, and
P_f = mean property of the exposed specimen.

123. Report

123.1 Report the following information:

123.1.1 Percent change in physical property, and

123.1.2 Original and heat aged results for other properties.

124. Precision and Bias

124.1 Precision statements are in the process of being prepared in the form specified by Practice D 4483 – 85.

125. Keywords

125.1 bonded; flexible cellular; molded; slab; urethane

APPENDIXES

(Nonmandatory Information)

X1. SUGGESTED METHOD FOR SPECIFYING FLEXIBLE URETHANE FOAMS

X1.1 The suggested practice for specifying flexible urethane foam is:

USU—Urethane Slab Uncored
USC—Urethane Slab Cored
UMU—Urethane Molded Uncored
UMC—Urethane Molded Cored

Digits following the number specify the firmness grade and the letters following that specify type of load deflection test.

X1.2 Suffix letters may be added singly or in combination after the above to indicate additional requirements. The values for these suffix tests are to be arranged between the supplier and the purchaser.

X1.3 *Example*: USU 30 IFD F E H

The foam is a urethane slab uncored with a 30-lb Indentation Force Deflection value at 25 % deflection. Minimum value tear (F), tension (E), and resilience values (H) have been agreed upon.

X2. SUGGESTED METHOD OF CONSTRUCTION FOR A ROLLER SHEAR DYNAMIC FLEX FATIGUE APPARATUS

X2.1 The following requirements are established to define the equipment and relationship of parts for a constant-load roller shear machine. See Fig. X2.1 and Fig. X2.2 for reference to part numbers.

X2.2 *Roller*, 1:

X2.2.1 *Dimensions*—457-mm minimum length, and 76.20 ± 1.27-mm diameter.

X2.2.2 *Material*—Corrosion and wear-resistant metal, either (*1*) chrome-plated material, or (*2*) stainless steel.

X2.2.3 *Surface Finish*—Finish surface on roller is to be ground and equivalent to at least 0.001 mm.

X2.2.4 The mass of the roller shall not exceed 11.340 kg.

X2.3 *Roller Mounting Bracket Assembly* 2, 3, 4, 11—The assembly consists of metal members designed to attach the roller to a pivot point, to provide bearing surfaces for minimum

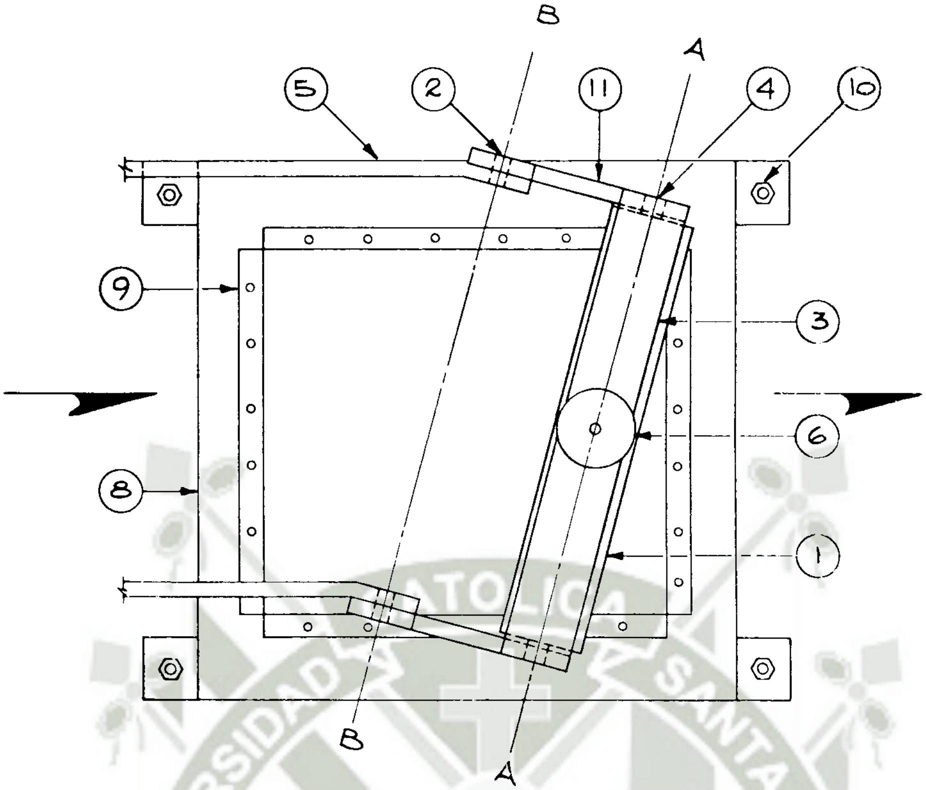

FIG. X2.1 Roller Shear Machine—Top View

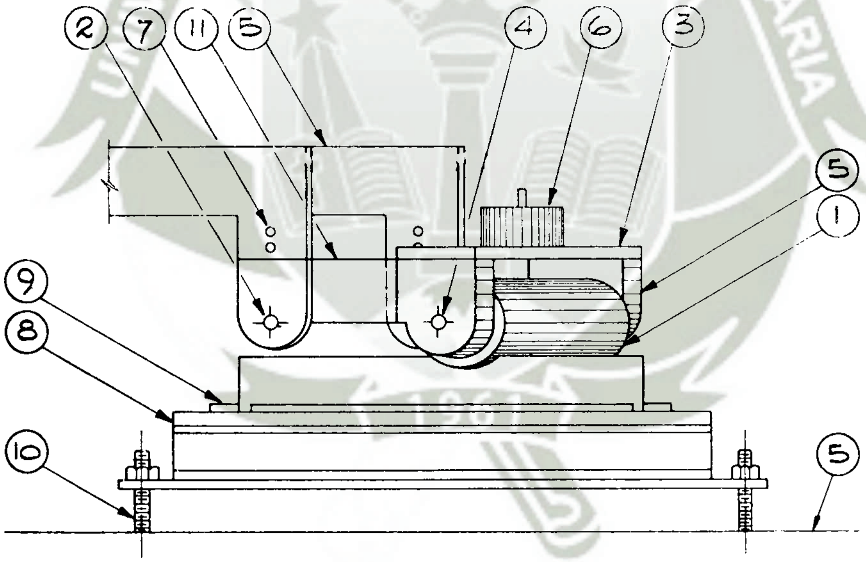

FIG. X2.2 Roller Shear Machine—Side View

friction for turning, and to serve as a platform to add required mass to the roller.

X2.3.1 *Bearings*, 2 and 4—The proper bearings are required on each end or roller axis (*A*-*A*) and also on the pivot axis (*B*-*B*). The bearing should be equivalent to the following example:

Bearing No. 4—Nice No. 1635, DC Ball Bearing 19 by 32 by 13 mm.

Bearing No. 2—Nice No. 6906, flange mounted radial bearing.

NOTE X2.1—Roller axis bearings may be mounted in the bracket with the axle attached to the roller or, if the roller is a hollow cylinder, the bearing may be press fit into the cylinder end with the bracket furnishing the axle.

X2.3.2 *Pivot Arm*, 11—The distance between the pivot axis and the roller axis shall be 203.20 ± 6.35 mm.

X2.3.3 *Roller Bracket Connector*, 3, connects the right and left bearing brackets across the top of the roller. The connection must also provide a flat horizontal surface with means (pin) to attach the weights. The weights must be centered directly above the axis of the roller.

X2.3.4 *Axis Relationship*—The roller axis (*A-A*) and pivot axis (*B-B*) must be parallel and lie in the same horizontal plane parallel to the specimen mounting base.

X2.3.5 *Alignment and Clearance*—Brackets and axles must be aligned so that no binding occurs to obstruct free turning on either axis. Brackets and other support members (5) must give free clearance so that specimen is not touched during test other than by roller surface.

X2.3.6 *Weight*, 6—The total vertical force exerted by the assembly plus the roller should not exceed 111 N as measured at a point directly above or below the roller axis when both roller and pivot axes are in the same horizontal plane (X2.3.4). Additional weights to be added as shown.

X2.3.7 *Vertical Adjustment*, 7—If the roller is not driven to provide stroke movement, provision should be made so that attachment of the pivot axis to the support can be raised or lowered at least 75 mm (3 in.). This adjustment must be able to be made in not less than 12.5-mm increments.

X2.4 *Specimen Mounting Base*, 8:

X2.4.1 *Dimensions*—500-mm minimum length. 500-mm minimum width, and 9.5-mm minimum thickness.

X2.4.2 *Material*—Structural-grade carbon steel.

X2.4.3 *Perforation*—6-mm diameter holes on 20-mm centers, over a minimum area covering 350 mm in length by 350 mm in width.

X2.4.4 *Surface Finish*—Top surface shall be a finish grind.

X2.4.5 *Hold-Down Plates*, 9—Provision to attach metal or wood hold-down plates for clamping cotton sheeting retaining strips to base. Four plates are required to cover perimeter of specimen size.

X2.4.6 *Vertical Adjustment and Level*, 10—If mounting base is not driven to provide stroke movement, provision should be made for vertical adjustment of at least 75 mm. This adjustment must be able to provide vertical movement in not less than 12.5-mm increments and maintain a horizontal level condition of the mounting base.

X2.5 *Mechanical Requirements*:

X2.5.1 *Stroke Length*—The length of stroke shall be 330 ± 12 mm.

X2.5.2 *Stroke Speed, Stroke Drive*—The rate of stroke speed should produce 0.47 ± 0.03 Hz. A cycle is a complete forward and reverse stroke. Either the roller or the mounting base may be driven to produce stroke travel. In either case, the drive mechanism must produce travel in a horizontal plane.

X2.5.3 *Angular Offset*—The axis of the roller should be level and mounted at a 15 ± 3° offset from perpendicular to the direction of the stroke.

X2.5.4 *Mounting Base Location*—The length of the mounting base should be parallel to the direction of the stroke and centered under the midpoint of the stroke and the center of the roller. The distance of the base surface from the roller axis (X2.3.4) should be 45 mm when vertical adjustment provides a minimum clearance.

X2.5.5 *Cycle Counter*—Means to record the number of cycles should be provided.

X3. DEFINITIONS OF TERMS USED TO DESCRIBE THE FORCE-DEFLECTION CURVE OF FLEXIBLE URETHANE FOAM

X3.1 *support factor*—the ratio of the 65 % indentation force deflection to the 25 % indentation force deflection determined after 1 min of rest. Most specifications are based on the 25 % IFD value of a 100-mm foam. The support factor thus indicates what 65 % IFD value would be acceptable for a particular application. The 65 % IFD measures the support region of the stress-strain curve. Seating foams with low support factors will usually bottom out and give inferior performance.

$$\text{Support factor (SF)} = (65\ \%\ \text{IFD}/25\ \%\ \text{IFD}) \tag{X3.1}$$

Synonyms—Sag factor, hardness ratio, comfort factor.

X3.2 *guide factor*—the ratio of the 25 % indentation force deflection to the density after a 1-min rest. Most specifications do not have a density requirement; therefore the product with the highest guide factor has the cost advantage but not necessarily the performance advantage.

$$\text{Guide factor (GF)} = (25\ \%\ \text{IFD/density}) \tag{X3.2}$$

X3.3 *initial hardness factor*—the ratio of the 25 % indentation force deflection force to the 5 % indentation force deflection determined without the 1-min rest. The initial hardness ratio defines the surface feel of a flexible urethane foam. Supple or soft surface foam will have a high value, while boardy or stiff surface foams will have a low value (Note X3.1).

$$\text{Initial hardness factor (IHF)} = (25\ \%\ \text{IFD}/5\ \%\ \text{IFD}) \tag{X3.3}$$

NOTE X3.1—Standard IFD curves can be used to generate the IHF, IM, and MIF data.

X3.4 *hardness index*—the term used in some specifications for the 50 % IFD value. The chair designer will often design furniture for a maximum 50 % indentation. Bar stools on the other hand may be designed for only a 20 % deflection.

X3.5 *indentation modulus*—the force required to produce an indentation of an additional 1 % between the limits of 20 % indentation force deflection and 40 % indentation force deflection determined without the 1-min rest. The slope of this line depends upon the resistance of the cells struts to post buckling (Note X3.1).

$$\text{Indentation modulus (IM)} = (40\ \%\ \text{IFD} - 20\ \%\ \text{IFD}/20\ \%\ \text{IFD}) \tag{X3.4}$$

X3.6 *modulus irregularity factor*—the intercept produced on the stress axis by extrapolation of the linear portion of the stress-strain curve. The indentation modulus, that is, the slope of the line, may be substantially constant up to and beyond the 40 % indentation level. In this event, the indentation stress-strain curve is linear and passes through the origin Fig. X3.1.

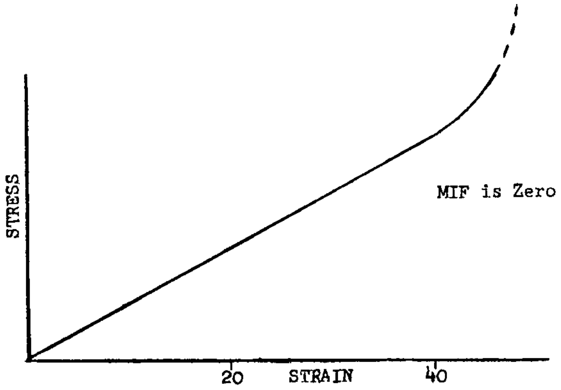

FIG. X3.1 Indentation Stress-Strain Curve (MIF is Zero)

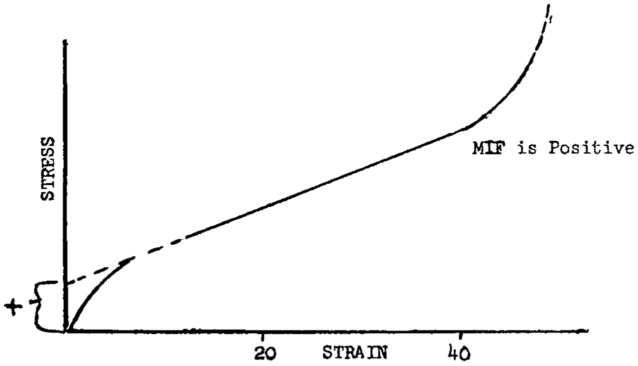

FIG. X3.2 Indentation Stress-Strain Curve (MIF is positive)

The indentation modulus usually varies at low levels of strain before reaching a constant value at above approximately 10 per strain. The stress-strain curve may exhibit a marked step in that region which may result in some discomfort in seating applications, Fig. X3.2 and Fig. X3.3. The MIF value is calculated from the same data necessary to derive the modulus of the foam as a seating material (Note X3.1).

$$\text{Modulus irregularity factor (MIF)} = 2 \times 20\,\%\ \text{IFD} - 40\,\%\ \text{IFD} \tag{X3.5}$$

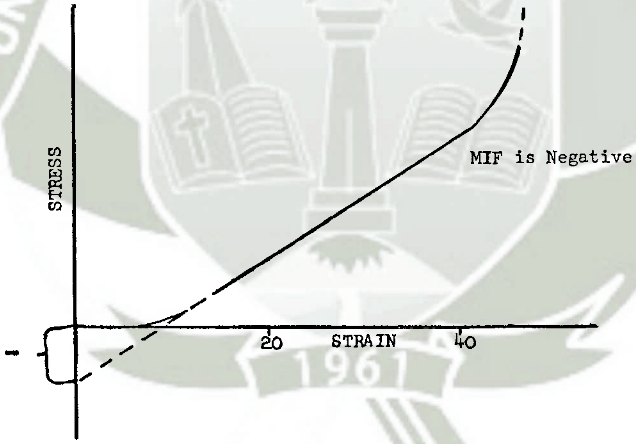

FIG. X3.3 Indentation Stress-Strain Curve (MIF is negative)

X4. SUGGESTED TESTS FOR DETERMINING COMBUSTIBILITY OF FLEXIBLE URETHANE FOAM

X4.1 This appendix lists for informational purposes only the test methods commonly used for determining the combustion properties of flexible urethane foams. These tests have been found useful in ascertaining the effectiveness of additives and reactants to modify the combustion characteristics of these materials. See 1.3.

X4.2 *Some Applicable Codes and Regulations for Specified Applications:*

Application	Regulation
Automotive	DOT MVSS 302
Mattress and cushion	DOC FF 4-72
Mattress and cushion	CAL TB 117
Mattress and cushion	CAL TB 133[A]
Mattress and cushion	NFPA 260[A]
Mattress and cushion	NFPA 261[A]
Mattress and cushion	BSI 5852[A]
Aviation	FAA Part 25.853 Par (b) App F
Aviation	FAA Oil Burner Test
Carpet cushion	ASTM E84
Carpet cusion	DOC FFI-70 (Pill Test)
Miscellaneous	ASTM D3675

[A] Composite test. Foam, fabric, and other components may have a synergistic effect on each other.

Various governmental bodies have issued regulations based on Test Method E 162. The regulations are not the same for all bodies issuing them. Hence, the regulation of the government having jurisdiction should be consulted.

X4.2.1 *Sources*:

Government Documents	Superintendent of Documents, US Government Printing Office, Washington, DC 20402
California	California Bureau of Home Furnishings, 3485 Orange Grove Ave., North Highlands, CA 95660
National Fire Protection Association	1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269
British Standard	British Standards Institute, 2 Park Street, London, England W1A 2B5

X5. SUGGESTED METHOD FOR THE VERIFICATION OF AN INCLINED OIL MANOMETER

X5.1 Adjust the feet to level the manometer. With a height gage resting on a level and flat surface measure the distance to the top of the glass tube at each major mark. Determine the area of the tube by direct measurement. The area of the reservoir is calculated by adding a measured amount of fluid with both ends of the manometer at atmospheric pressure. The calculation for the area of the reservoir (A):

$$A = (v - ay)/h \tag{X5.1}$$

where:
v = the volume added,
a = the area of the inside of the tube,
y = the distance between readings, and
h = the change in height.

X5.2 Change in pressure is calculated by:

$$Pm - Pn = wy\,(\sin\theta + a/A) \tag{X5.2}$$

where:
Pm = the low reading,
Pn = the high reading,
w = the specific gravity of the indicating fluid,
y = the distance between readings,
θ = the angle of the tube to normal,
a = the area of the inside of the tube, and
A = the area of the reservoir.

X5.3 The error is the difference between the calculated and the indicated value.

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Designation: F 1292 – 99

Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment[1]

INTRODUCTION

The need for a systematic means of evaluating surfacing materials for use on playgrounds has been amply demonstrated by the current difficulty in assessing the relative merits of such surfaces amid a diversity of testing methods, agencies, and terminology. Consequently, the goal of this specification is to establish a uniform means for measure to compare characteristics of the materials in order to provide the potential buyer with a useful yardstick by which to measure available materials as a surface under and around playground equipment.

1. Scope

1.1 This specification covers minimum impact attenuation requirements, when tested in accordance with Test Method F 355, for surface systems to be used under and around any piece of playground equipment from which a person may fall. This specification applies to all types of material that can be used under playground equipment.

1.2 This specification does not imply that an injury cannot be incurred if the surface system complies with this specification.

1.3 The values stated in inch-pound units are to be regarded as standard. The SI units given in parentheses are for information only.

1.4 The following precautionary statement pertains to the test method portions only, Sections 12 and 13, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[2]

F 355 Test Method for Shock-Absorbing Properties of Playing Surface Systems and Materials[3]

F 429 Test Method for Shock-Attenuation Characteristics of Protective Headgear for Football[3]

2.2 *SAE Standard:*

SAE J 211 Recommended Practice for Instrumentation for Impact Tests[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *acceleration*—the time rate of change of velocity.

3.1.2 *around playground equipment*—the area under and surrounding playground equipment established as protection from falls from equipment.

3.1.3 *deceleration*—the time rate of reduction of velocity.

3.1.4 *g*—acceleration into gravity at the earth's surface at sea level (32 ft/s (9.8 m/s)).

3.1.5 *g-max*—the multiple of g that represents a maximum deceleration experienced during an initial impact.

3.1.6 *headform*—the striking part of a testing apparatus.

3.1.7 *head injury criteria (HIC)*—a measure of impact severity that considers the duration over which the most critical section of the deceleration pulse persists as well as the peak level of that deceleration.

3.1.8 *impact attenuation*—the ability of a surface system to reduce and dissipate the energy of an impacting body.

3.1.9 *impact velocity*—the velocity of a falling body at the time of impact.

3.1.10 *loose fill system*—a surface system consisting of small independent, movable components; that is, sand, gravel, wood chips, and so forth.

3.1.11 *non-loose fill system*—a surface system consisting of one or more components bound together; that is, foam composites, urethane/rubber blocks, asphalt, and so forth.

3.1.12 *surface system*—all materials that contribute to the

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[1] This test method is under the jurisdiction of ASTM Committee F08 on Sports Equipment and Facilities and is the direct responsibility of Subcommittee F08.63 on Playground Surfacing Systems.

Current edition approved Aug. 10, 1999. Published August 1999. Originally published as F 1292 – 91. Last previous edition F 1292 – 96.

[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 15.07.

[4] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

impact absorbing unit.

3.1.13 theoretical drop height—equates the measured velocity of the headform at the moment of impact to a height that would generate the same velocity if the test were performed at sea level and there was no friction to retard the headform during a drop from that height.

3.2 For the definitions of other terms used in this specification, refer to Test Methods F 355 and F 429.

4. Performance Requirements

4.1 All surface systems must be tested in accordance with the performance requirements in 4.2. In addition, surfaces may also be tested in accordance with 4.3. Testing in accordance with the performance requirements in 4.3 is optional.

4.2 When tested in accordance with Test Method F 355 or the free fall test method in Annex A1, using an average of the last two of three drops, no value shall exceed 200 g-max or 1000 HIC for laboratory tests at temperatures of 30, 72, and 120°F (±1, 23, and 49°C), respectively.

4.3 When tested in the field at ambient temperature in accordance with Test Method F 355 or the free fall test method in Annex A1, using an average of the last two of three drops no value shall exceed 200 g-max or 1000 HIC at the height specified by the initial owner/operator prior to purchase of the surface.

4.4 When the surface system, while in use, is tested in accordance with Test Method F 355 or the free fall test method in Annex A1, using an average of the last two of three drops at each of three test sites, and exceeds 200 g-max or 1000 HIC at ambient temperature, as determined by Section 13, at the height specified by the initial owner/operator prior to the purchase of the surface, the surface system should be made to comply or the playground equipment on the surface should not be used until the surface complies.

5. Summary of Test Method

5.1 Representative playground surface systems or surfacing material samples, or both, are tested in accordance with Test Method F 355 or the free fall test method described in Annex A1. Conduct laboratory tests at various drop heights and test temperatures. Conduct the field tests at the drop height specified and at the ambient temperature of the site within a specified range. The laboratory test method will determine the maximum drop height at which the g-max does not exceed 200 or the HIC does not exceed 1000. The field test method will determine the g-max and the HIC from the drop height specified by the initial owner/operator at the ambient temperature of the test.

6. Significance and Use

6.1 Data obtained from this specification are indicative of the relative impact attenuation characteristics of the playground surface system and can be used only for comparisons and for establishing minimum requirements.

7. Operator Qualifications

7.1 If not an employee of an accredited or recognized laboratory, the operator shall be trained and certified by the equipment supplier, including written and performance testing, to establish competency in performing appropriate Specification F 1292 testing.

8. Test Apparatus

8.1 The signal from the acceleration transducer shall be conditioned with a low pass filter, complying to Channel Class 1000 of SAE J 211 (see Fig. 1).

8.2 The acceleration recording system must be capable of accurately resolving the deceleration to a minimum of 5 g from 0 to 500g.

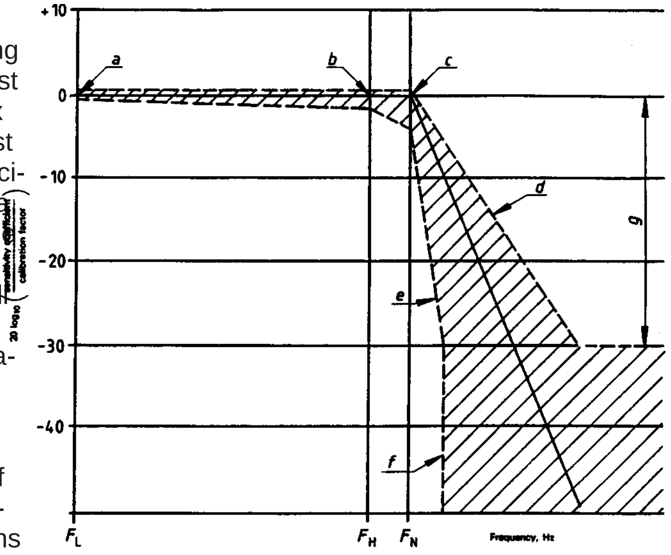
8.3 The acceleration transducer must be capable of withstanding impacts of at least 1000 g without damage.

8.4 Use the ANSI metal Headform C from Test Method F 355 or the hemispherical headform from the free fall test method in Annex A1.

8.4.1 The ANSI metal Headform C from Test Method F 355, Procedure C, must be connected to guides (such as monorail, dual rail, or guide wires) using a follower or other mechanism. Alternatively, the hemispherical headform from the free fall test method in Annex A1 may be used if connected to a system of guides. A uniaxial or triaxial accelerometer must be used. The guidance system must allow the headform to be leveled prior to and during the drop tests in the crown position. The vertical accelerometer must be aligned to within 5° of the vertical axis. The accelerometer must be attached at the center of mass of the headform.

8.4.2 The hemispherical headform from the free fall test method in Annex A1 must be used with a triaxial accelerometer. The vertical accelerometer must be aligned to within 5° of the vertical axis. The accelerometer must be attached at the center of mass of the headform.

8.5 The minimum system sampling rate required is 16 000 Hz or 16 000 samples/s.



CFC	F_L Hz	F_H Hz	F_N Hz
1 000	< 0,1	1 000	1 650
600	< 0,1	600	1 000
180	< 0,1	180	300
60	< 0,1	60	100

Logarithmic scale

a	± 0,5 dB
b	+ 0,5; − 1 dB
c	+ 0,5; − 4 dB
d	− 9 dB/octave
e	− 24 dB/octave
f	∞
g	− 30 dB

FIG. 1 Data Channel Dynamic Accuracy

8.6 The HIC shall be calculated based on the following mathematical expression:

$$HIC\ 5\ \left[-t_2\ 2\ t_1! \left(\frac{1}{-t_2\ 2\ t_1!} * _{t_1}^{t_2} a dt \right)^{2.5} \right]_{max},\ 1000 \qquad (1)$$

The specified algorithm and verification calculations for HIC are included as Appendix X2.[5]

9. Test Sample

9.1 Each sample of surfacing material shall represent the playground surface system as it is intended to be used in place, including seams, partitions, corners, and fasteners/anchors or other areas that may result in less than optimal impact characteristics.

9.2 In the case of non-loose fill playground surface systems, the minimum sample shall be 12 by 12 in. (300 by 300 mm).

9.3 In the case of loose fill playground surface systems, a box with a minimum inside dimension of 18 by 18 in. (450 by 450 mm) and side walls of sufficient height to hold the loose fill material at the thickness of intended use and to keep the loose fill materials in place should be constructed around the base of the test equipment. The loose fill materials shall be poured to an even depth and the surface leveled and left undisturbed for the entire test period.

10. Number of Specimens

10.1 At least nine specimens of a specific playground surface system shall be submitted for laboratory testing.

11. Sample Conditioning

11.1 Laboratory samples shall be preconditioned at 50 6 10 % relative humidity 72 6 5ÉF (23 6 3ÉC) for a minimum of 24 h prior to beginning testing.

11.2 Samples tested at various temperatures, 30, 72, and 120ÉF, (þ1, 23, and 49 6 1ÉC, respectively) shall be conditioned for 4 h minimum. Testing must be started within 1 min of taking each sample out of the environmental chamber with a time interval between drops of 3 6 0.25 min. If the test intervals are not met, an additional conditioning period of 4 h will be necessary.

12. Laboratory Procedure (Test Method)

12.1 Test all samples of the surface system in accordance with the selected test method, Test Method F 355, or the free fall test method in Annex A1, with the headform impacting in the crown position.

12.2 Conduct impact tests considering the following criteria:

12.2.1 Carry forth the impact test to a maximum drop height in whole foot increments, that is, 1, 2, 3 ... n, that gives both a deceleration force of 200 g-max and an HIC of 1000 or less. It must also be measured at intervals of 1 ft over and under this maximum drop height.

12.2.2 An impact test consists of three drops at the same impact site, at each height. The impact site shall be at the location that exhibits the least optimal impact characteristics (as described in 9.1). Calculate the average of the second and third drops.

12.2.3 The impact test uses a different sample at all heights at the given temperatures.

12.2.4 The impact test samples are to be tested at the three specific temperatures of 30, 72, and 120ÉF (þ1, 23, and 49ÉC, respectively) after the required conditioning.

12.2.5 If for any reason during the test, the headform holding fixture interferes with the test, note it in the report and discontinue the test. The information recorded shall be considered invalid.

12.2.6 When using Test Method F 355, measure and record the impact velocity for each drop. It cannot vary more than 6 0.5 ft/s from the theoretical free fall velocity at the drop height used.

13. Field Test Procedure (Test Method)

13.1 Test at least three different impact sites of each surface system in use in accordance with the selected test method, either Test Method F 355 or the free fall test method in Annex A1 with the headform in the crown position. The selected impact sites shall include those areas that may exhibit less than optimal impact characteristics. These areas may be high traffic or compressed areas as well as areas containing seams, partitions, corners, and fasteners/anchors.

13.2 Conduct impact test in accordance with the following criteria:

13.2.1 Carry forth the impact tests at the drop height, as specified by the initial owner/operator.

13.2.2 The impact test shall have three drops at each of the impact sites, for a total of nine impacts. Report the average of the second and the third drops for both g-max and HIC values.

13.2.3 Insert a temperature measuring device into the surface system (within 6 in. (152 mm) of the impact site) at the time of the impact test, to measure the temperature of the surface system, at 1/2-in. (12.5-mm) depth or no more than half the depth of the surface system.

13.2.4 Measure and record the impact velocity for each drop. The impact velocity cannot vary more than 6 0.5 ft./sec. from the theoretical free fall velocity at the drop height used.

14. Report

14.1 Report the following information:

14.1.1 The sample identification, including type, source, size, and thickness.

14.1.2 Test procedure used and missile description, including mass, geometry, and orientation.

14.1.3 Testing conditions, including sample temperatures and drop heights employed.

14.1.4 Individual drop values and the average of the second and third drop values for both g-max and HIC values.

14.1.5 The theoretical drop heights used.

14.1.6 The deceleration/time trace in 0.5-ms intervals.

NOTE 1ÐThe preferred method of exhibiting the data would be in chart form (see Figs. 2 and 3).

15. Precision

15.1 Potential sources of error or deviations are as follows:

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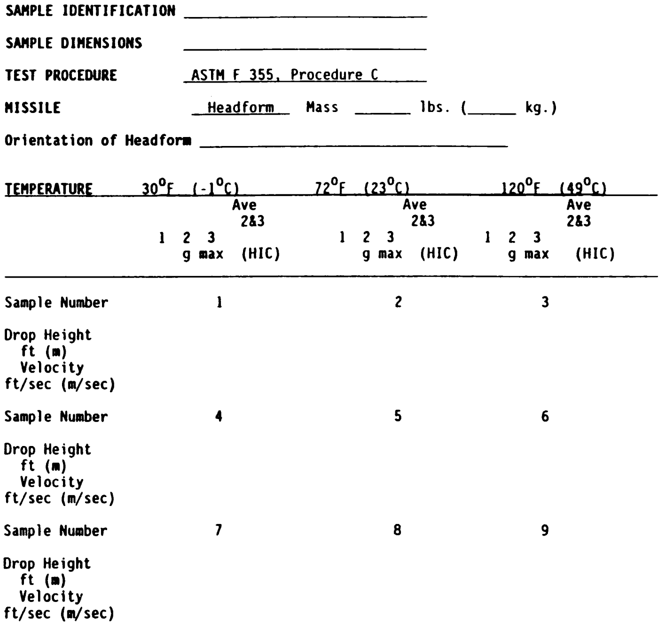
[5] Chou, C., and Nyquist, G., ªAnalytical Studies of the Head Injury Criterion,º Society of Automotive Engineers, SAE Paper No. 740082, 1974.



SAMPLE IDENTIFICATION ____________________

SAMPLE DIMENSIONS ____________________

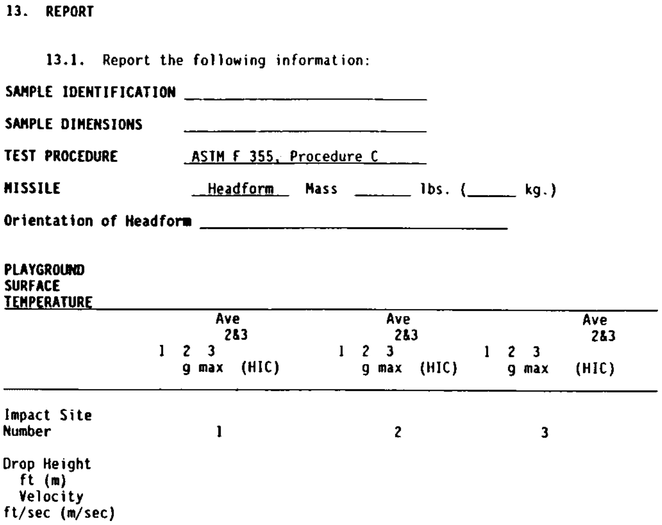
TEST PROCEDURE ASTM F 355, Procedure C

MISSILE Headform Mass ______ lbs. (______ kg.)

Orientation of Headform ____________________

TEMPERATURE	30°F (-1°C)	72°F (23°C)	120°F (49°C)
	1 2 3 Ave 2&3 g max (HIC)	1 2 3 Ave 2&3 g max (HIC)	1 2 3 Ave 2&3 g max (HIC)
Sample Number	1	2	3
Drop Height ft (m) Velocity ft/sec (m/sec)			
Sample Number	4	5	6
Drop Height ft (m) Velocity ft/sec (m/sec)			
Sample Number	7	8	9
Drop Height ft (m) Velocity ft/sec (m/sec)			

FIG. 2 Suggested Laboratory Test Report Form



13. REPORT

13.1. Report the following information:

SAMPLE IDENTIFICATION ____________________

SAMPLE DIMENSIONS ____________________

TEST PROCEDURE ASTM F 355, Procedure C

MISSILE Headform Mass ______ lbs. (______ kg.)

Orientation of Headform ____________________

PLAYGROUND SURFACE TEMPERATURE			
	1 2 3 Ave 2&3 g max (HIC)	1 2 3 Ave 2&3 g max (HIC)	1 2 3 Ave 2&3 g max (HIC)
Impact Site Number	1	2	3
Drop Height ft (m) Velocity ft/sec (m/sec)			

FIG. 3 Suggested Field Test Report Form

15.1.1 Variations in the time needed to conduct the test result in variable levels of recovery of the material during the room temperature tests. This variation is accentuated in non-room temperature tests by the addition of changing temperature conditions within the sample to the variable recovery of the material.

15.1.2 Variations in the impact velocity brought about by changes in drop height or friction in the drop guidance mechanism.

15.1.3 Use of missiles other than those referenced in this specification may cause substantial variations in results.

15.2 An interlaboratory study was conducted in 1996-97 during the development of this test method. Seven laboratories ran pairs of tests on eight surface materials using Test Method F 355, Procedure C. The same laboratories also ran pairs of tests on the same surface materials using the free fall test

TABLE 1 Precision Statistics for *g*-max, Test Method F 355, Procedure C

Material	Average	Repeatability Standard Deviation (S_r)	Reproducibility Standard Deviation (S_R)	Repeatability Limit (r)	Reproducibility Limit (R)
D	52.4	2.0	7.8	5.6	21.8
E	62.9	9.1	11.4	25.5	31.9
H	107.2	3.8	7.9	10.6	25.8
A	125.0	2.6	9.5	7.3	26.6
C	143.8	1.9	7.7	5.3	21.6
G	193.2	15.2	17.1	42.6	47.9
B	202.0	2.6	14.6	7.3	40.9
F	234.3	3.2	12.0	9.0	33.6

TABLE 2 Precision Statistics for *g*-max, Free Fall Test Method

Material	Average	Repeatability Standard Deviation (S_r)	Reproducibility Standard Deviation (S_R)	Repeatability Limit (r)	Reproducibility Limit (R)
D	54.4	7.6	9.4	21.3	26.3
E	51.5	11.0	11.0	30.8	30.8
H	100.9	3.9	6.9	10.9	19.3
A	118.0	2.1	6.2	5.9	17.4
C	148.9	5.6	10.0	15.7	28.0
G	180.6	5.7	9.1	16.0	25.5
B	213.0	7.9	16.3	22.1	45.6
F	247.1	10.9	20.2	30.5	56.6

TABLE 3 Precision Statistics for HIC, Test Method F 355, Procedure C

Material	Average	Repeatability Standard Deviation (S_r)	Reproducibility Standard Deviation (S_R)	Repeatability Limit (r)	Reproducibility Limit (R)
D	145.0	12.0	30.5	33.6	85.4
E	211.9	47.4	79.4	132.7	222.3
H	600.0	14.4	103.2	40.3	289.0
A	628.7	130.0	166.0	364.0	464.8
C	731.0	13.0	103.4	36.4	289.5
G	1162.0	31.9	177.0	89.3	495.6
B	1433.0	148.3	220.4	415.2	617.1
F	1849.0	17.3	188.2	48.4	527.0

TABLE 4 Precision Statistics for HIC, Free Fall Test Method

Material	Average	Repeatability Standard Deviation (S_r)	Reproducibility Standard Deviation (S_R)	Repeatability Limit (r)	Reproducibility Limit (R)
D	144.4	26.1	35.7	73.1	100.0
E	120.0	45.7	47.8	128.0	133.8
H	585.3	34.1	87.4	95.5	244.7
A	557.0	31.2	81.3	87.4	227.6
C	767.0	44.6	110.9	124.9	310.5
G	1262.0	87.8	194.8	245.8	545.4
B	1330.0	71.8	162.4	201.0	454.7
F	1849.0	295.9	398.7	828.5	1116.4

TABLE 5 Combined Results - Loose Fill and Non-loose Fill Materials

Uniaxial: Peak G (F 355, Procedure C)	±24 %
Free Fall: Peak G	±20 %
Uniaxial: HIC (F 355, Procedure C)	±54 %
Free Fall: HIC	±40 %

TABLE 6 Non-loose Fill Materials Only

Uniaxial: Peak G (F 355, Procedure C)	6 21 %
Free Fall: Peak G	6 11 %
Uniaxial: HIC (F 355, Procedure C)	6 31 %
Free Fall: HIC	6 24 %

method. In both series of tests, g-max and HIC values were determined. From the results of these tests, precision statistics were calculated in compliance with Practice E 691.

15.2.1 The precision results are summarized in Tables 1-4.

15.2.2 A statement on bias cannot be made because no reference surfaces are available.

15.2.3 An earlier interlaboratory study was completed in 1989.[6] The technique used to analyze the study data resulted in a 6 figure being generated for test method precision. Applying this method to the 1996-7 study, the results described in Tables 5 and 6 were obtained.

NOTE 2ÐThe method used to generate Tables 5 and 6 is not as statistically accurate as the analysis used in 15.2.1. It is provided for informational purposes only.

16. Keywords

16.1 impact attenuation; playground; surface system

ANNEXES

(Mandatory Information)

A1. FREE FALL TEST METHOD

A1.1 A nonguided headform may be used for impact testing of playground surface systems or surfacing material samples.

A1.2. Terminology

A1.2.1 Definition of Term Specific to This Annex:

A1.2.1.1 free fallÐthe trajectory of the headform is not restrained by rails, wires, or a mechanism or structure of any type.

A1.3 Apparatus

A1.3.1 Headform DesignÐThe headform as a 10.1 6 0.1 lb (4.6 6 0.05 kg) hemispherical missile of diameter 6.300 6 0.200 in. (160 6 5 mm). An optional handle may be affixed to the headform provided that the total weight of the headform and handle combination does not exceed 10.1 6 0.1 lb (4.6 6 0.05 kg).

A1.3.2 AccelerometerÐRigidly attach a triaxial accelerometer at the center of mass of the headform.

A1.3.2.1 One axis of the accelerometer must be mounted parallel within 5É to the primary axis of impact of the headform. This axis of the accelerometer shall have a linear output signal from 0 to 500 g.

A1.3.2.2 The remaining two axes of the accelerometer must define a plane normal to the primary axis. Both of these axes shall have a linear output signal from 0 6 to 500 g.

A1.3.2.3 All axes of the accelerometer must be capable of withstanding impacts of 1000 g without damage.

A1.3.2.4 Connect the output signal of the accelerometer to the recording device by a flexible multiple conductor cable. The cable shall be sufficiently flexible so as to not influence the trajectory of the headform before or during the impact test. The fully extended length of the cable shall be at least two times the drop height specified by the initial owner/operator. The cable shall be of self-coiling design. The cable shall be attached to the headform and recording device by a single multiple contact electrical connector with integral locking action.

A1.3.2.5 The axis nominally perpendicular to the impact surface shall be annotated Z. The axes forming the plane nominally parallel to the impact surface shall be annotated X and Y. This coordinate system complies with the right handed coordinate system, Orientation 2, of SAE J 211.

A1.3.3 Recording EquipmentÐThe recording equipment shall meet the following criteria:

A1.3.3.1 Acceleration TimeÐThe acceleration-time recording equipment shall have three input channels, each matched to the output signal levels of the triaxial accelerometer. Each input channel and accelerometer pair shall have a frequency response adequate to measure the peak acceleration to an accuracy of 6 5 % of the true value. The total system, accelerometers and recorders, shall be capable of measuring impulses up to 500 g at frequencies from 2 to an accuracy of 6 5 %. The minimum system sampling rate required is 20 000 Hz per input channel or 20 000 samples/s per input channels. The recording device must be capable of simultaneously sampling each of the three input channels at the specified sampling rate. Three independent digitizers or a single digitizer with three track and hold amplifiers is acceptable. Each acceleration data channel should comply with SAE J 211. A low pass filter having a 4-pole Butterworth transfer function and a corner frequency of 1650 Hz meets this requirement. Digitizer resolution shall be a minimum of twelve bits.

A1.3.3.2 Displacement - TimeÐProvision will be made to record the time, in seconds, from the release of the headform to the time of initial impact. The velocity at impact will be calculated by multiplying the fall time by the acceleration due to gravity (32.2 ft/s/s) to yield the velocity in feet per second. The time measurement function will be part of the recording device and will not require operator intervention to start and stop the measurement.

A1.3.3.3 System IntegrityÐPortable recording equipment shall provide continuous battery voltage monitoring. If recording equipment battery voltage falls below a level required for proper equipment operation, the recording function shall be

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[6] Available from ASTM Headquarters. Request RR:F08-1002.

inhibited and the person performing the test alerted by an indicator lamp or message on the LCD interface of the recording device. Auxiliary power means, such as automobile battery voltage converters or wall receptacle connected chargers, may be used to restore battery voltage to the acceptable operating level. Impact tests may be performed with the recording device connected to the auxiliary power source. Prior to use the recording equipment and headform shall be checked for proper operation by impact test on a reference surface material sample. The sample shall be provided by the recording device manufacturer and be furnished with reference impact test data including serial number of sample, drop height, ambient temperature, subsurface condition, *g*-max, and HIC. Average the results of the last two of three drops, and compare to the reference *g*-max and HIC. The manufacturer of the triaxial headform is to provide the criteria for the requirement for recalibration of the headform, recorder, and reference pad. The impact test on the reference sample will not be construed to be a calibration of the instrument, which can only be performed in a properly equipped metrology laboratory.

A1.3.3.4 *Calibration*—Check the recording equipment, headform, and reference surface material sample annually for proper calibration by returning them to the manufacturer's calibration laboratory or repair depot qualified by the manufacturer.

A1.3.3.5 *Impact Data and Waveform Display*—The recording device shall have a graphic display device capable of indicating the *g*-max, HIC, and impact waveform.

A1.3.3.6 *Drop Height Measurement and Control*-Drop Height, *h*, shall be measured from the top of the surface to be tested to the surface of the headform expected to initially impact the surface. Measurement shall be made with a steel rule or steel tape measure. Use a support structure or tripod to ensure repeatable drop height and location. The support structure or tripod shall be sufficiently rigid to support, with minimum deflection, the weight of the headform. The support structure or tripod must allow for the testing of the surface at any location within the playspace. A quick-release mechanism shall be provided to connect the headform to the support arm. The operation of the release mechanism shall not influence the trajectory of the headform during free fall. Erect the support structure or tripod in such a manner so as to prevent the headform from coming in contact with any part of the support structure or tripod before impact with the surface being tested.

A1.3.4 *Calculation*:

A1.3.4.1 *Triaxial Acceleration Component Summing*—The components of acceleration in each of the three axes must be vector summed to determine composite acceleration of the headform. Perform vector addition on each set of three samples to determine the composite acceleration for the respective sample period. The vector addition shall be based on the following mathematical expression:

$$a_{[n]} = (a_{z[n]}^2 + a_{y[n]}^2 + a_{x[n]}^2)^{0.5} \quad \text{(A1.1)}$$

where:

$a_{[n]}$ = composite acceleration at sample point [n],
$a_{z[n]}$ = acceleration value of *Z* axis at sample point [n],
$a_{y[n]}$ = acceleration value of *Y* axis at sample point [n], and
$a_{x[n]}$ = acceleration value of *X* axis at sample point [n].

A1.3.4.2 *g-Max and HIC*—The *g*-max and HIC shall be determined from the composite acceleration values. The specified algorithm and verification calculations for HIC are included as Appendix X2.

A1.4 Procedure

A1.4.1 For portable recording devices, verify battery voltage level as recommended by manufacturer.

A1.4.2 Perform the system integrity impact test using the testing equipment manufacturer's supplied surface sample. Verify that test results are in agreement with those quoted and supplied by the testing equipment manufacturer.

A1.4.3 Erect the support structure or tripod on the playground surface. The position of the release mechanism should allow the headform to impact the desired point repeatedly on the surface from the drop height and location as specified by the initial owner/operator.

A1.4.4 *Release the Headform*.

A1.4.5 Observe the impact waveform on the display of the recording device and confirm that it contains only one impact event. The impact waveform should start at 0 *g*, increase to the *g*-max of the drop, and return to 0 *g*. An impact waveform not showing this shape should be discarded. The increase and decrease portions of the waveform may be smooth or jagged and will depend upon the material being impacted upon.

A1.4.6 *Record and Report the Following Information*:

A1.4.6.1 The test surface identification, indicating type, source, size, and thickness.

A1.4.6.2 Test procedure used and headform description, including mass, geometry, and orientation.

A1.4.6.3 Testing conditions, including sample temperatures and drop heights employed.

A1.4.6.4 Individual drop values and the average of the second and third drop values for both *g*-max and HIC values.

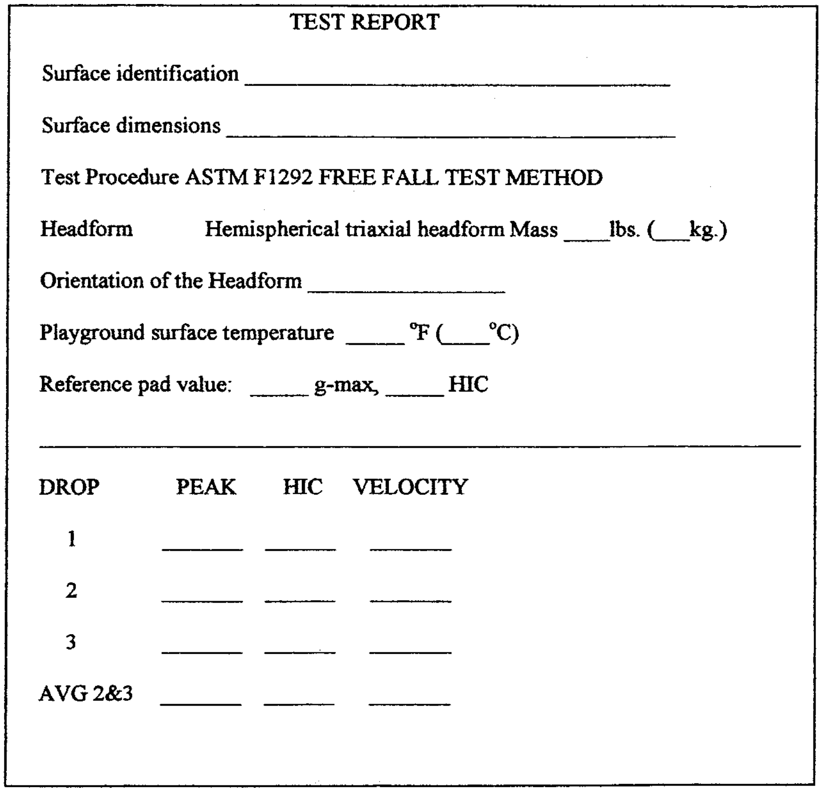
A1.4.6.5 The drop heights specified by the initial owner/operator.

NOTE A1.1—The preferred method of exhibiting the data would be in chart form (see Fig. 1).

A1.4.7 Make three consecutive drops at intervals of 3 ± 0.25 min, unless otherwise specified.

A1.5 Report

A1.5.1 A detailed report will be prepared to document the result of the drop tests. Fig. A1.1 is a suggested format for this report.



TEST REPORT

Surface identification ______________________

Surface dimensions ______________________

Test Procedure ASTM F1292 FREE FALL TEST METHOD

Headform Hemispherical triaxial headform Mass ____lbs. (___kg.)

Orientation of the Headform ____________

Playground surface temperature _____ °F (____°C)

Reference pad value: _____ g-max, _____ HIC

DROP	PEAK	HIC	VELOCITY
1	______	______	______
2	______	______	______
3	______	______	______
AVG 2&3	______	______	______

FIG. A1.1 Suggested Field Test Report Form

A2. INSTRUMENTATION REQUIREMENTS

A2.1 To adequately perform surface impact tests complying with Specification F 1292, the instrumentation employed must meet minimum requirements for resolution, accuracy, precision, and calibration.

A2.2 Accelerometers

A2.2.1 In guided head form systems, a single axis or triaxial accelerometer may be used. The active axis of the accelerometer must be rigidly attached to the head form and within 6 5É of the axis of impact of the head form.

A2.2.2 In free fall head form systems, a triaxial accelerometer is required. One axis of the accelerometer must be rigidly attached to the head form and within 6 5É of the primary axis of impact. The remaining two axes will form a plane parallel to the impact surface within 6 5É.

A2.2.3 The accelerometer oriented parallel to the axis of impact must have an output range from 0 to 500 g minimum. The secondary axes in a triaxial accelerometer must have an output range from 0 to 6 500 g minimum. All axes must be capable of withstanding a maximum shock of 1000 g.

A2.2.4 The frequency response of all accelerometers shall cover the complete range from 2 to 2000 Hz.

A2.2.5 Nominal accelerometer output will be 10.0 mV/g.

A2.3 Recording Device

A2.3.1 A digital electronic recorder will be used to capture impact wave forms. The recorder may be in the form of a digital storage oscilloscope or dedicated wave form digitizer. Analog oscilloscopes are not acceptable.

A2.3.2 Each digitizer input will have a minimum resolution of twelve bits spanning the full output range of the respective accelerometer.

A2.3.3 Minimum digitizer sampling rate will be 20.0 kHz. In triaxial head form systems, three individual digitizers (one per axis), each with a 20.0 kHz sampling rate, will be used. Alternatively, a single 60.0 kHz digitizer may be used if simultaneous track and hold amplifiers are provided for each accelerometer axis.

A2.3.4 Minimum digitizer memory length will be to allow a minimum of 20 ms of the impact wave form to be recorded.

A2.3.5 Analog filtering on all accelerometer input channels will be used to prevent digital signal aliasing. The filter will have a cut-off frequency of 1.0 kHz, with a minimum of a two pole roll off.

A2.3.6 Provision to measure head form velocity at impact will be provided.

A2.3.6.1 A light gate device may be used to measure the time an opaque flag interrupts a light sensor. The light gate will be located so as to be activated with the head form no more than 1 in. from impact with the surface being tested. Velocity of head form shall be calculated by dividing the length of the opaque flag (inches) by the time the light sensor was activated (seconds) to velocity in inches per second. Conversion to units of feet per second may be obtained by dividing the inches per second value by 12.0

A2.3.6.2 For free fall head forms, recording the time from when the head form was released to the time the accelerometer output signal begins may also be used. Head form velocity shall be calculated by multiplying the time of flight (seconds) by 32.2 ft/s/s (acceleration due to gravity) to yield head form velocity in feet per second.

A2.3.6.3 Either velocity measurement will be performed with a minimum timer resolution of 1.0 ms.

A2.3.6.4 Actual head form velocity will not deviate from theoretical velocity by more than ± 0.5 ft/s. Theoretical velocity shall be determined from conservation of energy, namely kinetic energy at impact must be equal to potential energy before release:

$$m\,g\,h = \frac{1}{2}\,m\,v^2 \qquad (A2.1)$$

where:
m = weight of head form (lb),
g = acceleration due to gravity (32.2 ft/s/s),
h = actual drop height (ft), and
v = velocity at impact (ft/s).

Solved for velocity, equation Eq A2.1 becomes:

$$v = \sqrt{(2gh)} \qquad (A2.2)$$

Thus, a head form dropped from a height of 10.0 ft will have a velocity at of

$$v = \sqrt{(2) \times (32.2) \times (10.0)}$$

$$v = 25.4 \text{ ft/s}$$

A2.4 Calibrations

A2.4.1 Accelerometers will be calibrated by comparison to a National Institute of Standards and Technology (NIST) traceable standard. Both the reference accelerometer and the test accelerometer will be excited by a shaker table at frequencies and amplitudes as determined suitable by the accelerometer manufacturer. Maximum recalibration interval will be one (1) year or as recommended by manufacturer.

A2.4.2 Recording devices will be calibrated by replacing the accelerometer input signal(s) with a wave form of known shape, period, and amplitude. Tables A2.1 and A2.2 provide calculated HIC values for half-sine wave forms applied to a 12 bit, 20.0 kHz digitizer.

A2.5 Calculation of Peak and HIC

A2.5.1 The peak g of an impact wave form shall be determined to be the g value with the largest positive amplitude. The recording device will have the capability to sequentially scan all digitized data of the impact wave form and report the higher value recorded.

A2.5.2 The HIC value of an impact wave form will be calculated in accordance with 8.6 of Specification F 1292. The dt term shall be an integer multiple of the sampling rate and in no case will be greater then 0.1 ms. The recording device will have the capability to perform the calculation for all possible combinations of t1 and t2 (HIC integration interval) and to report the highest IIIC value calculated. Manual selection of t1 and t2 intervals will not be allowed.

TABLE A2.1 HIC Values for 10 ms Half Sine

NOTE 1—The recording device will not produce HIC values with greater than ± 5 % from these values.

Peak G	HIC	T1 (seconds)	T2 (seconds)
50	73	0.0017	0.0084
100	413	0.0017	0.0084
150	1140	0.0017	0.0084
200	2341	0.0017	0.0084

TABLE A2.2 HIC Values for 20 ms Half Sine

NOTE 1—The recording device will not produce HIC values with grater than ±5 % from these values.

Peak G	HIC	T1 (seconds)	T2 (seconds)
50	146	0.0033	0.0167
100	827	0.0033	0.0167
150	2281	0.0033	0.0167
200	4684	0.0033	0.0167

APPENDIXES

(Nonmandatory Information)

X1. RATIONALE

X1.1 This specification addresses the impact attenuation requirements of surfacing materials used under and around playground equipment. A Consumer Product Safety Commission study of playground equipment-related injuries treated in U.S. hospital emergency rooms indicated that the majority resulted from falls from equipment to the underlying surface.

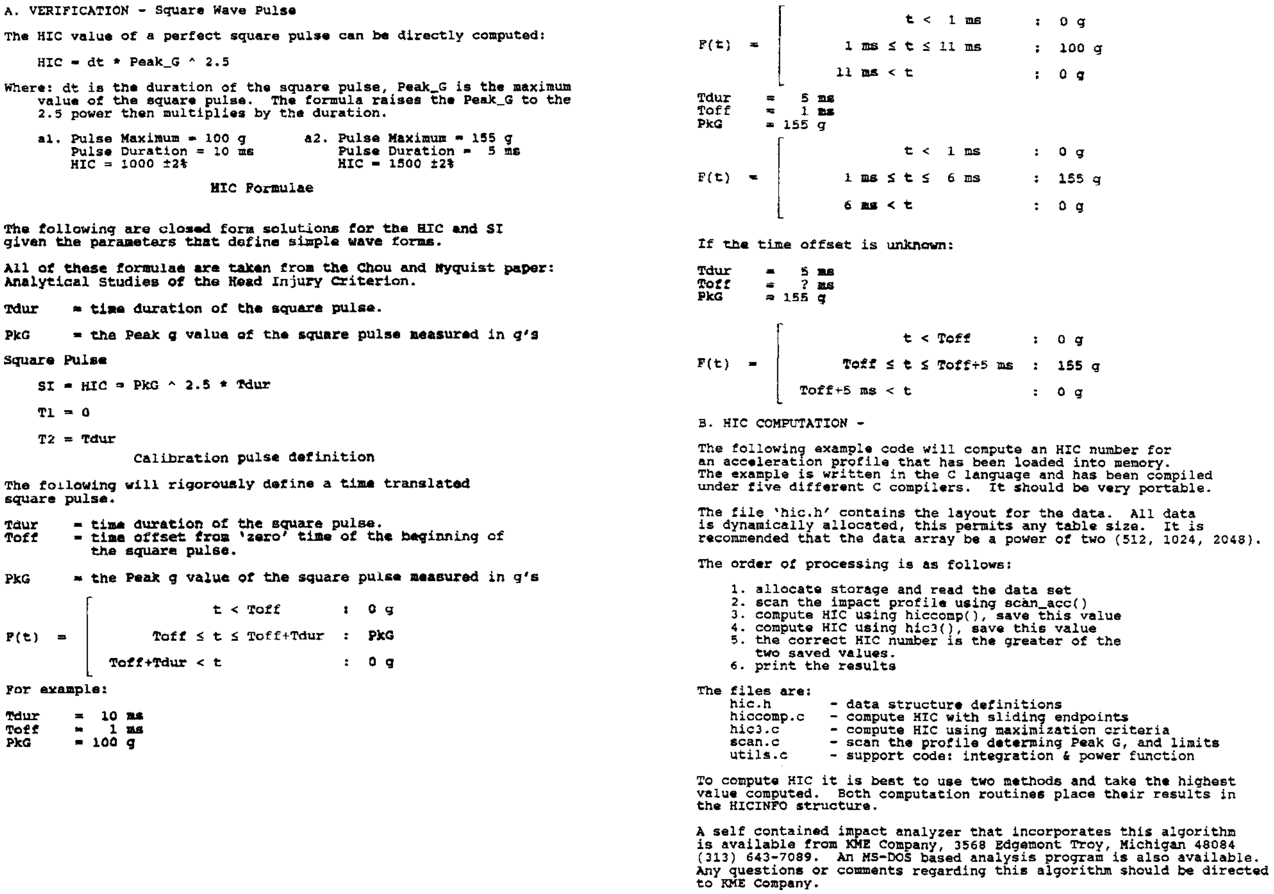
X1.1.1 Because head impact injuries from a fall have the potential for being life threatening, the more shock absorbing and attenuating a surface can be made, more is the likelihood that the severity of the injury will be reduced. In addition, the measurement of a peak deceleration of the head during impact plus the time duration over which the head decelerates to a halt is significant. Therefore, a mathematical formula is used to derive a value known as head injury criteria (HIC). Head impact injuries are not believed to be life threatening if the HIC does not exceed a value of 1000.

X1.1.2 However, it should be recognized that safety surfacing meeting these test measurements will not prevent nonlife-threatening injuries from occurring. The Consumer Product Safety Commission states, "It is self evident that a fall onto a shock absorbing surface is less likely to cause a serious injury than a fall onto a hard surface. However, it should be recognized that all injuries due to falls cannot be prevented no matter what playground surfacing material is used."

X1.2 This specification is limited to a test for g-max, HIC, and conditions that affect them, that is, drop height, temperature, and so forth. Other physical property factors could be taken into account in the comparison of surface systems but currently are beyond the scope of this specification. These factors should be considered and included after being studied.

X2. HIC CALCULATION PROGRAM

X2.1 See Fig. X2.1.



```
A. VERIFICATION - Square Wave Pulse

The HIC value of a perfect square pulse can be directly computed:

    HIC = dt * Peak_G ^ 2.5

Where: dt is the duration of the square pulse, Peak_G is the maximum
    value of the square pulse.  The formula raises the Peak_G to the
    2.5 power then multiplies by the duration.

    a1. Pulse Maximum = 100 g        a2. Pulse Maximum = 155 g
        Pulse Duration = 10 ms           Pulse Duration =  5 ms
        HIC = 1000 ±2%                   HIC = 1500 ±2%

                        HIC Formulae


The following are closed form solutions for the HIC and SI
given the parameters that define simple wave forms.

All of these formulae are taken from the Chou and Nyquist paper:
Analytical Studies of the Head Injury Criterion.

Tdur    = time duration of the square pulse.

PkG     = the Peak g value of the square pulse measured in g's

Square Pulse

    SI = HIC = PkG ^ 2.5 * Tdur

    T1 = 0

    T2 = Tdur
                Calibration pulse definition

The following will rigorously define a time translated
square pulse.

Tdur    = time duration of the square pulse.
Toff    = time offset from 'zero' time of the beginning of
          the square pulse.

PkG     = the Peak g value of the square pulse measured in g's

          ┌
          │               t < Toff        :  0 g
F(t)  =   │
          │         Toff ≤ t ≤ Toff+Tdur  :  PkG
          │
          │   Toff+Tdur < t               :  0 g
          └
For example:

Tdur    =  10 ms
Toff    =   1 ms
PkG     = 100 g
```

```
          ┌
          │               t <  1 ms       :  0 g
F(t)  =   │
          │         1 ms ≤ t ≤ 11 ms      :  100 g
          │
          │        11 ms < t              :  0 g
          └
Tdur    =   5 ms
Toff    =   1 ms
PkG     = 155 g
          ┌
          │               t <  1 ms       :  0 g
F(t)  =   │
          │         1 ms ≤ t ≤  6 ms      :  155 g
          │
          │         6 ms < t              :  0 g
          └

If the time offset is unknown:

Tdur    =   5 ms
Toff    =   ? ms
PkG     = 155 g

          ┌
          │               t < Toff        :  0 g
F(t)  =   │
          │         Toff ≤ t ≤ Toff+5 ms  :  155 g
          │
          │   Toff+5 ms < t               :  0 g
          └
B. HIC COMPUTATION -

The following example code will compute an HIC number for
an acceleration profile that has been loaded into memory.
The example is written in the C language and has been compiled
under five different C compilers.  It should be very portable.

The file 'hic.h' contains the layout for the data.  All data
is dynamically allocated, this permits any table size.  It is
recommended that the data array be a power of two (512, 1024, 2048).

The order of processing is as follows:

     1. allocate storage and read the data set
     2. scan the impact profile using scan_acc()
     3. compute HIC using hiccomp(), save this value
     4. compute HIC using hic3(), save this value
     5. the correct HIC number is the greater of the
        two saved values.
     6. print the results

The files are:
     hic.h        - data structure definitions
     hiccomp.c    - compute HIC with sliding endpoints
     hic3.c       - compute HIC using maximization criteria
     scan.c       - scan the profile determing Peak G, and limits
     utils.c      - support code: integration & power function

To compute HIC it is best to use two methods and take the highest
value computed.  Both computation routines place their results in
the HICINFO structure.

A self contained impact analyzer that incorporates this algorithm
is available from KME Company, 3568 Edgemont Troy, Michigan 48084
(313) 643-7089.  An MS-DOS based analysis program is also available.
Any questions or comments regarding this algorithm should be directed
to KME Company.
```

FIG. X2.1 HIC Calculation Program

```
/*
 * @(#)hiccomp.c v1.0 kpc 04/28/88 -- HIC 68k  hic computation module



 * this module computes hic for a passed in waveform
 *
 * we assume that the limits have been determined for the waveform
 * and are set in the hicinfo struct
 */

#include    "hic.h"
#include    <stdio.h>


/*
 * compute integral from partial sums array
 *  from i1 to i2
 */
#define INTEG( i1, i2 )          (s[i2] - s[i1])
#define AVE( i1, i2 )            ( INTEG(i1,i2) / (SUMTYPE)((i2)-(i1)) )
#define HIC( i1, i2 )            (power2( AVE(i1, i2))*(SUMTYPE)(i2-i1))

static int      debug = 0;       /* debug mode? */


/*
 * compute hic with sliding endpoints
 */
void        hiccomp( ip, chan )
IMPINFO     *ip;
short       chan;
{
    Idx     maxn;
    short   improve;             /* loop until no improvement in answer */
    short   i,j;                 /* limits for ave */
    short   g;                   /* guess */
    short   iter;                /* iteration count */

    SUMTYPE ave;                 /* current best average */
    SUMTYPE aveg;                /* next guess at best average */
    SUMTYPE hicv;
    SUMTYPE hicvs;               /* special hic value */

    HICINFO     *hp;
    SUMTYPE     *s;              /* to hold the partial sums */

    double          power2();
    extern char     *malloc();


    /* hp = ip->chan[0]; */
    hp = ip->chan[chan];

    maxn = hp->imax - hp->i0 + 1;


#define SAME            (0)
#define LOWER           (-1)
#define HIGHER          (1)

/* is it near zero? */
#define ZERO( v )           ((v) < eps && (v) > -eps)
#define ZEROF( v )          ((v) < epsf && (v) > epsfn)

#define min( a, b )         ((a>b)?(b):(a))
#define max( a, b )         ((a>b)?(a):(b))

/* debugging aid */
#if 0
#define CTR( x )            x
#else
#define CTR( x )
#endif

/*
 * variables for the algorithm
 */
static SUMTYPE          *s;         /* partial sums array */

static SUMTYPE          eps;         /* my epsilon for comparisons */
static DTYPE            epsf;        /* my float epsilon for comparisons */
static DTYPE            epsfn;       /* my negative epsilon */

/* counts, # of equal value, # of ave ok, # of bracket pairs, # of hicv's */
static unsigned short   ev, av, fv, hv;
/* more counts, # of times the prev hic val was used, # of times cur val used
static unsigned short   pv, cv;
static short            dbg = 0;    /* debugging flag */

static    Idx           i, j;       /* 1st & 2nd limit */
static    Idx           n;          /* i + wind, upper bounds on j */
static    Idx           wind;       /* # of samples to make 15ms */
static    Idx           tmp;        /* temp var */
static    Idx           ipk;        /* idx of peak g value */
static    Idx           npnts;      /* number of pnts in dp[] */
static    DTYPE         diff;       /* difference btwn dp[i] and dp[j] */
static    SUMTYPE       diff2;      /* diff btwn ave & v53 */
static    SUMTYPE       ave;        /* average value from dp[i] to dp[j] */
static    DTYPE         v,          /* value of dp[i] */
                        v2,         /* value of dp[j] */
                        v53;        /* dp[i] * 5/3  what the ave should be */
static    SUMTYPE       a0;         /* s[i] so we don't refetch it */
                                    /* in the inner loop */
static    SUMTYPE       hicv,       /* best hic value so far */
                        hicg;       /* next guess at hic -- HIC(i,j) */
static    Idx           hici, hicj; /* limits for hicv -- the best so far */
static    DTYPE         *dp;        /* ptr to accel array */
static    short         prevf,      /* flag for dp[j-1], - +1/0/-1 */
                                    /* whether it is above, same, or below */
                        curf;       /* flag for current pnt - dp[j] */
static    Idx           w;          /* width of the interval */


/*
 * perform the HIC computation with
 * bracketing logic and functional analysis criteria
```

```
 */
void        hiccomp3( ip, chan )
IMPINFO     *ip;
short       chan;        /* data channel # used to compute HIC */
{
    double          power2();       /* we will need this */
    extern char     *malloc();

    HICINFO         *hp;

    hp = ip->chan[chan];

    eps = 1.0e0;                /* if it is within 1g then its close */
    epsf = eps;                 /* float version of eps */
    epsfn = -eps;               /* float negative eps */

    /* init vars */
    hicv = 0.0;
    hici = 0;
    hicj = 0;

    /* loop & cycle counters */
    ev = av = fv = hv = pv = cv = 0;

    /* number of samples in 50.0 msec (50000 usec = 50.0 msec) */
    wind = 50000L / ip->samptime;
    ipk  = hp->ipk - hp->i0;

    /* how many pnts are there? */
    npnts = 1 + hp->imax - hp->i0;
    dp    = hp->acc + hp->i0;       /* base addr for part of array we need */


    if( (s = (SUMTYPE *)malloc((npnts+3)*sizeof(SUMTYPE))) == NULL )
    {
        printf("hiccomp3: malloc bomb (%d bytes)\n",
            (npnts+3)*sizeof(SUMTYPE));
        return;
    }

    /* compute partial sums array */
    partsum( s, dp, npnts );

    fprintf(stderr, ".");
    fflush( stderr );

    /*
     * The starting point scans over every point upto the peak g Idx
     */
    i = max( 0, ipk-wind );
    for( ; i<ipk; i++ )
    {
        /* precompute data for this 'i' */
        v = dp[i];
        v53 = v * (5.0F/3.0F);
        a0 = s[i];

        /* setup loop ctl vars */
        prevf = curf = 0;


      tmp = i + wind;
      n = min( tmp, npnts );

      tmp = i + MINWIDTH;
      j = max( ipk, tmp );

      w = j - i;

      for( ; j<n; j++,w++ )
      {
          v2 = dp[j];
          diff = v2 - v;

          if( ZEROF(diff) )
          {
              /*
               * points are "equal"
               * so check the average value of this interval
               */
              CTR( ev++ );
              curf = 0;
              ave = (s[j] - a0) /(SUMTYPE)(w);

              diff2 = ave - v53;
              if( ZERO( diff2 ) )
              {
                  /*
                   * the average value is close to 5/3*dp[i] !!
                   * here is where we compute a HIC!
                   */
                  CTR( av++ );
                  hicg = (SUMTYPE)(w) * power2( ave );

                  if( hicg > hicv )
                  {
                      /* found a new maximum */
                      CTR( hv++ );
                      hicv = hicg;
                      hici = i;
                      hicj = j;
                  }
              }
          }
          else
          {
              /*
               * points are not equal
               * So check if we have gone from above 'v'
               * to below 'v', or vice versa.
               */
              /* set curf to 1 or -1 if v2 is higher or lower than v */
              curf = (diff > 0.0F) ? 1:-1;

              if( prevf != curf )
              {
                  /* we have moved from above to below or vice versa */
                  CTR( fv++ );
                  ave = (s[j] - a0)/(SUMTYPE)(w);
                  hicg = (SUMTYPE)(w) * power2( ave );
```

FIG. X2.1 HIC Calculation Program *(continued)*

```
                if( hicg > hicv )
                {
                    /* found a new maximum */
                    CTR( hv++ );
                    CTR( cv++ );
                    hicv = hicg;
                    hici = i;
                    hicj = j;
                }

                /* try it on the previous point too */
                ave = (s[j-1] - a0) /(SUMTYPE)(w-1);
                hicg = (SUMTYPE)(w-1) * power2( ave );

                if( hicg > hicv )
                {
                    /* found a new maximum */
                    CTR( hv++ );
                    CTR( pv++ );
                    hicv = hicg;
                    hici = i;
                    hicj = j-1;
                }
            }
        }

        /* adjust loop ctl vars */
        prevf = curf;
    }
}

if( dbg )
    printf("\n");

hicv *= ((double)ip->samptime * 1.0e-6);

/*
 * have just scanned through all of the points, print info
 */
if( dbg )
{
    printf("hiccomp3: #ev:%d #av:%d #fv%d #hv:%d #pv:%d #cv:%d\n",
        ev, av, fv, hv, pv, cv );
    printf("hiccomp3: eps:%.2f hicv:%.2f (%d,%d)\n", eps,hicv,hici,hicj);
}

/* now translate limits into correct offset */
hp->i1 = hici + hp->i0;
hp->i2 = hicj + hp->i0;
hp->hic = hicv;

/* free up the partial sums array */
free( s );
}
```

```
/*
 * @(#) hic3.c



    HIC is defined as:
                                                  I t2
    HIC(t1,t2) = (t2-t1) * ( 1/(t2-t1) * I     a(t)*dt } ^ 2.5
                                                  I t1

    We are trying to maximize this function.  To do this in a brute force
    way, we would have to compute approximately:

        0.5 * n^2 - n

    HIC numbers.  For a 1000 point pulse, this becomes 499,000 evaluations
    -- this is far too expensive.

    Functional analysis can guide this maximization process.  Using
    multivariable calculus and a lot of algebra we find that the critical
    times meet the following criteria:

        a(t1) = a(t2)           _
        a(t1) = 3/5 * ( a(t1,t2) )

    The acceleration value at one limit of integration is equal to the
    acceleration value at the other limit of integration.  The acceleration
    value at one limit of integration is equal to three-fifths the average
    acceleration value over the limits of integration.

    These criteria assume that a(t) is continuous!  - which is not the
    case.  Thus the implementation is important.

    First we setup a tolerance to the comparison operations call it 'eps'
    -- short for epsilon.  If we are within eps from zero then the number
    is zero -- and so on.

    Simply tempering the above criteria with a large epsilon will work for
    about 90% of the time.  The problem is high frequency components cause
    too large a delta-V from one conversion to the next, and the value that
    would meet the criteria is between two samples.

    To improve this situation we must add some pattern matching logic to
    the algorithm that will determine when we are 'bracketing' the original
    point and when we bracket, compute HIC for the last point and the
    current point.

*/

#include    "hic.h"
#include    <stdio.h>

#define MINWIDTH        (3)     /* min # of sample points in an interval */

/* possible values for prevf & curf */
```

```
if( (s = (SUMTYPE *)malloc((maxn+3)*sizeof(SUMTYPE))) == NULL )
{
    printf("hiccomp: malloc bomb (%d bytes)\n",
        (maxn+3)*sizeof(SUMTYPE));
    return;
}

/* compute partial sums array */
partsum( s, hp->acc + hp->i0, maxn );

/* compute over entire array */
hicvs = HIC( 0, maxn );

i = 0;
j = maxn;
ave = HIC( i, j );
improve = YES;
iter = 0;
while( improve )
{
    /* if answer doesn't improve, then exit */
    improve = NO;

    /* work with 1st lim */
    while( 1 )
    {
        g = i + 1;
        aveg = HIC( g, j );

        /* better? */
        if( aveg >= ave )
        {
            /* yes */
            i = g;
            ave = aveg;
            improve = YES;
        }
        else
        {
            /* no, then the main vars (i & ave) are ok */
            /* and we should exit */
            break;
        }
    }

    /* work with 2nd lim */
    while( 1 )
    {
        g = j - 1;
        aveg = HIC( i, g );

        /* better? */
        if( aveg >= ave )
        {
            /* yes */
            j = g;
            ave = aveg;
            improve = YES;
        }


        else
        {
            /* no, then the main vars (i & ave) are ok */
            /* and we should exit */
            break;
        }
    }

    /* show them we are working */
    fprintf( stderr, "." );
    fflush( stderr );

    iter++;
}

if( debug )
{
    printf("Iter:%d, ave:%.3f i:%d, j:%d, hicvs:%.3f (%d,%d)\n",
        iter, ave, i, j, hicvs, 0, maxn );
}

/*
 * make one special check
 */
if( ave < hicvs )
{
    ave = hicvs;
    j = maxn;
    i = 0;
}

/* now compute the hic value */
hicv = ave * ((double)(ip->samptime)/1.0e6);

hp->hic = hicv;

hp->i1 = hp->i0 + i;
hp->i2 = hp->i0 + j;

/* free up the array */
free( s );
```

FIG. X2.1 HIC Calculation Program *(continued)*

```
/*
 * @(#)hic.h  v1.0  kpc 04/26/88 -- HIC 68k  defs for the hic computation



 * In here, we have several useful #defs,
 * several critical typedefs to adjust the precision & size of
 * the hic data items
 * and a structure that identifies a particular hic computation
 */

#define TRUE    (!0)
#define FALSE   (0)
#define YES     (!0)
#define NO      (0)

#define MAXPNTS (4096)          /* max number of pnts in an accel array */
#define MAXCHAN (4)             /* max number of channels to be digitized */
#define MAXLVL  (2)             /* max number of g levels for cum. dur. comp *,
#define FUZZ    (4)             /* number of elements to over allocate */

typedef short   Idx;            /* array index type */
typedef double  SUMTYPE;        /* what sums are computed as (HIC, SI, etc) */
typedef float   DTYPE;          /* what the data are stored as */
typedef short   SAMPTYPE;       /* adc sample type */

/*
 * struct for the computation parms
 * one set for each mode: Accel, Force, Voltage
 */
struct  comp_info   {
    float   thresh;     /* begin/end threshold */
    float   trans_cal;  /* transducer calib constant */
};
typedef struct comp_info        COMP;

/*
 * struct to hold all critical info for a HIC computaion
 */
struct hic_info {               /* info for 1 HIC computation/one channel */
    SUMTYPE     hic;            /* hic value */
    SUMTYPE     si;             /* si value */
    DTYPE       peak;           /* peak value in acc[] ([g] or volts) */
    DTYPE       maxd;   /*new*/ /* maximum displacement [m] */
                                /* the following are idx's into the acc arr. */
    Idx         i0;             /* begining of impulse */
    Idx         i1;             /* first critical time */
    Idx         ipk;            /* idx where Pk accel is */
    Idx         i0v;    /*new*/ /* idx where velocity is zero (hopefully) */
                                /* this is time of maximum displacement */
    Idx         i2;             /* second critical time */
    Idx         iend;           /* the end of the si computation */
    Idx         imax;           /* end of impact waveform (incld rebounds) */
    Idx         nsamp;          /* number of elements in samp[] & acc[] */

    SAMPTYPE    *samp;          /* ptr to array of samples (fixed point) */



    DTYPE       *acc;           /* ptr to array of accel pts ([g] or volts) */
};
typedef struct hic_info     HICINFO;        /* struct for each hic comp. */

/*
 * need a structure that can hold the global info for an impact
 * and upto 4 hic info structs.
 * The global info for an impact is:
 *  timestamp, velocity, desc of what was done,
 *  flags to indicate what config was used.
 *  including, which channels were dig'd & which channels
 *  are independant -- which channels had HIC computations done.
 *
 * kpc 12/31/90
 * added vel_ai, vel_ao, p_axis, vel_dx_i, vel_dx_o, off_axis, coef_rest
 * made flg a long
 */
struct impinfo  {               /* tracks multiple HIC structs */
    long        flg;            /* flag bits */

    short       nsamp;          /* number of pnts in the data arrays, samp[] */
                                /* and acc[], always a power of 2 */
    short       npre;           /* # of pretigger points */

    short       maxwin;         /* maximum event window, from beginning of */
                                /* impact (i0) (samples) */

    COMP        cparms;         /* computation parms */

    long        samptime;       /* delta-t in usec */

    short       wchan;          /* bitmap indicating which channels are valid */
                                /* channel bits are from the LSB on up */
                                /* ie channel 0 is BIT(0) */

    short       schan;          /* bitmap indicating which channels are saved */
                                /* in permanent storage */

    HICINFO     *chan[MAXCHAN]; /* ptrs to the hicinfo structs for each chan */
};
typedef struct impinfo      IMPINFO;        /* struct for each impact */
```

```
/*
 *@(#)scan.c v1.0 kpc 04/27/88 -- HIC 68k scan accel wave form & determine lims



 * this function scans the waveform converts to g from volts computes limits
 * if a parm is set, it will eliminate negative values in the wave form
 *
 */

#include    "hic.h"

/*
 * scans accel waveform check lims & look for pk value
 *
 * returns:
 *      1 - ok
 *      0 - misformed waveform
 */
static int      scan_acc( ip, chan, trunc )
IMPINFO     *ip;
int         trunc;      /* flag indicates whether to truncate negative values */
                        /* 0 -> do nothing to negative values */
                        /* 1 -> truncate negative values */
                        /* 2 -> take absolute value of negative values */
{
    Idx         i;
    DTYPE       min,max;
    Idx         mini, maxi;
    DTYPE       *dp;
    HICINFO     *hp;

    double      fabs();

    hp = ip->chan[chan];

    i = hp->nsamp;
    dp = hp->acc;

    /* handle negative points? */
    if( trunc == 1 )
    {
        while( i-- )
        {
            if( *dp < 0.0 )
                *dp = 0.0;
            dp++;
        }
    }
    else if( trunc == 2 )
    {
        while( i-- )
        {
            if( *dp < 0.0 )
                *dp *= -1.0;
            dp++;



        }
    }

    dp = hp->acc;
    for( i=0; i < hp->nsamp; i++ )
        if( fabs(dp[i]) >= ip->cparms.thresh )
            break;

    hp->maxd = 0.0;
    hp->hic = hp->si = 0.0;

    if( i >= hp->nsamp )
    {
        /* degenerate curve, all zero! */
        hp->i0 = hp->imax = hp->i0v = hp->ipk = hp->i1 = hp->i2 = hp->iend = 0;
        hp->peak = 0.0;

        return(0);
    }

    /* now we can get down to business */
    hp->i0 = i;
    hp->i1 = i;
    hp->i0v = i;

    /* now start at the end */
    dp = hp->acc;
    for( i=hp->nsamp; i--; )
        if( fabs(dp[i]) >= ip->cparms.thresh )
            break;

    if( i <= 0 || i <= (hp->i0 + 8) )
    {
        /* zero curve? */
        hp->i2 = hp->i0v = hp->imax = hp->ipk = 0;
        hp->peak = 0.0;

        return(0);
    }

    /* otherwise i is good */
    hp->imax = i;
    hp->i2 = i;

    /* find peak value */
    /* start at end of waveform */
    dp = hp->acc + hp->imax;
    /* the ctr runs backwards */
    i = hp->imax;

    max = min = *dp;
    maxi = mini = i;
    for( ; i >= hp->i0; )
    {
        if( *dp > max )
        {
            max = *dp;
            maxi = i;
        }
```

FIG. X2.1 HIC Calculation Program *(continued)*

```
        if( *dp < min )
        {
            min = *dp;
            mini = i;
        }

        dp--;
        i--;
    }

    hp->peak = max;
    hp->ipk  = maxi;

    /* now we need to compute the iend */
    /* find the first place the waveform goes below 'thresh' after the peak */
    dp = hp->acc + maxi;
    i = maxi;
    while( i < hp->imax )
    {
        if( *dp <= ip->cparms.thresh )
            break;

        dp++;
        i++;
    }

    hp->iend = i;

    return( 1 );
}
```

```
/*
 * @(#)utils.c v2.0 kpc




 * Raise a double to the 2.5 power
 */
double  power2( v )
double  v;
{
    double      val;

    double      sqrt();

    if( v <= 0.0 || v == 1.0 )
        return( v );

    val = v * v * sqrt( v );

    return( val );
}


/*
 * compute the partial sums of the
 * the acceleration waveform
 *
 * we assume the separation of the points is 1.
 * and thus the calling program must scale the result.
 */
void        partsum( dp, sp, n )
DTYPE       *sp;        /* src ptr */
SUMTYPE     *dp;        /* dest ptr */
Idx         n;
{
    double      num;    /* integral */

    num = 0.0;
    *dp++ = 0.0;
    sp++;

    while( n-- )
    {
        /* recursive trapazoidal rule */
        num = num + (sp[0] + sp[-1])/2.0;

        *dp++ = (SUMTYPE)num;
        sp++;
```

FIG. X2.1 HIC Calculation Program *(continued)*

Designation: D 5963 – 97a (Reapproved 2001)$^{\epsilon 1}$

Standard Test Method for Rubber Property—Abrasion Resistance (Rotary Drum Abrader)[1]

This standard is issued under the fixed designation D 5963; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Footnotes 7, 8, 9, and 10 were editorially updated in October 2002.

1. Scope

1.1 This test method covers the measurement of abrasion resistance of rubbers (vulcanized thermoset rubbers and thermoplastic elastomers) that are subject to abrasive/frictional wear in actual service. The abrasion resistance is measured by moving a test piece across the surface of an abrasive sheet mounted to a revolving drum, and is expressed as volume loss in mm^3 or abrasion resistance index in percent. For volume loss, a smaller number indicates better abrasion resistance, while for the abrasion resistance index, a smaller number denotes poorer abrasion resistance.

1.2 Test results obtained by this test method shall not be assumed to represent the wear behavior of rubber products experienced in actual service.

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 297 Test Methods for Rubber Products—Chemical Analysis[2]

D 1765 Classification System for Carbon Blacks Used in Rubber Products[2]

D 2240 Test Method for Rubber Property—Durometer Hardness[2]

D 3182 Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets[2]

D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[3]

2.2 *Other Standards:*

DIN 53516 Determination of Abrasion Resistance[4]

ISO 868 Plastics and Ebonite—Determination of Indentation Hardness by Means of a Durometer (Shore Hardness)[5]

ISO 2393 Rubber Test Mixes—Preparation, Mixing and Vulcanization—Equipment and Procedures[5]

ISO 2781 Rubber, Vulcanized—Determination of Density[5]

ISO 4649 Rubber—Determination of Abrasion Resistance Using a Rotating Cylindrical Drum Device[5]

ISO 5725 Precision of Test Methods—Determination of Repeatability and Reproducibility for a Standard Test Method by Interlaboratory Tests[5]

ISO 9298 Rubber Compounding Ingredients—Zone Oxide Test Methods[5]

3. Terminology

3.1 *abrasion loss, A,* (mm^3), *n*—the volume loss of a defined rubber test piece determined by sliding the test piece under specified conditions over the surface of an abrasive sheet of “nominal abrasiveness,” S_O, mounted to a rotating drum of specified dimensions.[6]

3.1.1 *Discussion*—The designation A_A is used to indicate that the test was run in accordance with Method A.

3.2 *abrasion resistance index ARI (%), n*—the ratio of the volume loss of a Standard Rubber to that of a test rubber expressed in percent, with the volume loss determined by

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[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.15 on Degradation Tests.

Current edition approved Nov. 10, 1997. Published May 1998.

This test method is an adaptation of ISO Standard 4649 (1985 revision), Rubber—Determination of Abrasion Resistance Using a Rotating Cylindrical Drum Device, and is being coordinated with a current draft revision of that standard (see Appendix X1).

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] *Annual Book of ASTM Standards*, Vol 09.02.

[4] Available from DIN (Deutches Institut Fuer Normung), Burggrafenstrasse 6, 10787,Berlin, Germany.

[5] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

[6] This corresponds to the test method of DIN 53516 and to Method A (Relative volume loss) of ISO 4649:1985. The same calculation could be made for the other test methods if the proper value for the “nominal abrasiveness,” S_0, for the test method were known or assumed. (150 mg has been indicated as a possible value for Method D but its accuracy has not been established to the degree of the Method A value.)

sliding a defined rubber test piece under specified conditions over the surface of an abrasive sheet of known abrasiveness *S* (180 to 220 mg) mounted to a rotating drum of specified dimensions.

3.2.1 *Discussion*—The designations ARI_A, ARI_B, ARI_C, and ARI_D are used to indicate that the test was run in accordance with Method A, B, C or D, respectively.

3.3 *"nominal abrasiveness," S_O of the abrasive sheet*, (mg), *n*—a specified (theoretical) mass loss of 200 mg of a defined test piece of a Standard Rubber, obtained by sliding the test piece under specified conditions over the surface of the abrasive sheet mounted to a rotating drum of specified dimensions.

3.4 *abrasiveness, S of the abrasive sheet*, (mg), *n*—the actual mass loss, within a specified range of 180 to 220 mg, of a defined test piece of a Standard Rubber, obtained by sliding the test piece under specified conditions over the surface of the abrasive sheet mounted to a rotating drum of specified dimensions.

3.5 *Standard Rubber*—A natural rubber compound of specified composition, mixed and vulcanized under defined conditions.

3.5.1 *Discussion*—Standard Rubber # 1 is used to determine the abrasiveness, *S*, of the abrasive sheet and to ensure that *S* is within the specified range of 180 to 220 mg. The ratio of the "nominal abrasiveness," S_O, and the actual abrasiveness, *S*, is used to correct the abrasion loss of a test rubber for any deviation of the abrasiveness of the abrasive sheet from the specified "nominal abrasiveness" (200 mg).

4. Summary of Test Method

4.1 This test method provides procedures for preparing cylindrical test pieces of specified dimensions from vulcanized thermoset rubbers or thermoplastic elastomers and for evaluating their abrasion resistance by sliding a test piece across the surface of an abrasive sheet attached to a rotating drum. It also describes the preparation and compliance testing of a Standard Rubber (see Annex A1).

4.2 The test is performed under specified conditions of contact pressure, sliding distance, and travel speed of the test piece, rotational speed of the drum, and degree of abrasiveness of the abrasive sheet.

4.3 The abrasiveness, *S*, of the abrasive sheet is defined by the mass loss in mg of a test piece prepared from Standard Rubber #1 when tested under the same specified conditions.

4.4 Four different methods may be used to test the abrasion resistance. Method A, uses a *non-rotating* test piece and Method B a *rotating* test piece, both utilizing Standard Rubber #1 as the reference. Methods C and D use Standard Rubber #2 as reference with a *non-rotating* and *rotating* test piece, respectively. The rotating test pieces provide, in many cases, a more uniform abrasion wear pattern.

4.5 The abrasion resistance, A_A, obtained in accordance with Method A is reported as abrasion (volume) loss in mm^3, calculated from the mass loss of the test piece, density of the test rubber and the abrasiveness of the abrasive sheet in relation to the "nominal abrasiveness," S_O, defined by a mass loss of 200 mg. A smaller number indicates a higher resistance to abrasion.

4.6 The abrasion resistance, ARI_{A-D}, obtained in accordance with Methods A, B, C and D is reported as the abrasion resistance index in percent, calculated from the mass losses and densities of the Standard Rubbers and test rubbers. A smaller number indicates a lower resistance to abrasion.

4.7 The mass loss obtained by the different methods can differ and the same method shall therefore be used if mass (and volume) losses are to be compared directly.

5. Significance and Use

5.1 Abrasion resistance is a performance factor of paramount importance for many rubber products, such as tires, conveyor belts, power transmission belts, hoses, footwear, and floor covering. A test capable of measuring resistance to abrasion of rubber, including uniformity of wear behavior under abrasive/frictional service conditions is therefore highly desirable.

5.2 This test method may be used to estimate the relative abrasion resistance of different rubbers. Since conditions of abrasive wear in service are complex and vary widely, no direct correlation between this accelerated test and actual performance can be assumed.

5.3 This test method is suitable for comparative testing, quality control, specification compliance testing, referee purposes, and research and development work.

6. Limitations

6.1 Test pieces containing voids or porosity, or both, will yield unreliable test results.

6.2 Test pieces that bounce (chatter) over the surface of the abrasive sheet rather than running smoothly will produce inaccurate test results.

6.3 Test pieces that tend to extensively smear the surface of the abrasive sheet will provide meaningless test results.

6.4 Test results obtained under any of the above conditions shall not be used to reach conclusions regarding the relative abrasion resistance of rubbers.

7. Apparatus and Materials

7.1 *Abrasion Tester.*[7]

7.1.1 The abrasion tester consists of a machine frame holding a laterally movable test piece holder, a rotary cylindrical drum to which an abrasive sheet can be fastened and a drive system as shown in Fig. 1. Dimensions are given in Fig. 2.

7.1.2 The diameter of the cylindrical drum shall be 150.0 ± 0.2 mm (5.906 ± 0.008 in.) and its length approximately 500 mm (20 in.), operating at a rotational frequency of 0.11 ± 0.003 rad/s (40 ± 1 rpm).

7.1.3 The abrasive sheet shall be bonded tightly to the drum using three evenly spaced double faced pressure-sensitive adhesive tapes, extending the full length of the drum. The tapes shall be about 50 mm (2 in.) wide and not more than 0.2 mm

---

[7] A suitable tester can be obtained under the name Zwick 6102 Abrasion Tester, from Zwick USA, 1620 Cobb International Blvd., Suite 1, Kennesaw, GA 30152, website: www.zwick.com, e-mail: info@zwickusa.com, or from Zwick GmbH & Co., August Nagel Strasse 11, Postfach 4350, D 89079 Ulm, Germany, website: www.zwick.de, e-mail: info@zwick.de.

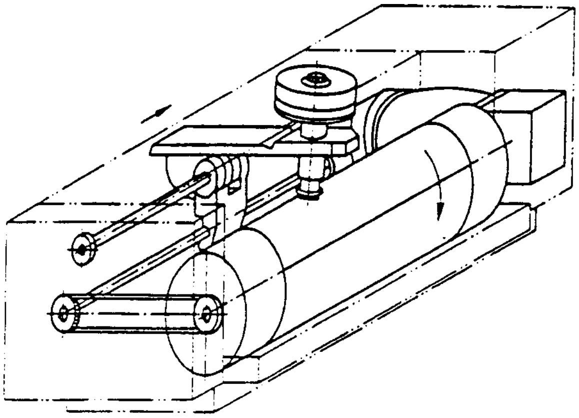

FIG. 1 Abrasion Tester

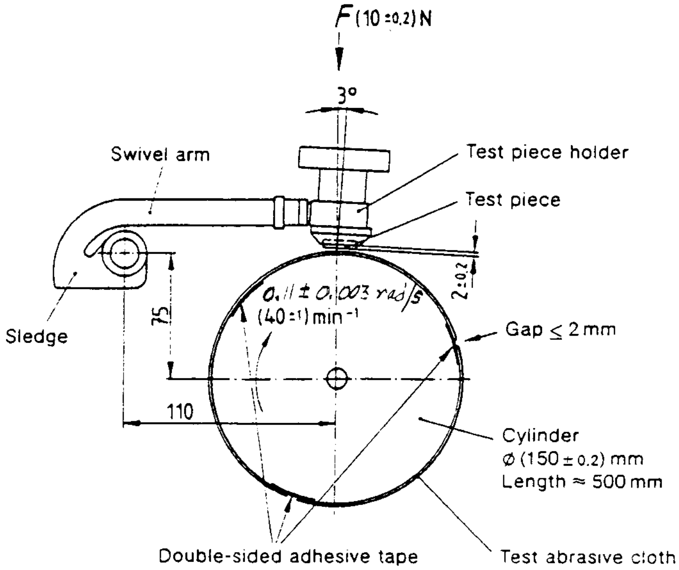

FIG. 2 Side View and Dimensions of Abrasion Tester

(0.008 in.) thick. The gap where the ends of the abrasive sheets meet on the adhesive tapes shall not exceed 2 mm (0.08 in.).

7.1.4 It is mandatory that the abrasive sheet is bonded to the drum in the direction of rotation marked on the surface or back of the sheet.

7.1.5 The test piece holder shall be mounted on a pivoted swivel arm, which can be swung into vertical position to insert and remove the test piece (see Note 1).

NOTE 1—It is recommended to install a device preventing the test piece holder and abrasive sheet from coming into contact and damaging each other.

7.1.6 Suitable attachments may be provided to rotate the test piece around its own axis during the test run by rotation of the test piece holder (Methods B and D). The test piece shall rotate at the rate of 1 revolution for each 50 revolutions of the cylindrical drum with the abrasive sheet fastened to the drum.

7.1.7 The center axis of the test piece holder shall have an angle of 3° to the perpendicular in the direction of rotation and the center of the test piece shall be within ±1 mm (±0.04 in.) directly above the longitudinal axis of the drum.

7.1.8 The design of the swivel arm and holder shall be such that the test piece is pressed against the abrasive sheet with a force of 10.0 ± 0.2 N (2.25 ± 0.04 lbf). Both swivel arm and holder shall be free from vibration during operation.

7.1.9 The test piece holder shall consist of a cylindrical opening with an adjustable diameter of at least 15.5 mm (0.610 in.) to 16.3 mm (0.642 in.) and a device for adjusting the length of the test piece protruding from the opening to 2.0 ± 0.2 mm (0.08 ± 0.008 in.).

7.1.10 The swivel arm with the test piece holder is connected to a worm gear that moves the holder on a guide rod laterally across the surface of the abrasive sheet attached to the cylindrical drum. The lateral displacement shall be approximately 4.2 mm (0.165 in.) per revolution of the drum, so that the test piece passes only four times across the same area of the sheet during one test cycle.

7.1.11 Placement of the holder with the test piece on the drum at the beginning of the test and removal at the end shall be automatic. The normal length of the abrasion path shall be 40.0 ± 0.2 m (131.2 ± 0.7 ft). This is equivalent to about 84 revolutions when allowing for the thickness of 1 mm (0.04 in.) for the abrasive sheet.

7.1.12 For special cases of very high volume loss, half the length of the abrasion path, that is, 20 ± 0.1 m (65.6 ± 0.3 ft), equivalent to roughly 42 revolutions, may be used.

7.1.13 The test machine may be equipped with a vacuum hose and a brush that contacts the drum and aids in the removal of debris.

7.2 *Abrasive Sheet.*[8]

7.2.1 Corundum (aluminum oxide) of grit 60 bonded to a carrier sheet of at least 400 mm (15.8 in.) width, 474 ± 1 mm (18.66 ± 0.04 in.) length and an average thickness of 1 mm (0.04 in.) shall be used as the abrasive medium.

7.2.2 The sheets shall be of an abrasiveness as to cause a mass loss between 180 and 220 mg when tested over an abrasion path of 40 m (131.2 ft) using a non-rotating test piece (Method A) of Standard Rubber #1 specified in Section 8.

7.2.3 Since the abrasiveness of virgin abrasive sheets is usually higher than desired, it is necessary to blunt the sheets with one or two test runs using a steel test piece in place of the Standard Rubber to bring it into the desired range. The direction of rotation used for blunting shall be marked on the sheets.

7.2.4 After blunting, the abrasive sheets shall be thoroughly cleaned by brushing, blowing, or suction and two test runs with the Standard Rubber shall be made.

7.2.5 Test results obtained with abrasive sheets, thus calibrated, are more consistent, and it is normally possible to run several hundred single tests using the same sheet.

7.3 *Test Piece Cutting Tool.*[9]

---

[8] Suitable abrasive sheets can be obtained under Item No. 1027.10–1 from Zwick USA, 1620 Cobb International Blvd., Suite 1, Kennesaw, GA 30152, website: www.zwick.com, e-mail: info@zwickusa.com, or from Bundesanstalt für Materialforschung und-prüfung (BAM), Unter den Eichen 87, Postfach POB, D 12200 Berlin, Germany, website: www.zwick.de, e-mail: info@zwick.de.

[9] A suitable cutting tool can be obtained under Item No. BH04.6102.060 from Zwick USA, 1620 Cobb International Blvd., Suite 1, Kennesaw, GA 30152, website: www.zwick.com, e-mail: info@zwickusa.com, or from Zwick GmbH & Co., August Nagel Strasse 11, Postfach 4350, D 89079 Ulm, Germany, website: www.zwick.de, e-mail: info@zwick.de.

Dimensions in millimeters

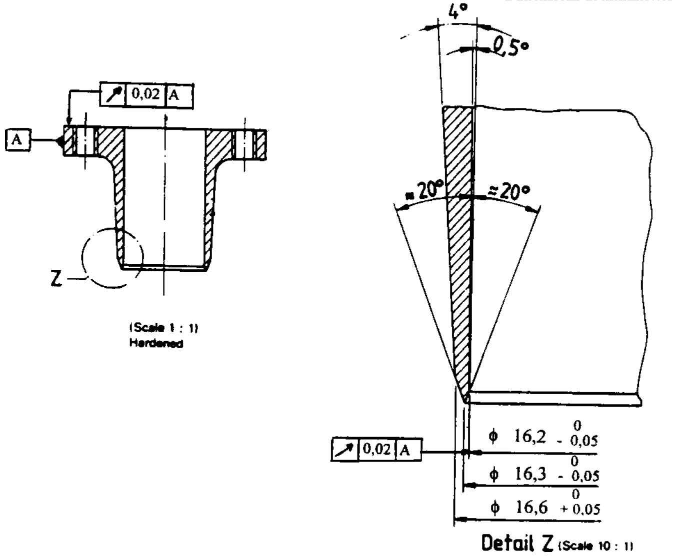

FIG. 3 Hollow Drill for Test Piece Preparation

7.3.1 The circular cutting tool for test piece preparation is a hollow drill made from hardened metal with dimensions shown in Fig. 3.

7.3.2 The rotational frequency of the drill should be about 2.65 rad/s (1000 rpm) and even higher for rubbers with a hardness of less than 50 Shore A (see Test Method D 2240 and ISO 868).

7.3.3 When cutting, the cutting edge of the drill shall be lubricated with water containing a wetting agent.

8. Standard Rubber

8.1 Sheets of Standard Rubber may be obtained commercially[10] or prepared in-house, following the directions given in Annex A1.

8.2 If prepared in-house, it is mandatory to test a commercially obtained reference sheet for comparison.

8.3 Standard Rubber sheets shall be stored under cool, dry, and dark conditions, and wrapped in a suitable protective covering such as polyehtylene film, which protects the sheets from ozone attack (see Note 2).

NOTE 2—Sheets of Standard Rubber stored under the above conditions remain usable for at least three years.

8.4 Standard Rubber sheets of satisfactory quality shall meet the requirements of Section A1.3.1 in Annex A1.

8.5 Standard Rubber test pieces may be used for up to three test runs per test piece (see 11.3).

9. Preparation of Rubber Test Pieces

9.1 Test pieces are cylindrical in shape with a diameter of 16 ± 0.2 mm (0.630 ± 0.008 in.) and a minimum thickness of 6 mm (0.24 in.).

9.2 They are cut from sheets of at least 6 mm (0.24 in.) thickness, using a hollow drill as described in 7.3.

9.3 Preparation of test pieces by die cutting is not permitted, but test pieces may be vulcanized or formed in an appropriate mold.

9.4 If test pieces of the required thickness are not available, the necessary thickness may be obtained by bonding a test piece of at least 2 mm (0.08 in.) to a base piece with a hardness of at least 80 Shore A (see Test Method D 2240 and ISO 868). Care shall be taken that test pieces prepared in this manner are not abraded down to the bond line.

9.5 When testing finished products such as fabric reinforced conveyor belts, test pieces shall be prepared, if possible, from the entire product including the fabric. In this case it is also important that test pieces are not abraded down to the adhesive layer or the fabric and that only the density of the rubber layer tested for abrasion is determined.

10. Procedure

10.1 The test shall be carried out at 23 ± 5°C (73 ± 9°F) and no sooner than 16 h after vulcanization or forming of the test compounds.

10.2 The density of the rubbers to be tested shall be determined using a hydrostatic method (see Test Methods D 297 or ISO 2781).

10.3 *Method A—Test Run*:

10.3.1 Method A is run with a non-rotating test piece, using Standard Rubber #1 as reference.

10.3.2 Prior to each test, any debris left on the abrasive sheet from a previous abrasion test shall be removed by vigorous brushing, blowing, or suction. If necessary, the sheet may be cleaned by running a blank test with the Standard Rubber in case the sheet has been smeared by a test piece from the previous test.

10.3.3 First, at least three test runs shall be made with the Standard Rubber, followed by a maximum of ten runs (see Note 3) with one or more rubbers to be tested (test series). This shall be followed by at least another three runs with the Standard Rubber.

NOTE 3—Do not split tests of one test rubber. Run nine tests, and so forth, if that completes the tests for a test rubber.

10.3.4 When more than one rubber is to be tested, the test runs for each rubber shall be carried out consecutively. Only one test run per test rubber piece is permitted.

10.3.5 At least three test pieces and, for referee purposes, ten test pieces shall be run. The results shall be expressed as the mean value.

10.3.6 The test pieces shall be weighed to the nearest 1 mg and firmly fixed into the holder so that it protrudes 2.0 ± 0.2 mm (0.08 ± 0.008 in.) from the opening of the holder. Turn the vacuum on if it is provided. The swivel arm is moved into starting position and the automatic test run is started (see Note 4).

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[10] Standard Rubber #1 sheets can be obtained from the following sources: Zwick USA, 1620 Cobb International Blvd., Suite 1, Kennesaw, GA 30152 under Item No. MA11.15-5/3, website: www.zwick.com, e-mail: info@zwickusa.com; Bundesanstalt für Materialforschung und Prüfung (BAM), Unter den Eichen 87, Postfach POB, D 12200 Berlin, Germany; Laboratoire de Recherches et de Controle du Caoutchouc et des Plastiques (LRCCP), 60 Rue Auber, F94408 Vitry Sur Seine, France. Standard rubber #2 sheets would normally be prepared by the user. Users who do not have the facilities to do so may request it from Rapra Technology Ltd., Shawbury, Shrewsbury, Shropshire, SY4 4NR, UK.

NOTE 4—A preparatory run to hollow-grind the test piece is not necessary.

10.3.7 There shall be no vibration in the test piece holder during the run. After completing an abrasion path of 40 m (131.2 ft), the test piece shall automatically disengage from the abrasive sheet.

10.3.8 The test piece is reweighed to the nearest 1 mg. Test pieces that have heated up during testing shall be conditioned to room temperature prior to weighing. Any loose material shall be removed from the test piece prior to weighing.

10.3.9 If there is a considerable loss in mass (400 mg or more per 40 m [131.2 ft] abrasion path), the test may be run by stopping the abrasion drum approximately halfway through the test, readjusting the test piece to protrude 2.0 ± 0.2 mm (0.08 ± 0.008 in.) from the opening of the holder and then complete the run. Care shall be taken that the test piece does not abrade to a thickness of less than 5 mm (0.2 in.).

10.3.10 If very high mass losses are encountered (600 mg or more per 40 m [131.2 ft] abrasion path), it may be necessary to terminate the test after an abrasion path of 20 m (65.6 ft). This shall be noted in the test report and the volume loss reported for an abrasion distance of 40 m (131.2 ft) by multiplying the value by two.

10.4 *Method B—Test Run*:

10.4.1 Method B is run with a rotating test piece. This applies to the test rubber as well as the Standard Rubber. Standard Rubber #1 is used as reference.

10.4.2 All other test conditions are the same as described in 10.3.

10.5 *Method C—Test Run*:

10.5.1 Method C is run with a non-rotating test piece. This applies to the test rubber as well as the Standard Rubber. Standard Rubber #2 is used as reference.

10.5.2 All other test conditions are the same as described in 10.3.

10.6 *Method D—Test Run*:

10.6.1 Method D is run with a rotating test piece. This applies to the test rubber as well as the Standard Rubber. Standard Rubber #2 is used as reference.

10.6.2 All other test conditions are the same as described in 10.3.

11. Determination of Abrasiveness of the Abrasive Sheet

11.1 The abrasiveness, *S*, of the sheet used for the test (expressed as mass loss in mg) shall be determined with the aid of the Standard Rubber #1 in at least three, or, for referee purposes, at least five test runs, both before and after each test series. The test procedure described in 10.3 shall be followed (Method A, non-rotating test piece).

11.2 The abrasiveness is reported as the mean value of the individual mass losses before and after each test series.

11.3 Up to three runs may be carried out with the same test piece of Standard Rubber, making certain that the test piece is placed into the holder the same way each time.

11.4 For test rubbers that have a tendency to smear, it may be necessary to determine the abrasiveness after each test run.

12. Calculation of Test Results

12.1 *Calculation of Abrasion Loss—Method A*:

12.1.1 Calculate the abrasion loss, A_A, the loss in mass (mean value of 3 to 10 single tests) shall be converted into volume loss using the density (volume loss equal mass loss divided by density) of the test rubber (see Note 5). The volume loss is then corrected by using the ratio $\frac{S_O}{S}$ where S_O is the “nominal abrasiveness” of the abrasive sheet and S that of the abrasive sheet used for the test. See Eq 1.

$$A_A = \frac{\Delta m_t \cdot S_0}{d_t \cdot S} \tag{1}$$

where:
A_A = abrasion loss in mm^3 (non-rotating test piece),
Δm_t = mass loss of the test piece in mg,
d_t = density of the test rubber in mg/m^3,
S_0 = “normal abbrasiveness” = 200 mg, and
S = abrasiveness in mg.

NOTE 5—The volume loss of non-porous test pieces may also be determined by forced immersion in a buoyant medium, such as water, before and after the test run, instead of weighing the loss in mass and converting this from the density. The volume for the test piece is then obtained by weighing the displaced mass of the buoyant medium.

12.2 *Calculation of Abrasion Resistance Index—Method A*:

12.2.1 To calculate the abrasion resistance index, ARI_A, the loss in mass (mean value of 3 to 10 single tests) shall be converted into volume loss using the density of the test rubber (see Note 5). The ratio of the volume loss of Standard Rubber #1 to that of the test rubber is then expressed in percent, as shown in Eq 2.

$$ARI_A = \frac{\Delta m_1 \cdot d_t}{\Delta m_t \cdot d_1} \cdot 100 \tag{2}$$

where:
ARI_A = abrasion resistance index in percent (non-rotating test piece),
Δm_1 = mass loss of the Standard Rubber #1 test piece in mg,
d_1 = density of Standard Rubber #1 in mg/m^3,
Δm_t = mass loss of the test rubber piece in mg, and
d_t = density of the test rubber in mg/m^3.

12.3 *Calculation of Abrasion Resistance Index—Method B*:

12.3.1 The abrasion resistance index, ARI_B, is calculated as described in 12.2.1 using Eq 3:

$$ARI_B = \frac{\Delta m_1 \cdot d_t}{\Delta m_t \cdot d_1} \cdot 100 \tag{3}$$

where:
ARI_B = abrasion resistance index in percent (rotating test piece),
Δm_1 = mass loss of the Standard Rubber #1 test piece in mg,
d_1 = density of Standard Rubber #1 in mg/m^3,
Δm_t = mass loss of the test rubber piece in mg, and
d_t = density of the test rubber in mg/m^3.

12.4 *Calculation of Abrasion Resistance Index—Method C*:

12.4.1 The abrasion resistance index, ARI_C, is calculated as described in 12.2.1 using Eq 4, except that Standard Rubber #2 is used instead of Standard Rubber #1.

$$ARI_C = \frac{\Delta m_2 \cdot d_t}{\Delta m_t \cdot d_2} \cdot 100 \tag{4}$$

where:

ARI_C = abrasion resistance index in percent (non-rotating test piece),

Δm_2 = mass loss of the Standard Rubber #2 test piece in mg, and

d_2 = density of Standard Rubber #2 in mg/m^3,

12.5 *Calculation of Abrasion Resistance Index—Method D*:

12.5.1 The abrasion resistance index, ARI_D, is calculated as described in 12.2.1 using Eq 5, except that Standard Rubber #2 is used instead of Standard Rubber #1.

$$ARI_D = \frac{\Delta m_2 \cdot d_t}{\Delta m_t \cdot d_2} \cdot 100 \tag{5}$$

where:

ARI_D = abrasion resistance index in percent (rotating test piece),

Δm_2 = mass loss of the Standard Rubber #2 test piece in mg, and

d_2 = density of Standard Rubber #2 in mg/m^3,

13. Test Report

13.1 Report the following information:

13.1.1 Type and identification of the product under test,

13.1.2 Date and temperature of testing,

13.1.3 Rubber compound details, if available (rubber type, vulcanization temperature and time),

13.1.4 Density of the test rubbers,

13.1.5 Method of test piece preparation (cut or molded),

13.1.6 Test method used: Method A, B, C or D,

13.1.7 The mean value of either the abrasion loss in mm^3 or the abrasion resistance index in percent,

13.1.8 The standard deviation of the test result (optional) and

13.1.9 Any deviations from standard test methods, especially if the length of the abrasion path was reduced from the specified 40 m (131.2 ft) to 20 m (65.6 ft).

14. Precision and Bias

14.1 The precision and Bias section deals with test results of Methods A, C, and D obtained in an international interlaboratory program organized in accordance with ISO 5725[11]. This section has been prepared in accordance with Practice D 4483, which is equivalent to ISO 5725. Refer to this practice for terminology and other statistical calculation details.

14.2 The precision results in this section give an estimate of the precision of Methods A, C, and D using the materials of the particular interlaboratory test program as described below. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that the parameters are applicable to the group of materials and the specific testing protocols of the test method. Abrasion tests were conducted for each rubber in triplicate on each of two days, separated by three to four days. A test result was reported as the mean of three individual test runs (abrasion loss in mm^3).

14.3 A Type 1 interlaboratory test program was conducted in 1986 with 16 participating laboratories, using five different vulcanized rubbers at different abrasion levels. The vulcanized rubbers were distributed in sheet form by one laboratory, and test pieces were cut from these sheets by each of the participating laboratories.

14.4 The precision is given in terms of *Sr, r,* (*r*), *SR, R,* and (*R*) for the measured abrasion loss values.

14.5 The precision of the test method may be expressed in the format of the following statements which use an "appropriate value" of *r, R,* (*r*), or (*R*), that is, that value to be used in decisions about test results obtained with this test method. The appropriate value is that value of *r* or *R* associated with the mean level in Tables 1-3 closest to the mean level under consideration (at any given time, for any given material) in routine testing operations.

14.6 *Repeatability*—The repeatability, *r,* of this test method has been established as the appropriate value tabulated in Tables 1-3. Two single test results obtained under normal test method procedures that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or nonidentical sample populations.

14.7 *Reproducibility*—The reproducibility, *R,* of this test method has been established as the appropriate value tabulated in Tables 1-3. Two single test results obtained in two different laboratories under normal test method procedures that differ by more than the tabulated *R* (for any given value) must be considered to have come from different or nonidentical sample populations.

14.8 Repeatability and reproducibility expressed as percent of the mean level (*r*) and (*R*), have equivalent application statements as above for *r* and *R*. For (*r*) and (*R*) statements, the

TABLE 1 Type 1 Precision (Method A: Non-Rotating Test Piece)

Test Rubber Compound	Property Mean Abrasion Loss *A* (mm^3)	Within Laboratory			Between Laboratory		
		S_r	*r*	(*r*)	S_R	*R*	(*R*)
A (NR/BR)	68	2.3	6.5	9.6	6.6	18.8	27.6
B (NR/SBR)	106	3.8	10.8	10.2	7.6	21.4	20.2
C (NR)	160	8.2	23.2	14.5	10.7	30.4	19.0
D (IIR)	257	10.7	30.2	11.8	20.3	57.5	22.4
E (EPDM)	345	14.1	39.8	11.5	29.3	83.0	24.1

NOTE 1—S_r = repeatability standard deviation in measurement units; *r* = repeatability = 2.83 × S_r (in measurement units); (*r*) = repeatability in percent of the mean; S_R = reproducibility standard deviation in measurement units; *R* = reproducibility = 2.83 × S_r (in measurement units); and (*R*) = reproducibility in percent of the mean.

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[11] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D11-1079.

TABLE 2 Type 1 Precision (Method C: Non-Rotating Test Piece)

Test Rubber Compound	Property Mean Abrasion Loss *A* (mm^3)	Within Laboratory			Between Laboratory		
		S_r	r	(r)	S_R	R	(R)
A (NR/BR)	157	10.9	30.8	19.6	21.1	59.6	38.0
B (NR/SBR)	102	5.3	15.0	14.7	6.7	19.1	18.7
C (NR)	67	3.2	9.1	13.6	4.8	13.6	20.3
D (IIR)	43	2.8	7.9	18.4	3.6	10.2	23.7
E (EPDM)	32	1.3	3.8	11.9	2.5	7.2	22.5

NOTE 1—S_r = repeatability standard deviation in measurement units; r = repeatability = 2.83 × S_r (in measurement units); (r) = repeatability in percent of the mean; S_R = reproducibility standard deviation in measurement units; R = reproducibility = 2.83 × S_r (in measurement units); and (R) = reproducibility in percent of the mean.

TABLE 3 Type 1 Precision (Method D: Rotating Test Piece)

Test Rubber Compound	Property Mean Abrasion Loss *A* (mm^3)	Within Laboratory			Between Laboratory		
		S_r	r	(r)	S_R	R	(R)
A (NR/BR)	144	7.1	20.2	14.0	16.2	45.8	31.8
B (NR/SBR)	101	3.4	9.6	9.5	5.6	15.9	15.7
C (NR)	71	2.5	7.0	9.9	3.9	11.0	15.5
D (IIR)	43	1.2	3.4	7.9	1.9	5.3	12.3
E (EPDM)	34	1.2	3.3	9.7	2.5	7.2	21.2

NOTE 1—S_r = repeatability standard deviation in measurement units; r = repeatability = 2.83 × S_r (in measurement units); (r) = repeatability in percent of the mean; S_R = reproducibility standard deviation in measurement units; R = reproducibility = 2.83 × S_r (in measurement units); and (R) = reproducibility in percent of the mean.

difference in the two single test results is expressed as a percent of the arithmetic mean of the two-test results.

14.9 In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the values of abrasion loss are exclusively defined by this test method. Bias, therefore, cannot be determined.

ANNEX

(Mandatory Information)

A1. STANDARD RUBBERS FORMULA, MIXING, VULCANIZATION AND COMPLIANCE TESTING

A1.1 Preparation of Standard Rubber #1 for Method A and Method B

A1.1.1 The formula for Standard Rubber #1 is given in Table A1.1.

A1.1.2 *Mixing*:

A1.1.2.1 The following procedure is recommended in mixing the Standard Rubber:

NOTE A1.1—Other mixing procedures may be employed provided they yield good dispersion of the ingredients and produce a Standard Rubber in compliance with requirements set forth in Section A1.3.1.

A1.1.2.1.1 An internal mixer with a capacity to accommodate batch sizes of 3000 to 4000 g (6.6 to 8.8 lbs) has been found suitable to produce a Standard Rubber of acceptable quality.

A1.1.2.1.2 The internal mixer typically has a chamber colume of 4.6 I (measured with wheat grain) and is charged with 2000 g of natural rubber, bringing the fill factor of the finished compound to 65 ± 5 %. Mixing is carried out at a rotor speed of about 0.080 rad/s (30 rpm), with full cooling turned on and following the procedure outlined in Table A1.2.

A1.1.2.1.3 After dropping the stock from the internal mixer, it is homogenized on a two roll rubber mill at a nip setting of 0.5 mm (0.02 in.) and a surface temperature of 50 ± 5°C (122 ± 9°F), by making about four ¾ cuts from alternate end of the roll and crossblending for about 5 min. The rolled sheet is then passed endwise through the nip until it is sheeted from the mill at a nip setting of 5 mm (0.2 in.) after 10 min total mixing time. Final batch temperature shall be approximately 70°C (158°F).

A1.1.2.1.4 The two mill rolls shall have a nominal diameter of 250 mm (10 in.), a working width of 400 mm (16 in.), and a rotational frequency of about 0.032/0.048 rad/s (12/18 rpm), giving a friction ratio of 1:1.5.

A1.1.3 *Vulcanization*:

TABLE A1.1 Standard Rubber #1

Ingredients	Parts by Mass
Natural rubber, SMR L	100.0
2.2′ Dibenzothiazyl disulfide[A]	1.8
N-Isopropyl-N′-phenyl-p-phenylene diamine[B]	1.0
Zinc oxide,[C] ISO 9298, Class B4c[D]	50.0
N 330 carbon black[E]	36.0
Sulfur	2.5
TOTAL	191.3

NOTE—If optimum reproducibility is desired, the following materials shall be used:
Vulkacit DM/C[A] and Vulkanox 4010 NA/LG[B] from Bayer Corporation, 2603 West Market Street, Akron, OH 44313 or Bayer AG, Rubber Business Group, D 51368 Leverkusen—Bayerwerk, Germany.

[C] Zinkweiss G9 available from Grillo Zinkoxid GmbH, Halberstädter Strasse 15, D 38644 Goslar, Germany.

[D] Zinc oxide, ISO 9298, Class B4c is an indirect (French process) type with the following typical properties: 99.0 % zinc oxide, 0.25 % lead, 0.05 % cadmium, surface area 9.0 m^2/g, volatile matter 0.3 %, sieve residue (45 µm) 0.05 %, acidity 0.12 g sulfuric acid/100 g, copper 0.001 %, manganese 0.001 %, acid-insoluble 0.1 % and water-soluble 0.2 %.

[E] Corax N 330 from Degussa Corporation, 3500 Embassy Parkway, Akron, OH 44333 or Degussa AG, Dept. AC-KP-AT, D 50354 Hürth—Werk Kalscheuren, Germany.

TABLE A1.2 Mixing Procedure

Addition	min
Rubber	0
Ingredients A, B, C—premixed	7.5
Carbon black	11
Sulfur	14
Dump at 100 to 110°C (212 to 230°F)	18

A1.1.3.1 Blanks are prepared by plying up milled sheets and weighing them to an excess mass of approximately 7 %. The blank is inserted into a mold, preheated to 150 ± 2°C (302 ± 4°F).

A1.1.3.2 The mold is placed into the press, and after applying several bumping cycles, vulcanization is carried out for 20 ± 1 min under a pressure of at least 3.5 MPa (508 psi). It is recommended that the pressure be applied slowly.

A1.1.3.3 Recommended dimensions of the vulcanized sheets are 8 × 116 × 182 mm (0.32 × 4.57 × 7.17 in.), yielding approximately 60 test pieces.

A1.1.3.4 After vulcanization, sheets of the Standard Rubber shall be conditioned at ambient conditions for at least 16 h prior to use.

A1.1.3.5 The hardness in Shore A[8] of each sheet shall be measured at a minimum of five different locations and the median reported. The mean of the median values of all sheets from one lot shall be 60 ± 3 Shore A.

A1.2 Preparation of Standard Rubber #2 for Method C and Method D

A1.2.1 The formula for Standard Rubber #2 is given in Table A1.3.

A1.2.2 *Mixing and Vulcanization*:

TABLE A1.3 Standard Rubber #2

Ingredients	Parts by Mass
Natural rubber, SMR 5	100.0
Stearic acid	2.0
Zinc oxide	5.0
N 330 carbon black[A]	50.0
N-Isopropyl-N′-phenyl-p-phenylene diamine	1.0
Cyclohexyl benzothiazole sulfenamide	0.5
Sulfur	2.5
TOTAL	161.0

[A] For referee purposes the current Industry Reference Black (IRB) should be used (see Classification D 1765); this may, however, generate different test results.

A1.2.2.1 Mixing shall be carried out with equipment and procedures described in Practice D 3182 or ISO 2393.

A1.2.2.2 Vulcanization of sheets for the preparation of test pieces shall be carried out in accordance with Practice D 3182 or ISO 2393 at 140 ± 2°C (284 ± 4°F) for 60 min.

A1.2.2.3 The dimensions of the sheets shall meet the guidelines outlined in A1.3.3.

A1.3 Compliance Testing for Mass Loss

A1.3.1 Compliance testing for mass loss of Standard Rubbers shall be conducted no sooner than 16 hours and no later than seven days after vulcanization.

A1.3.2 One sheet is selected from each lot of Standard Rubber, prepared in accordance with Sections A1.1 or A1.2. Fifteen test pieces are cut from each sheet in accordance with Section 9. If several lots are prepared under the same conditions by the same operator over a period of one or two days, one sheet shall be selected for every fifth lot.

A1.3.3 The mass losses of fifteen test pieces of a (commercial) reference material (see 8.1) are determined first. Each test piece is run three times, the median reported and the mean calculated from the fifteen median values. This mean serves as the reference value.

A1.3.4 The same procedure is repeated for the fifteen test pieces of each sheet of Standard Rubber. The difference between the mean of the reference material and the mean of each lot (sheet) of Standard Rubber shall not exceed 15 mg.

A1.3.5 All compliance testing for mass loss shall be conducted with abrasive sheets especially conditioned and reserved for this purpose. The abrasiveness of these sheets, determined as the mean of fifteen median values for the reference material, shall be between 200 and 220 mg for Standard Rubber #1, when tested in accordance with A1.3.3, using Method A (non-rotating test piece).

A1.3.6 It has been determined that Standard Rubber #2 yields an abrasion loss of about 150 mg when tested in accordance with Method D (rotating test piece).

A1.3.7 It is recommended to retain test pieces of a number of Standard Rubber sheets as references for future lots of Standard Rubber. The test pieces shall be stored as described in 8.3.

APPENDIX

(Nonmandatory Information)

X1. BACKGROUND INFORMATION

X1.1 The method described in this test method is in substantial agreement with a current draft revision of ISO 4649:1985, Rubber—Determination of Abrasion Resistance Using a Rotating Drum Device, with the minor exception noted below. Some elements of the German Standard DIN 53516, Determination of Abrasion Resistance, for forerunner of ISO 4649, have been retained in this test method.

X1.2 This method specifies 10 N as the only force for pressing the test piece against the revolving abrasive drum (the same as in DIN 53516). ISO 4649 allows the use of an alternate force of 5 N.

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Standard Consumer Safety Performance Specification for Playground Equipment for Public Use[1]

INTRODUCTION

This consumer safety performance specification establishes nationally recognized safety standards for public playground equipment to address injuries identified by the U.S. Consumer Product Safety Commission (CPSC).

During 1999 the CPSC estimated that about 156 000 victims were treated in U.S. hospital emergency rooms for injuries associated with public playground equipment. About three fourths of these injuries resulted from falls, primarily to the surface on which the equipment was located. Other hazard patterns involved impact by swings and other moving equipment and contact with protrusions, pinch points, and sharp edges. Fatalities reported to the CPSC resulted from falls; entanglement of clothing or similar items on equipment; entanglement in ropes tied to or caught on equipment; head entrapment; impact by equipment that tipped over or otherwise failed; and impact by moving swings. This consumer safety performance specification does not eliminate the need for supervision of children on public playground equipment. It is intended to minimize the likelihood of life-threatening or debilitating injuries, such as those identified by the CPSC.

There has been significant harmonization of this performance specification and CAN/CSA-Z614.

1. Scope

1.1 This consumer safety performance specification provides safety and performance standards for various types of public playground equipment. Its purpose is to reduce life-threatening and debilitating injuries.

1.2 The range of users encompassed by this consumer safety performance specification is the 5th percentile 2-year-old through the 95th percentile 12-year-old.

1.3 Home playground equipment, amusement park equipment, sports equipment, fitness equipment intended for users over the age of 12, and soft contained play equipment are not included in this specification.

1.4 This consumer safety performance specification includes the following sections:

Title	Section Number
Scope	1
Referenced Documents	2
Terminology	3
Materials and Manufacture	4
General Requirements	5
Performance Requirements	6
Requirements for Access/Egress	7
Equipment	8
Public Use Playground Layout	9
Accessibility	10
Installation	11
Structural Integrity	12
Maintenance	13
Labeling	14
Figures	Annex A1

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are for information only.

NOTE 1—The conversion factor from inch-pound to metric units is 1 in. = 25.4 mm, and 1 lb = 0.45359 kg.

NOTE 2—See Annex A1 for figures referenced throughout this specification.

NOTE 3—General dimensional tolerances for this specification (unless otherwise noted) are as follows:

Dimension	Tolerance
X in.	±0.5 in.
X.X in.	±0.05 in.
X.XX in.	±0.005 in.

2. Referenced Documents

2.1 *ASTM Standards:*

D 2240 Test Method for Rubber Property—Durometer Hardness[2]

F 698 Specification for Physical Information to be Provided for Amusement Rides and Devices[3]

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[1] This specification is under the jurisdiction of ASTM Committee F15 on Consumer Products and is the direct responsibility of Subcommittee F15.29 on Playground Equipment for Public Use.

Current edition approved June 10, 2001. Published August 2001. Originally published as F 1487 – 93. Last previous edition F 1487 – 98.

[2] *Annual Book of ASTM Standards*, Vol 09.01.

[3] *Annual Book of ASTM Standards*, Vol 15.07.

F 846 Guide for Testing Performance of Amusement Rides and Devices[3]
F 853 Practice for Maintenance Procedures for Amusement Rides and Devices[3]
F 893 Guide for Inspection of Amusement Rides and Devices[3]
F 1004 Consumer Safety Specification for Expansion Gates and Expandable Enclosures[3]
F 1077 Guide for the Selection of Committee F-16 Fastener Specifications[4]
F 1148 Consumer Safety Performance Specification for Home Playground Equipment[3]
F 1159 Practice for the Design and Manufacture of Amusement Rides and Devices[3]
F 1292 Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment[3]
F 1951 Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment[3]

2.2 *ANSI Standards:*[5]
Z535.1 Safety Color Code
Z535.4 Products Safety—Signs and Labels

2.3 *Federal Standards:*[6]
16 CFR Part 1303 Ban of Lead-Containing Paint and Certain Consumer Products Bearing Lead-Containing Paint
16 CFR 1500 Hazardous Substances Act Regulations, including Sections:
1500.48 Technical Requirements for Determining a Sharp Point in Toys and Other Articles Intended for Use by Children Under 8 Years of Age
1500.49 Technical Requirements for Determining a Sharp Metal or Glass Edge in Toys and Other Articles Intended for Use by Children Under 8 Years of Age
16 CFR Section 1501 Method for Identifying Toys and Other Articles Intended for Use by Children Under 3 Years of Age Which Present Choking, Aspiration or Ingestion Hazards Because of Small Parts
36 CFR Part 1191 Americans with Disabilities Act Disability Accessibility Guidelines (ADAAG) for Buildings and Facilities; Section 15.6 Play Areas

2.4 *UL Standards:* [7]
UL 969 Standard for Safety: Marking and Labeling Systems

2.5 *CSA Standards:*[8]
CAN/CSA-Z614 Children's Playspaces and Equipment

3. Terminology

3.1 *Descriptions of Terms Specific to This Standard:*

3.1.1 *accessible*, *adj*—relating to a part or portion of the playground equipment, (*1*) capable of being contacted by any body part, or (*2*) accessible to and usable by persons with disabilities.

3.1.2 *accessible playground*, *n*—playground equipment area, that, when viewed in its entirety, may be approached, and entered and provides a range of play opportunities and experiences to users of varying abilities.

3.1.3 *accessible route*, *n— to a piece of playground equipment*, a continuous unobstructed pathway from the perimeter of the use zone to the equipment.

3.1.4 *adjacent platforms*, *n*—two platforms having a common vertical plane with some deviation in their height.

3.1.5 *completely bounded opening*, *n*—any opening in a piece of play equipment that is totally enclosed by boundaries on all sides so that the perimeter of the opening is continuous.

3.1.6 *component*, *n*—of a play structure, any portion thereof that generates specific activity and cannot stand alone.

3.1.7 *composite play structure*, *n*—two or more play structures attached or functionally linked, to create one integral unit that provides more than one play activity; an example is a combination climber, slide, and horizontal ladder.

3.1.8 *designated play surface*, *n*—any elevated surface for standing, walking, sitting, or climbing, or a flat surface larger than 2.0 in. (51 mm) wide by 2.0 in. (51 mm) long having less than 30° angle from horizontal.

3.1.9 *enclosed swing seat*, *n*—a suspended device upon which a user sits with non-removable supports on all sides of a user, which are intended to prevent a user from falling off the device while it is in motion.

3.1.10 *entanglement*, *n*—a condition in which the user's clothes or something around the user's neck becomes caught or entwined on a component of playground equipment.

3.1.11 *entrapment*, *n*—any condition which impedes withdrawal of a body or body part that has penetrated an opening.

3.1.12 *fall height*, *n*—the vertical distance between a designated play surface and the protective surfacing beneath it.

3.1.13 *flexible component*, *n*—any part of the playground equipment, excluding swings, that temporarily changes its shape when in use; examples include the tire net, the cargo net, and the log bridge.

3.1.14 *functionally linked play structure*, *n*— a play structure that acts as a single unit in its physical form or sense of function as continuous play even if the components are not physically attached.

3.1.15 *guardrail*, *n*—a device around an elevated surface that prevents inadvertent falls from the elevated surface.

3.1.16 *handrail*, *n*—a rigid linear device, following the path of access or egress, that when grasped, provides balance and support in maintaining a specific body posture.

3.1.17 *maximum user*, *n*—a 12-year-old child; measurement characteristics are the 95th percentile values for combined sexes.

3.1.18 *minimum user*, *n*—a 2-year-old child; measurement characteristics are the 5th percentile values for combined sexes.

3.1.19 *partially bounded opening*, *n*—any opening in a piece of play equipment that is not totally enclosed by

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[4] *Annual Book of ASTM Standards*, Vol 15.08.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[6] *Code of Federal Regulations*, available from U.S. Government Printing Office, Washington, DC 20402.

[7] Available from Underwriters Laboratories, Inc., 333 Pfingsten Rd., Northbrook, IL 60062.

[8] Available from Canadian Standards Association, Etobicoke (Toronto), 178 Rexdale Blvd., Etobicoke (Toronto), ON M9W 1R3.

boundaries on all sides so that the perimeter of the opening is discontinuous.

3.1.20 *pinch, crush, and shear point*, *n*— the juncture at which the user could suffer contusion, laceration, abrasion, amputation, or fracture during use of the playground equipment.

3.1.21 *platform*, *n*—a flat surface, intended for more than one user to stand, and upon which the user(s) can move freely.

3.1.22 *play structure*, *n*—a free standing structure with one or more components and their supporting members.

3.1.23 *preventive maintenance*, *n*—a planned program of inspections and maintenance intended to keep equipment functioning properly and to forestall equipment failures.

3.1.24 *professional judgment*, *n*—the ability of an individual with current knowledge, skill or experience, or both, in the field of playgrounds/playground equipment design, use, or operations, which enables the person to form an opinion or make a decision, or both, concerning a matter within that field of expertise.

3.1.25 *projection*, *n*—a condition which, due to its physical nature, must be tested to the requirements of this standard to determine whether it is a protrusion or entanglement hazard, or both.

3.1.26 *protective barrier*, *n*—an enclosing device around an elevated surface that prevents both inadvertent and deliberate attempts to pass through the device.

3.1.27 *protective surfacing*, *n*—material(s) to be used within the use zone of any playground equipment.

3.1.27.1 *Discussion*—Protective surfacing shall meet the minimum impact attenuation requirements of Specification F 1292.

3.1.28 *protrusion*, *n*—a projection which, when tested in accordance with the requirements of this standard, is found to be a hazard having the potential to cause bodily injury to a user who impacts it.

3.1.29 *public use playground equipment*, *n*— a play structure anchored to the ground or not intended to be moved, for use in play areas of schools, parks, child-care facilities, institutions, multiple-family dwellings, private resorts and recreation developments, restaurants, and other areas of public use.

3.1.29.1 *Discussion*—Requirements for amusement park equipment, sports use, and home playground equipment are covered in Specifications F 698 and F 1148, Guides F 846 and F 893, and Practices F 853 and F 1159.

3.1.30 *rocking/springing equipment*, *n*—any play structure that rocks about a fixed base.

3.1.31 *rotating equipment*, *n*—any play structure that moves about a vertical or horizontal axis (for example, a merry-go-round, whirl, logroll, or spinner).

3.1.32 *rotating swing*, *n*—a play structure with at least one suspended seat designed for swinging by the user, in a seated position, in more than one plane and spins about its axis.

3.1.33 *rung*, *n*—a crosspiece in a ladder or other climbing equipment used for supporting the user's feet or for grasping by the user's hands, or both.

3.1.34 *sharp edge*, *n*—an edge that can cut a user's skin.

3.1.34.1 *Discussion*—An edge is judged as potentially sharp pursuant to the provisions of 16 CFR Section 1500.49.

3.1.35 *sharp point*, *n*—a point that can puncture or lacerate a user's skin during use.

3.1.35.1 *Discussion*—A point is judged as potentially sharp pursuant to the provisions of 16 CFR Section 1500.48.

3.1.36 *signal word*, *n*—the word that designates a degree or level of hazard.

3.1.36.1 *Discussion*—The signal word for safety labels is WARNING.

3.1.37 *small part*, *n*—an object that may become detached and presents a choking, aspiration, or ingestion hazard to the user.

3.1.37.1 *Discussion*—A small part is determined to be a hazard pursuant to the provision of 16 CFR Part 1501.

3.1.38 *stability*, *n*—the ability of the playground equipment to withstand anticipated forces which act to tip or slide the playground equipment when properly assembled and installed.

3.1.39 *stair*, *n*—a device having a slope of 50° or less from a horizontal plane and consisting of a series of steps that can be used for ascending and descending.

3.1.40 *stationary equipment*, *n*—any play structure which has a fixed base and does not move.

3.1.41 *step*, *n*—a horizontal flat crosspiece of a ladder or stair used primarily as a foot support.

3.1.41.1 *Discussion*—Also referred to as a *tread.*

3.1.42 *swing bay*, *n*—the space beneath the overhead beam bounded by one or more supports on which swing assembly or assemblies are attached.

3.1.43 *to-fro swing*, *n*—a play structure with at least one suspended component designed for swinging by the user in a single vertical plane, such as a seat, ring, bar, platform, or net.

3.1.44 *track rides*—play components designed for coasting, with a rolling mechanism enclosed within or surrounding a track.

3.1.45 *transfer point*, *n*—a platform along an accessible route of travel or an accessible platform provided to allow a child in a wheelchair to transfer from the chair onto the equipment.

3.1.46 *trip hazard*, *n*—an abrupt change in elevation that is not clear and obvious to the user.

3.1.47 *upper body equipment*, *n*—overhead component designed to support a child by the hands only (for example, horizontal ladders, chinning bars, and ring ladders).

3.1.48 *use zone*, *n*—the area beneath and immediately adjacent to a play structure or equipment that is designated for unrestricted circulation around the equipment and on whose surface it is predicted that a user would land when falling from or exiting the equipment.

3.1.48.1 *Discussion*—The surface area within the use zone shall meet the minimum impact attenuation requirements of Specification F 1292 from the maximum fall height.

3.1.49 *warning*, *n*—a notice or communication to indicate a potentially hazardous situation that if not avoided could result in death or serious injury.

4. Materials and Manufacture

4.1 *General Requirements*—Playground equipment shall be manufactured and constructed only of materials that have a demonstrated durability in the playground or similar outdoor setting. Any new materials shall be documented or tested accordingly for durability by the playground equipment manufacturer.

4.1.1 Metals subject to structural degradation such as rust or corrosion shall be painted, galvanized, or otherwise treated. Woods shall be naturally rot- and insect-resistant or treated to avoid such deterioration. Plastics and other materials that experience ultraviolet (UV) degradation shall be protected against ultraviolet light.

4.1.2 Regardless of the material or the treatment process, the manufacturer shall ensure that the users of the playground equipment cannot ingest, inhale, or absorb any potentially hazardous amounts of substances through body surfaces as a result of contact with the equipment. All paints or other similar finishes shall comply with 16 CFR Part 1303.

4.1.3 Wood intended for playground equipment that is not naturally rot- and insect-resistant shall be treated to resist rot and insect attack from standard procedures. Any wood not naturally rot- and insect-resistant, which has any fabrication up to 6 in. (150 mm) above, or any portion at or below the level of the protective surface of the playground, shall be treated after wood fabrication. Deviations shall have independent documentation of durability. Creosote, pentachlorophenol, tributyl tin oxide, and surface coatings that contain pesticides shall not be used for playground equipment. Wood treaters and playground equipment manufacturers shall practice technologies and procedures that minimize the level of dislodgeable toxin.

4.2 All fasteners used to construct public playground equipment shall be manufactured in accordance with Guide F 1077 and shall meet the requirements of Section 4.

4.2.1 All fasteners, connecting, and covering devices shall be inherently corrosion resistant or be provided with a corrosion-resistant coating.

4.2.2 When installed in accordance with the manufacturer's instructions, fasteners, connecting, and covering devices shall not loosen or be removable without the use of tools. Lock washers, self-locking nuts, or other locking means shall be provided for all nuts and bolts to protect them from detachment. Hardware in moving joints shall also be secured against unintentional loosening.

4.2.3 Moving suspended elements shall be connected to the fixed support with bearings or bearing surfaces that serve to reduce friction or wear.

4.2.3.1 Steel cable that is permanently affixed to a hanger assembly performs as a bearing surface. Cable ends should be inaccessible or capped to prevent injury from frayed wires. Cables and steel-cored ropes should be protected to prevent fraying, loosening, unraveling, or excessive shifting of joints.

4.2.4 Hooks and connecting devices shall be subject to the requirements of 6.4.5.

4.3 *Tires*

4.3.1 Tires shall not trap water.

4.3.2 Tires shall not have exposed steel belts.

5. General Requirements

5.1 Playground equipment represented as complying with this consumer safety performance specification shall meet all applicable requirements specified herein. Anyone representing compliance with this specification shall keep such essential records as are necessary to document any claim that the requirements within this specification have been met.

5.2 Play equipment designed for a specific age group (2 through 5, 5 through 12, 2 through 12) shall have all play activities on that equipment meet the requirements for that age group.

5.3 *Small Parts*—When installed in accordance with the manufacturer's instructions, equipment for children under 3 years of age shall meet the requirements of 16 CFR Part 1501.

6. Performance Requirements

6.1 *Head and Neck Entrapment*—Public playground equipment shall be designed and constructed or assembled so that any accessible opening shall meet the following performance requirements to reduce the risk of accidental head or neck entrapment by either a head-first or feet-first entry into the opening. Openings between the protective surfacing and the bottom edge of the equipment (that is, rails, platforms, steps, and so forth) are exempt from this requirement as indicated by Fig. A1.1.

6.1.1 *Accessible Openings*—A completely bounded rigid opening is accessible when a torso test probe (see Fig. A1.2) can be inserted into the opening to a depth of 4.0 in. (102 mm) or more.

6.1.1.1 *Test Procedure for Completely Bounded Rigid Openings*—Place the torso probe (see Fig. A1.2) in the opening with the plane of the base of the probe parallel to the plane of the opening; rotate the probe to its most adverse orientation (that is, major axis of the base of the probe parallel to the major axis of opening). If the torso probe can be inserted into the opening to a depth of 4.0 in. (102 mm) or more, place the head probe (see Fig. A1.3) in the opening with the plane of the base of the probe parallel to the plane of the opening. An opening passes this test if (*1*) the opening does not admit the torso probe when it is rotated to any orientation about its own axis, or (*2*) the opening admits the torso probe and also admits the head probe. An opening fails the test if the opening admits the torso probe but does not admit the head probe.

6.1.2 *Nonrigid Completely Bounded Openings*—A nonrigid opening such as may be found in but not limited to flexible nets, tarps, and plastic enclosures is considered accessible if a torso probe will penetrate the opening to a depth of 4.0 in. (102 mm) or more when tested in accordance with the test procedure outlined in 6.1.2.1. (See Figs. A1.2 and A1.3 for probe dimensions.)

6.1.2.1 *Test Procedure for Completely Bounded Nonrigid Openings*—Place the torso probe in the opening, tapered-end first, with the plane of its base parallel to the plane of the opening; rotate the probe to its most adverse orientation (that is, the major axis of the base of the probe parallel to the major axis of the opening); apply a force of 50 lbf (222 N) to the probe to attempt to pass it through the opening. If the base of the probe passes through the opening, place the large head probe in the opening, tapered end first, with the plane of its base parallel to the plane of the opening. Apply a force of 50 lbf (222 N) to the probe to attempt to pass it through the opening. A nonrigid opening passes the test if: (*1*) the opening does not allow the torso probe to be inserted so deep that the opening admits the base of the probe when it is rotated to any orientation about its own axis, or (*2*) the opening allows full passage of the torso probe and also allows the large head probe to pass completely through. A nonrigid opening fails the test if the opening allows full passage of the torso probe but does not admit the large head probe.

6.1.3 *Boundaries of Large Openings*—If the opening admits the 9.0-in. (229-mm) head probe, each portion of its boundary shall be evaluated for partially bounded opening requirements of 6.1.4.

6.1.4 *Partially Bounded Openings:*

6.1.4.1 A partially bounded opening is considered accessible when any of the following conditions exist, and must meet the performance requirements as recommended in 6.1.4.2 and 6.1.4.3.

6.1.4.2 If the unbounded part of a partially bounded opening is between 1.875 ± 0.005 in. (47.6 mm) and 9.0 in. (229 mm) in width when measured perpendicular to each surface, the opening can be considered accessible and must meet the conditions of 6.1.4.3.

6.1.4.3 *Test Method*— The "A" portion of the test template (Fig. A1.4) is to be inserted along the centerline of the opening (determine the most adverse condition) (see Fig. A1.5) so that the centerline of the template follows the centerline of the opening and the plane of the template is parallel to the plane of the opening until the motion is arrested by contact between the test template and the boundaries of the opening. By visual inspection, determine if there is simultaneous contact between the sides of the template. If simultaneous contact is made the opening is accessible and must be tested using the "B" portion of the test template (see Fig. A1.6).

6.1.4.4 If the angle test template "A" indicates failure, check for an exempted thick surface condition by positioning the plane of the "B" portion of the test template between and perpendicular to the plane of the boundaries of the opening (see Fig. A1.7 and Fig. A1.9). If the test template fits completely within the boundaries of the opening, the opening is considered hazardous and fails the test unless it allows full passage of the 9.0-in. (229 mm) head probe (see Fig. A1.8). If the template does not fit down within the boundaries of the opening (defined as the opening outlined by the contact points of the test template "A") the opening is not considered accessible.

6.1.4.5 The test template is divided into two sections. Section "A" is used first to determine accessibility and is based on the Specification F 1004 standard rationale. Section "B" is used to determine if the thickness of the material or the location of the opening prevents access to the opening. The thickness of 0.75 in. (19.1 mm) for the template itself is based on half of the neck depth of a 5th percentile two year old minus compression. This dimension is consistent with Specification F 1004.

6.1.4.6 Other dimensions are based on the following:

(*1*) 6.1 in. (155 mm) width represents 95th percentile 5 year old head width,

(*2*) 1.875 ± 0.005 in. (47.6 mm) is the neck breadth of the 5th percentile 2 year old (2.5 in. (64 mm) minus tissue compression),

(*3*) 8.5 in. (216 mm) shoulder width of 5th percentile 2 year old, and

(*4*) 3.0 in. (76 mm) neck length of a five year old.

6.1.4.7 *Exemption to 6.1.4*:

(*1*) Those partially bounded openings which are inverted. A partially bounded opening is considered inverted if the lowest interior boundary immediately adjacent to the opening is horizontal or slopes downward.

(*2*) Partially bounded openings that form "V" angles less than 55 degrees where the apex of the angle is formed by an inclined or vertical climbing surface and a rope, chain or cable are exempt if the rope, chain or cable are in contact with the inclined surface at or below the protective surface at the point of the formed "V" angle.

6.2 *Sharp Points and Sharp Edges*—There shall be no accessible sharp points or sharp edges on public play equipment.

6.2.1 All points and edges on public play equipment shall be tested for sharpness in accordance with the requirements in 16 CFR 1500.48 and 1500.49 referenced in 2.3.

6.2.2 The exposed open ends of all tubing shall be provided with caps or plugs that cannot be removed without the use of tools.

6.2.3 Suspended members, such as rings on upper body equipment and swing seats, shall have a minimum radius of 0.25 in. (6.4 mm) on corners and edges. This requirement does not apply to swing belt seats, straps, ropes, chains, connectors, and other flexible components.

6.2.4 A cut-off bolt end projecting beyond the face of the nut shall be free of burrs, sharp points, and sharp edges.

6.3 *Protrusions*— There shall be no protrusions on public play equipment. Four protrusion test gages (shown in Figs. A1.10 and A1.11) are required to determine whether projections are protrusions. Their use is described in this section.

6.3.1 *Accessible Projections*—A projection is not accessible and is not a protrusion when it is recessed or located in such a manner that will not allow any of the protrusion gages to be placed over it. Any of the conditions described in the remainder of this section constitute a protrusion hazard.

6.3.2 *Determining Whether a Projection is a Protrusion*—Successively place each of three gages (see Fig. A1.10) over each accessible projection in all orientations (see Fig. A1.12 and Fig. A1.13). Determine whether the projection extends beyond the face of any gage. The projection fails the test and is a protrusion if it extends beyond the face of any of the three gages.

6.3.3 *Swing Seat Protrusions*—Test for this condition with the suspended member in all positions of its intended travel. Keeping the protrusion gage (see Fig. A1.11) oriented vertically, and its axis parallel to the plane of travel, place it over any projection accessible throughout the path of travel. Any projection on the suspended member which extends beyond the face of the test gage is a protrusion.

6.4 *Entanglement*— There shall be no entanglement hazards on public play equipment. Three test gages, a feeler gage, and the means to accurately measure a 0.12 in. (3.0 mm) extension are required to determine whether entanglement hazards exist. Any of the conditions described in this section constitutes an entanglement hazard.

6.4.1 *Slides*—The following requirements apply to slides in the areas shown in Fig. A1.14. Examples are shown in Fig. A1.15, Fig. A1.16 and Fig. A1.22.

6.4.1.1 A projection that meets both of the following requirements is an entanglement hazard:

(*1*) One of the three protrusion gages (see Fig. A1.10) passes over the projection and contacts the initial surface.

(*2*) The projection extends perpendicular (±5°) from the initial surface more than 0.12 in. (3.0 mm). The thickness of the protrusion gage (see Fig. A1.11) may be used to measure the 0.12 in. (3.0 mm) extension.

6.4.1.2 Slides shall be constructed in such a manner as to provide a smooth continuous sliding surface (roller slides exempted) and have no gaps or spaces that might create an entanglement hazard such as but not limited to the space created between sidewalls when two single slides are combined to create a doublewide slide or the point where a hood attaches to the sidewalls of a slide.

6.4.2 *Projections from a Horizontal Plane*—A projection that meets the conditions of 6.4.1.1 (*1*) and (*2*) and which also projects upwards from a horizontal plane (see Figs. A1.15 and A1.16) is an entanglement hazard.

6.4.3 *Exposed Bolt End Projections*—Any accessible bolt end projecting beyond the face of the nut more than two full threads is an entanglement hazard. A bolt end is inaccessible and not an entanglement hazard (see Fig. A1.15(6))when the bolt end is recessed and the 3.5 in. (89 mm) OD protrusion gage (see Fig. A1.10) cannot be made to contact the bolt end when the outside curve of the gage is placed flat against the recessed area (see Fig. A1.17).

6.4.4 *Projections Which Increase in Size*—Any projection which fits within any of the three protrusion test gages (see Fig. A1.10) and increases in size or diameter from the initial surface to the outer end (see Fig. A1.15(7)) is an entanglement hazard.

6.4.5 *Connecting Devices*—Connecting devices such as, but not limited to, S-hooks, pelican hooks and C-hooks, when properly closed, are not entanglement hazards. These connectors are considered closed when there is no gap or space greater than 0.04 in. (1.0 mm) when measured with a feeler gage (see Fig. A1.18(1)).

6.4.5.1 S-hook connectors are subject to these further requirements. If any of the following requirements are not met, an entanglement hazard exists:

(*1*) No portion of the closed end of an S-hook lower loop may project beyond the vertical boundary established by the upper loop (see Fig. A1.18(2)).

(*2*) An S-hook upper loop may align with, may partially overlap, or may completely overlap the connector body. If the upper loop completely overlaps the connector body, it must not extend past the connector body (see Fig. A1.18(3)).

(*3*) An S-hook lower loop must align with the connector body and not overlap it in any way (see Fig. A1.18(4)).

6.5 *Pinch, Crush, and Shear Points*—There shall be no pinch, crush, or shear points caused by junctures of two components moving relative to one another, or at an opening present at the junction of a stationary support and a rigid supporting member for a swinging element (that is, pendulum see saw, glide rides, and so forth) while the swinging elements are within their normal swinging angles. A pinch, crush, or shear point is any point that entraps at one or more positions a 0.62 in. (15.7 mm) diameter rod.

6.5.1 To reduce the likelihood of unintentional contact with a pinch, crush, or shear point, an opening shall comply with either 6.5.1.1 or 6.5.1.2.

6.5.1.1 An opening with a minor dimension of less than 1.0 in. (25 mm) is acceptable if a finger probe (as illustrated in Fig. A1.19), when inserted point first into an opening, cannot be made to touch any pinch, crush, or shear point. The probe shall be applied in all possible articulated positions with an application force not to exceed 1 lb (4 N).

6.5.1.2 An opening in an enclosure with a minor dimension of 1.0 in. (25 mm) or more, shall require that the pinch, crush, or shear point be located at a distance as specified in Table 1 from the plane of the opening.

NOTE 4—An enclosure in this case covers a pinch, crush, or shear point.

6.5.1.3 *Exemptions to 6.5:*

(*1*) Chain and its method of attachment, and

(*2*) The attachment area of heavy duty coil springs to the body and base of rocking equipment.

(*3*) The area between a swinging element and a horizontal toprail.

(*4*) The area between small, lightweight moving parts necessary as an integral part of the play activity (for example, abacus beads, bell clappers, telephone receivers, etc.) provided that this area is not considered a pinch, crush, or shear point as defined in 3.1.20.

6.6 *Suspended Hazards*—There shall be no single nonrigid component (cable, wire, rope, or other similar component) suspended between play units or from the ground to the play unit within 45° of horizontal, unless it is above 84 in. (2130 mm) from the playground surface and is a minimum of 1.0 in. (25 mm) at its widest cross-section dimension. It is recommended that the suspended elements be either brightly colored or contrast with surrounding equipment to add to visibility.

6.6.1 Rope, cable, or chain shall be fixed at both ends and not be capable of being looped back on itself, creating an inside loop perimeter greater than 5.0 in. (127 mm).

6.6.2 *Exemptions for Suspended Components (Rigid or Flexible):*

6.6.2.1 Multiple (two or more) suspended components (cables, wire, rope, or similar components) located at two or more elevations, may be suspended below 84 in. (2130 mm) when they comply with all other aspects of the single suspended component section and cannot be looped or stretched to contact another suspended component(s).

TABLE 1 Minimum Acceptable Distance from an Opening to a Pinch, Crush, or Shear Point

Minimum Dimension of Opening,[A] in. (mm), ±0.05[B]	Minimum Distance from Opening to Part, in. (mm)
1 (25)	6.5 (165)
1.25 (32)	7.5 (190)
1.5 (38)	12.5 (318)
1.875 (48)	15.5 (394)
2.125 (54)	17.5 (445)
More than 2.125 (54) and less than 6 (152)	30 (762)

[A] See 6.5.1.2.

[B] Between 1 and 2.5-in. (25 and 64-mm) interpolation is used to determine values specified in the table.

6.6.2.2 Chain or cable used to support a swing is exempt from this requirement. Rope shall not be used as a method of suspending swings.

6.6.2.3 Rope, cable, or chain with a length of 7.0 in. (178 mm) or less may be attached at one end only. Multiple lengths of such cords that can contact each other would be treated as one length of cord.

7. Requirements for Access/Egress

7.1 *Rung Ladders, Stepladders, Stairways, and Ramps (Does Not Address Wheelchair Use):*

7.1.1 Steps and rungs shall be evenly spaced within a tolerance of ±0.25 in. (±6.4 mm) and horizontal within a tolerance of ±2°.

7.1.2 Steps and rungs shall not trap water (that is, no standing water) and should not encourage the accumulation of debris.

7.1.3 See Table 2 for access slope; tread, rung, or ramp width; tread depth; ladder rung diameter; and vertical rise.

7.1.4 *Handrails:*

7.1.4.1 Continuous handrails shall be provided on both sides of stairways (see 7.2.1.3 for spiral stairways) and stepladders that have more than one tread.

7.1.4.2 Stairways or stepladders which consist of only one tread shall have handrails or alternate means of hand support on both sides.

7.1.4.3 Handrails or other means of hand support shall be available for use at the beginning of the first step.

7.1.4.4 Handrails shall be between 0.95 and 1.55 in. (24 and 39 mm) in diameter or maximum cross section.

7.1.4.5 Handrail height (the vertical distance between the top front edge of a step or, if used on a ramp, the top of the ramp surface, and the top surface of the handrail above it) shall be between 22 and 38 in. (560 and 970 mm).

7.2 *Other Means of Access:*

7.2.1 *Spiral Stairways:*

7.2.1.1 Spiral stairways shall meet the general requirements for spacing, orientation, drainage, tread width, and vertical rise specified for stairway access in 7.1.1-7.1.3.

7.2.1.2 The depth of the outer edge of the tread on spiral stairways shall be 7.0 in. (178 mm) or greater on equipment for children 2 through 5 years, and 8.0 in. (203 mm) or greater on equipment for children 5 through 12 years. These depth requirements apply to spiral stairways with both open and closed risers.

7.2.1.3 Spiral stairways shall meet the requirements specified for handrails in 7.1.4. However, when the design of the stairway does not permit handrails on both sides of the stairway, a continuous handrail shall be provided along the outside perimeter of the steps.

7.2.2 *Climbers:*

7.2.2.1 Arch climbers and flexible components shall not be

TABLE 2 Rung Ladders, Stepladders, Stairways, and Ramps (Access Slope; Tread, Rung, and Ramp Width; Tread Depth; Rung Diameter; and Vertical Rise, by Age of Intended User)

Type of Access	Age of Intended User, years		
	2 through 5	5 through 12	2 through 12
Rung Ladders:[A]			
Slope	75 to 90°	75 to 90°	75 to 90°
Total ladder width[B]	≥12 in. (300 mm)	≥16 in. (410 mm)	≥16 in. (410 mm)
Vertical rise (top of rung to top of rung)	≤12 in.[C] (300 mm)	≤12 in.[C] (300 mm)	≤12 in.[C] (300 mm)
Rung diameter	0.95 to 1.55 in. (24 to 39 mm)	0.95 to 1.55 in. (24 to 39 mm)	0.95 to 1.55 in. (24 to 39 mm)
Stepladders:			
Slope	50 to 75°	50 to 75°	50 to 75°
Tread width:			
Single file access	12 to 21 in. (300 to 530 mm)	≥16 in. (410 mm)	16 to 21 in. (410 to 530 mm)
Two-abreast access	[A]	≥36 in. (910 mm)	[A]
Tread depth:			
Open riser	≥7.0 in. (178 mm)	≥3.0 in. (76 mm)	≥7.0 in. (178 mm)
Closed riser	≥7.0 in. (178 mm)	≥6.0 in. (152 mm)	≥7.0 in. (178 mm)
Vertical rise (top of step to top of step)	≤9.0 in.[C] (229 mm)	≤12.0 in.[C] (305 mm)	≤9.0 in.[C] (229 mm)
Stairways:			
Slope	<50°	<50°	<50°
Tread width:			
Single file access	≥12 in. (300 mm)	≥16 in. (410 mm)	≥16 in. (410 mm)
Two-abreast access	≥30 in. (760 mm)	≥36 in. (910 mm)	≥36 in. (910 mm)
Tread depth:			
Open riser	≥7.0 in. (178 mm)	≥8.0 in. (203 mm)	≥8.0 in. (203 mm)
Closed riser	≥7.0 in. (178 mm)	≥8.0 in. (203 mm)	≥8.0 in. (203 mm)
Vertical rise (top of step to top of step)	≤9.0 in.[C](229 mm)	≤12.0 in.[C] (305 mm)	≤9.0 in.[C] (229 mm)
Ramps (does not address wheelchair use):			
Slope (vertical/horizontal)	≤1:8	≤1:8	≤1:8
Width:			
Single file access	≥12.0 in. (300 mm)	≥16.0 in. (410 mm)	≥16.0 in. (410 mm)
Two-abreast access	≥30.0 in. (760 mm)	≥36.0 in. (910 mm)	≥36.0 in. (910 mm)

[A] Not recommended as sole access for preschoolers.

[B] Excluding side supports.

[C] Entrapment provisions apply.