


# PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
# FACULTAD DE INGENIERIA
# ESCUELA DE CIVIL

**DISERTACION PREVIA A LA OBTENCION DEL TITULO DE:**
INGENIERO CIVIL

UTILIZACION DE DISOLVENTES COMERCIALES COMO ALTERNATIVA AL USO DEL TRICLOROETILENO EN LA EXTRACCION DE PORCENTAJE DE BITUMEN EN MEZCLAS ASFALTICAS CON AGREGADOS PÉTREOS DE ALTA ABSORCION.

ESTUDIO: MINA “EL CHASQUI”

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## DEDICATORIA

A mis queridos padres, Patri y Tere, que han sido desde siempre un ejemplo de perseverancia, sacrificio y AMOR, por su incondicional apoyo en inmenso corazón.
A mis hermanas Salo y Majo, que son sin duda mis mejores amigas, dueñas de innegables palabras de apoyo y solidaridad.
A mis sobrinas, que alegran nuestro mundo y complementan nuestra vida.
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*Juan Sebastián Baquero Mosquera*

Quiero dedicar a mis padres, quienes a lo largo de mi vida han velado por mi bienestar y educación. A mis hermanos, Gisela, David, quienes me brindaron su apoyo. A mi novio Sebas, que ha sido un gran amigo para mí, que siempre ha estado a mi lado, apoyándome en todo momento.

*Nashyra Soledad Cabrera Maldonado*

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*Juan Sebastián Baquero Mosquera*
*Nashyra Soledad Cabrera Maldonado*

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# 1.- INTRODUCCION

## 1.1 Justificación y Antecedentes

Se decidió realizar ésta disertación para obtener parámetros o criterios que complementen la investigación realizada anteriormente en la Pontificia Universidad Católica del Ecuador, Escuela de Civil, titulada: "UTILIZACION DE DISOLVENTES COMERCIALES COMO ALTERNATIVA AL USO DEL TRICLOROETILENO EN LA EXTRACCION DE PORCENTAJE DE BITUMEN DE MEZCLAS ASFALTICAS" la misma que fue realizada con mezclas asfálticas, cuya característica esencial del agregado pétreo era un porcentaje de absorción bajo (3.26% en agregado fino y 1.75% en agregado grueso)[1]. Una vez realizados los ensayos de extracción del porcentaje de bitumen, se obtuvieron resultados favorables, al comparar los porcentajes de extracción de bitumen usando disolventes alternos, en relación con el disolvente que establece la norma (ASTM D 2172), pero se especifica que solamente deben ser tomados en cuenta como referencia en mezclas asfálticas cuyos agregados tengan similares características de absorción baja (hasta un 7 % aproximadamente).

Es por eso que se ha considerado importante realizar esta investigación con mezclas asfálticas cuyo agregado pétreo tenga un porcentaje de absorción alto (mayor a 18%), con el que se estudiará la posibilidad de utilizar

[1] Puente, 2009:3

disolventes comerciales como alternativa al TRICLOROETILENO en la extracción del porcentaje de bitumen.

Los disolventes alternos que se usaron son los siguientes:

- Gasolina Extra
- Gasolina Súper
- Gasolina de avión: "JP1"
- Gasolina de avión : "AVGAS -130"
- Tricloroetileno

## 1.2 Objetivo

Esta investigación determinará si el comportamiento de los disolventes alternos en la utilización del ensayo de extracción del porcentaje de bitumen en mezclas asfálticas con agregado cuya absorción sea alta, es semejante al del disolvente normado (TRICLORIETILENO).

Es por eso que en la investigación que se ha realizado, se quiere ampliar las conclusiones de la disertación anterior ("*Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen de mezclas asfálticas*", realizada por Patricio Xavier Puente Ontaneda en el año 2009).[2], en lo relacionado a la absorción de los agregados para analizar el comportamiento de los disolventes comerciales

[2] Puente, 2009:37

como alternativa al TRICLOROETILENO y complementar de ésta manera a la investigación anterior.

Con cada disolvente se realizará el ensayo de la extracción del porcentaje de bitumen de las mezclas asfálticas cuyo agregado pétreo cumpla con las características de absorción establecidas, de ésta manera se obtendrá resultados de cada uno de ellos para compararlos, y así se obtendrán las diferencias y variaciones de bitumen extraído al utilizar cada disolvente alterno.

## 1.3 Alcance

Se obtendrá dicho objetivo mediante la caracterización de los agregados pétreos para confirmar su alta absorción y la caracterización del cemento asfaltico que servirá para diseñar las muestras patrón con su porcentaje óptimo de asfalto por el método Marshall, para uniformizar las características de las muestras y así obtener resultados aptos para ser relacionados entre sí.

En esta disertación se obtendrá conclusiones sobre el uso de los disolventes alternativos al Tricloroetileno, aplicados en el ensayo de extracción de porcentaje de bitumen y ensayando mezclas asfálticas cuyo agregado pétreo posea un porcentaje de absorción alto. El material pétreo usado es de la Mina "Los Chasquis" ubicada en Latacunga, Provincia de Cotopaxi.

El cemento asfáltico que se ha utilizado fue obtenido de la planta asfáltica ubicada a orillas del Río Guayllabamba, por lo que no está por demás recordar, que ésta investigación está dirigida a evaluar el comportamiento de los disolventes comerciales, aplicados a mezclas asfálticas con las características que se obtenga de cada uno de los materiales constitutivos de la misma, y no el cumplimiento de requisitos establecidos por el MOP, de los materiales ni de la mezcla asfáltica como tal.

Vale mencionar además que, por el alto costo y falta de disponibilidad del TRICLOROETILENO, usualmente se ocupa los disolventes alternos antes mencionados, pero no existe una base de datos que permitan comparar o relacionar resultados en cuanto a su uso con mezclas asfálticas de las características establecidas en ésta investigación, y por esto se consideró importante realizarla, ya que las conclusiones del trabajo se podrían considerar como un apoyo técnico o fuente de consulta útil para cualquier laboratorio, pero de ninguna manera sus resultados podrán ser usados como factores de corrección ni parámetros de correlación.

# 2.- CARACTERIZACIÓN DE LOS MATERIALES PÉTREOS

En las capas de rodadura el uso de agregados de alta calidad se justifica por las solicitaciones a que están sometidas y se persigue la optimización de la respuesta mecánica y de la durabilidad de la mezcla. Por la misma razón, la calidad de los agregados es absolutamente imprescindible, aunque todo aquellos suponga un costo mayor para el pavimento.

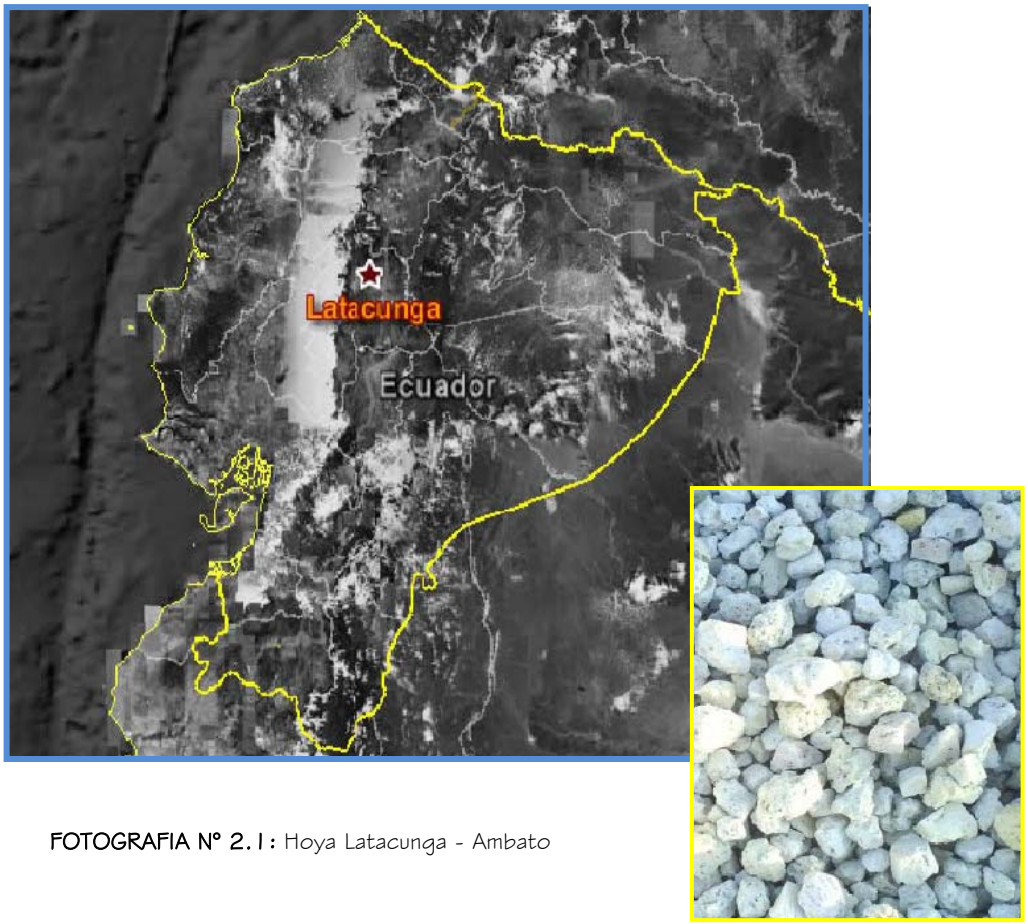
Las mezclas asfálticas están constituidas aproximadamente por un 90% de agregados pétreos grueso y fino, un 5% de polvo mineral (filler) y otro 5% de ligante asfaltico. Los componentes mencionados anteriormente son de gran importancia para el correcto funcionamiento del pavimento y la falta de calidad en alguno de ellos afecta el conjunto.

Por estas razones ha sido necesario realizar un análisis del material pétreo que se ha usado en la mezcla asfáltica.

Se ha realizado la caracterización del agregado de la Mina "El Chasqui", ubicada en Latacunga, provincia Cotopaxi. La mina de la cual se obtuvo el agregado, expende el material sin clasificar por tamaños, sin embargo, en todos los ensayos realizados, en algunos casos se separo el material fino del grueso y se trabajó independientemente de acuerdo a los procedimientos establecidos para cada ensayo.

A continuación se dará una breve descripción de la formación del material que se encuentra en la zona:

*La Hoya de Latacunga – Ambato*




**FOTOGRAFIA N° 2.1 :** Hoya Latacunga - Ambato

*Un vistazo al mapa geológico enseña que los contornos Oriental y Occidental de la hoya carecen de formaciones cuaternarias, especialmente de conos sobresalientes de volcanes, encima de las cadenas cordilleranas. Sin embargo las alturas de ambas cordilleras y sus declives hacia la depresión de la hoya están incrustados de material volcánico, Pliocénico,*

*entre lavas, arenas y cenizas. No se alzan nevados volcánicos en ningún lado, sino ya cerca del nudo de Sanancajas e Igualata.*

*En la cordillera occidental al Oeste de Latacunga se esconde en el callejón del río Toachi entre las cadenas de las cordilleras de Guangaje- Isinlivi y de Sigchos – Chugchillán la caldera del volcán Quilotoa. La historia de su estructuración puede haber decurrido como sigue:*

*A fines del Pleistoceno se habría abierto el canal de erupción en medio del fondo del valle, mediante la falla tectónica longitudinal paralela al rumbo de la cordillera, falla que facilitó la erosión del típico valle longitudinal del rio Toachi. Probablemente un potente volcán estratiforme se habría edificado por superposición alternamente de efusiones de las viscosas lavas acidas de dacita anfibólico biotítica y de material piroclástico suelto, arrojado por erupciones explosivas, correspondientes al mismo tipo de dacita. Al fin de la actividad del volcán habrían acaecido grandiosas explosiones que hicieron saltar a la atmosfera la mayor parte del cono del cerro, y transformándolo en una gigantesca caldera de tres kilómetros de diámetro, de la cual aún habrían salido las ultimas erupciones explosivas. Las enormes cantidades de material piroclástico de lava y piedra pómez arrojadas al aire se depositaron en los alrededores para ser acarreadas por lluvias y torrentes al fondo del profundo valle y acumuladas en espesores hasta de centenares de metros sobre el fondo.*

*Actualmente el rio ha cortado un profundo cauce en el gigantesco terraplén y tomado su curso en torno de la circunvalación de la caldera. El fondo del cráter lo ocupa una laguna de agua salada y algo caliente de 16°, en contraste a la temperatura media de esta región de solo unos 8 °.*

*El borde más alto del cráter, de 4010 metros de altitud, no alcanza las elevaciones de las cordilleras vecinas, pero sobresale por 440 metros sobre nivel de la laguna interior. Del agua turbia de color amarillento verdusco brotan moderadas cantidades de gas carbónico.*

*Las acumulaciones de bombas volcánicas, guijos, arenas y cenizas de piedras pómez se extienden rio arriba y abajo a gran distancia y constituyen terrazas planas en las que el rio ha excavado su cañón de laderas hasta descubrir el fondo de su lecho original cortado en las antiguas pizarras y porfiritas.*[3]

De acuerdo a las especificaciones del MOP-001-F-2002, las características de los materiales pétreos para la fabricación del hormigón asfaltico mezclado en planta (405-5 TOMO I), podrán estar constituidos por roca o grava triturada total o parcialmente, materiales fragmentados naturalmente, arenas y rellenos minerales los cuales deberán cumplir con los requisitos especificados en el MOP en el artículo 811.2 (TOMO II – Capitulo

[3] Sauer, 1965:244-246

Agregados para hormigón asfáltico) donde se hace referencia en el anexo "A 45 – A 47".[4]

> "Las mezclas asfálticas a emplearse en capas de rodadura para vías de tráfico pesado y muy pesado deberán cumplir que la relación entre el porcentaje en peso del agregado pasante del tamiz INEN 75 micrones y el contenido de asfalto en porcentaje en peso total de la mezcla (Relación filler/betún), sea mayor o igual 0.80 y nunca superior a 1.20".[5]

Para verificar los requisitos establecidos por el MOP se han realizado los ensayos explicados posteriormente para determinar la caracterización del agregado pétreo.

[4] Capítulo Anexos: A 45
[5] MOP, 2001:IV-95

## 2.1- Granulometría Del Agregado (ASTM C 136-05)



**FOTOGRAFIA N° 2.2:** Tamizadora Mecánica

Este método de ensayo tiene por objeto determinar cuantitativamente la distribución de los tamaños de las partículas de agregados gruesos y finos de un material, por medio de tamices de abertura cuadrada progresivamente decreciente.

La granulometría se realiza por medio del tamizado en seco del agregado pétreo para obtener la distribución de los tamaños de las partículas que posee el agregado.

Este método se ha usado para determinar la granulometría del material propuesto, y que se utilizó como agregado pétreo de la mezcla asfáltica de esta investigación. Los resultados se han empleado para determinar el cumplimiento de los requisitos de las especificaciones que se aplica a este ensayo.

## EQUIPO[6]

- *Balanza* – Con sensibilidad de por lo menos 0.1% de la masa de la muestra que va a ser ensayada.
- *Tamices* – Se dispondrá de la serie de tamices de ensayo adecuada para obtener la información deseada de acuerdo con las especificaciones para el material que se ensaya. Los marcos de los tamices se deberán acoplar de forma que se evite cualquier pérdida de material durante el proceso de tamizado.
- *Tamizadora mecánica* – Una tamizadora mecánica que imparta un movimiento
- Vertical, o lateral y vertical a los tamices de tal forma que al producir rebotes y giros en las partículas del agregado éstas presenten diferentes orientaciones con respecto a la superficie de los tamices.

[6] Lara: 13

- *Horno* – De tamaño adecuado, capaz de mantener una temperatura uniforme de 110° ± 5°C (230° ± 9°F).

De acuerdo a la norma, que indica que para mezclas de agregados gruesos y finos, la muestra adecuada deberá tener la misma masa recomendada para agregados gruesos tal como se presenta en la Tabla 2.1.

De manera visual se ha determinado que el tamaño máximo del agregado es de 1 pulgada por lo tanto se ha pesado 10 Kg como masa mínima de la muestra de ensayo como lo indica la tabla 2.1.

| Máximo tamaño nominal con aberturas cuadradas | | Masa mínima de la muestra de ensayo |
|---|---|---|
| mm | (Pulg.) | kg |
| 9.5 | (3/8) | 1 |
| 12.5 | (½) | 2 |
| 19.0 | (3/4) | 5 |
| 25.0 | (1) | 10 |
| 37.5 | (1½) | 15 |
| 50.0 | (2) | 20 |
| 63.0 | (2½) | 35 |
| 75.0 | (3) | 60 |
| 90.0 | (3½) | 100 |
| 100.0 | (4) | 150 |
| 125.0 | (5) | 300 |

TABLA 2.1: MASA MINIMA DE MUESTRA PARA AGREGADO GRUESO

## Procedimiento[7]

1. Se seca la muestra a una temperatura de 110° ± 5°C (230° ± 9°F), hasta obtener masa constante, con una aproximación de 0.1% de la masa seca original de la muestra.

2. Se selecciona un grupo de tamices de tamaños adecuados para suministrar la información requerida por las especificaciones del material que se va a ensayar. Se encajan los tamices en orden decreciente, por tamaño de abertura y se coloca la muestra en el tamiz superior de la serie.

3. El proceso de tamizado puede hacerse manual o mecánicamente, y consiste en movimientos horizontales con rotación y pequeños golpes verticales.

4. El tiempo de tamizado es variable; se debe tamizar hasta que el material que pase no sea mayor al 1% del material que se retiene en cada tamiz.

5. Se determina la masa del material que se retiene en cada tamiz; también se incluye la masa de material que se retiene en el recipiente.

[7] Lara: 15

## Cálculos

Se calculan los siguientes porcentajes:

1. En cada tamiz se calcula la masa retenida acumulada; ésta es igual a la suma de la masa retenida en el tamiz más las masas retenidas en los tamices de mayor abertura.

2. El porcentaje total retenido

$$\% \text{ Retenido} = \frac{\text{Masa retenida acumulada}}{\text{Masa de la muestra}} \times 100$$

3. El porcentaje que pasa

$$\% \text{ Pasa} = 100 - \% \text{ Retenido}$$

4. Los resultados deben incluir:

    4.1 Masa retenida parcial.

    4.2 Masa retenida acumulada.

    4.3 Porcentaje retenido.

    4.4Porcentaje que pasa.

Se han realizado tres ensayos de granulometría para obtener un promedio más acertado. A continuación se presentan los resultados del ensayo:

| GRANULOMETRIA N° 1 | | | | | |
|---|---|---|---|---|---|
| MALLA | ABERTURA (mm) | MASA RET PAR. (gr) | MASA RET ACUM. (gr) | % RETENIDO (gr) | % PASA (gr) |
| 2 | 50.8 | - | - | - | 100,0 |
| 1 1/2 | 58.1 | - | - | - | 100,0 |
| 1 | 25.4 | 10,00 | 10,00 | 0,10 | 99,9 |
| 3/4 | 19 | 12,00 | 22,00 | 0,22 | 99,8 |
| 1/2 | 12.7 | 350,00 | 372,00 | 3,72 | 96,3 |
| 3/8 | 9.51 | 506,00 | 878,00 | 8,78 | 91,2 |
| N. 4 | 4.76 | 1.830,00 | 2.708,00 | 27,08 | 72,9 |
| N. 8 | 2.362 | 2.437,94 | 5.145,94 | 51,46 | 48,5 |
| N. 16 | 1.19 | 2.154,34 | 7.300,28 | 73,00 | 27,0 |
| N. 30 | 0.595 | 1.535,59 | 8.835,87 | 88,35 | 11,6 |
| N. 50 | 0.297 | 361,69 | 9.197,56 | 91,97 | 8,0 |
| N. 100 | 0.149 | 116,34 | 9.313,90 | 93,13 | 6,9 |
| N. 200 | 0.074 | 116,77 | 9.430,67 | 94,30 | 5,7 |
| PASA N. 200 | | 281,60 | 9.712,27 | 97,12 | 2,9 |
| SUMAN | | 9.712,27 | | | |

TABLA 2.2: Resultados de la Granulometría N° 1

| GRANULOMETRIA N° 2 | | | | | |
|---|---|---|---|---|---|
| MALLA | ABERTURA (mm) | MASA RET PAR. (gr) | MASA RET ACUM. (gr) | % RETENIDO (gr) | % PASA (gr) |
| 2 | 50.8 | 0 | 0 | 0,00 | 100,0 |
| 1 1/2 | 58.1 | 0 | 0 | 0,00 | 100,0 |
| 1 | 25.4 | 10 | 10 | 0,10 | 99,9 |
| 3/4 | 19 | 66,52 | 76,52 | 0,77 | 99,2 |
| 1/2 | 12.7 | 457,72 | 534,24 | 5,34 | 94,7 |
| 3/8 | 9.51 | 484,13 | 1018,37 | 10,18 | 89,8 |
| N. 4 | 4.76 | 1767,2 | 2785,57 | 27,86 | 72,1 |
| N. 8 | 2.362 | 2474,09 | 5259,66 | 52,60 | 47,4 |
| N. 16 | 1.19 | 2252,16 | 7511,82 | 75,12 | 24,9 |
| N. 30 | 0.595 | 1626,71 | 9138,53 | 91,39 | 8,6 |
| N. 50 | 0.297 | 365,57 | 9504,1 | 95,04 | 5,0 |
| N. 100 | 0.149 | 145,72 | 9649,82 | 96,50 | 3,5 |
| N. 200 | 0.074 | 132,7 | 9782,52 | 97,83 | 2,2 |
| PASA N. 200 | | 72 | 9854,52 | 98,55 | 1,5 |
| SUMAN | | 9854,52 | | | |

TABLA 2.3: Resultados de la Granulometría N° 2

| GRANULOMETRIA N° 3 | | | | | |
|---|---|---|---|---|---|
| MALLA | ABERTURA (mm) | MASA RET PAR. (gr) | MASA RET ACUM. (gr) | % RETENIDO (gr) | % PASA (gr) |
| 2 | 50.8 | - | - | - | 100,0 |
| 1 1/2 | 58.1 | - | - | - | 100,0 |
| 1 | 25.4 | 6,00 | 6,00 | 0,06 | 99,9 |
| 3/4 | 19 | 34,00 | 40,00 | 0,40 | 99,6 |
| 1/2 | 12.7 | 357,87 | 397,87 | 3,98 | 96,0 |
| 3/8 | 9.51 | 511,04 | 908,91 | 9,09 | 90,9 |
| N. 4 | 4.76 | 1.974,00 | 2.882,91 | 28,83 | 71,2 |
| N. 8 | 2.362 | 2.574,16 | 5.457,07 | 54,57 | 45,4 |
| N. 16 | 1.19 | 2.003,83 | 7.460,90 | 74,61 | 25,4 |
| N. 30 | 0.595 | 1.512,50 | 8.973,40 | 89,73 | 10,3 |
| N. 50 | 0.297 | 346,40 | 9.319,80 | 93,20 | 6,8 |
| N. 100 | 0.149 | 105,32 | 9.425,12 | 94,25 | 5,7 |
| N. 200 | 0.074 | 103,74 | 9.528,86 | 95,29 | 4,7 |
| PASA N. 200 | | 405,37 | 9.934,23 | 99,34 | 0,7 |
| SUMAN | | 9.934,23 | | | |

**TABLA 2.4:** Resultados de la Granulometría N° 3

A continuación se presenta el porcentaje que pasa promedio de las tres granulometrías:

| | | GRANULOMETRIA | | | |
|---|---|---|---|---|---|
| | | N° 1 | N° 2 | N° 3 | |
| MALLA | ABERTURA (mm) | % PASA | % PASA | % PASA | % PASA PROMEDIO |
| 2 | 50,8 | 100,0 | 100,0 | 100,0 | 100,0 |
| 1 1/2 | 58,1 | 100,0 | 100,0 | 100,0 | 100,0 |
| 1 | 25,4 | 99,9 | 99,9 | 99,9 | 99,9 |
| 3/4 | 19 | 99,8 | 99,2 | 99,6 | 99,5 |
| 1/2 | 12,7 | 96,3 | 94,7 | 96,0 | 95,7 |
| 3/8 | 9,51 | 91,2 | 89,8 | 90,9 | 90,6 |
| N. 4 | 4,76 | 72,9 | 72,1 | 71,2 | 72,1 |
| N. 8 | 2,362 | 48,5 | 47,4 | 45,4 | 47,1 |
| N. 16 | 1,19 | 27,0 | 24,9 | 25,4 | 25,8 |
| N. 30 | 0,595 | 11,6 | 8,6 | 10,3 | 10,2 |
| N. 50 | 0,297 | 8,0 | 5,0 | 6,8 | 6,6 |
| N. 100 | 0,149 | 6,9 | 3,5 | 5,7 | 5,4 |
| N. 200 | 0,074 | 5,7 | 2,2 | 4,7 | 4,2 |
| PASA N. 200 | | 2,9 | 1,5 | 0,7 | 1,7 |

**TABLA 2.5:** Granulometría Promedio del Agregado

Con los resultados obtenidos del porcentaje que pasa Promedio se ha realizado la curva granulométrica del agregado que se presenta a continuación:

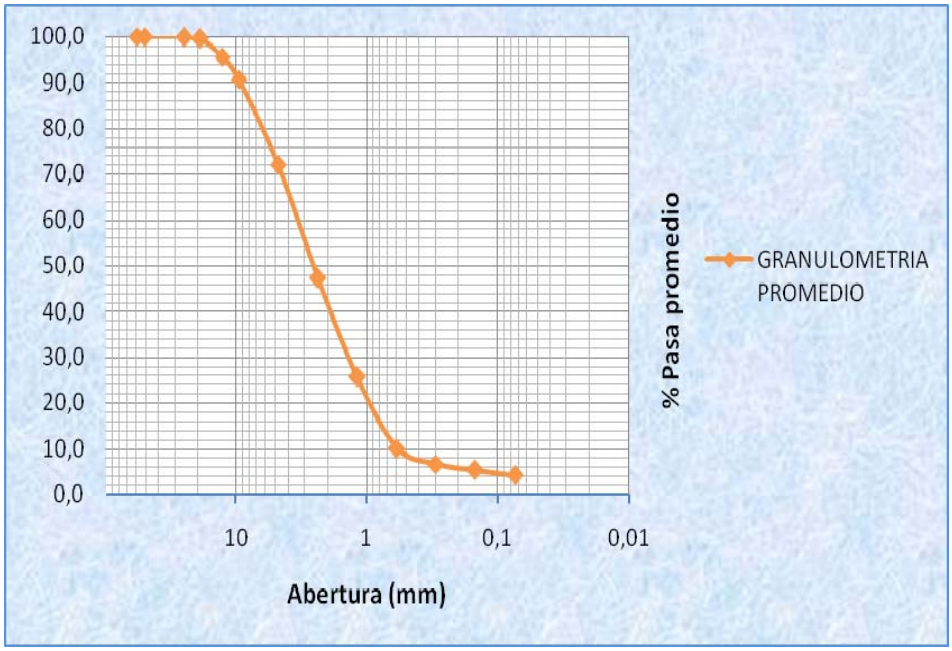



**GRÁFICO 2.1:** Curva Granulométrica

En la siguiente tabla (2.6) se ha realizado el promedio de las masas retenidas de las tres granulometrías para determinar el tipo de gradación que tiene la muestra, para usarla en el ensayo de abrasión que se explicará posteriormente. Como se puede observar en el resultado de masa retenida parcial promedio de cada abertura, el tamiz que pasa el N° 4 y retiene el N° 8 es donde se retiene mayor masa.

| | | GRANULOMETRIA | | | |
|---|---|---|---|---|---|
| | | N° 1 | N° 2 | N° 3 | |
| MALLA | ABERTURA (mm) | Masa Ret. Parcial ( gr) | Masa Ret. Parcial ( gr) | Masa Ret. Parcial ( gr) | Masa Ret. Parcial Promedio ( gr) |
| 2 | 50,8 | 0 | 0 | 0 | 0,0 |
| 1 1/2 | 58,1 | 0 | 0 | 0 | 0,0 |
| 1 | 25,4 | 10 | 10 | 6 | 8,7 |
| 3/4 | 19 | 12 | 66,52 | 34 | 37,5 |
| 1/2 | 12,7 | 350 | 457,72 | 357,87 | 388,5 |
| 3/8 | 9,51 | 506 | 484,13 | 511,04 | 500,4 |
| N. 4 | 4,76 | 1830 | 1767,2 | 1974 | 1857,1 |
| N. 8 | 2,362 | 2437,94 | 2474,09 | 2574,16 | 2495,4 |
| N. 16 | 1,19 | 2154,34 | 2252,16 | 2003,83 | 2136,8 |
| N. 30 | 0,595 | 1535,59 | 1626,71 | 1512,5 | 1558,3 |
| N. 50 | 0,297 | 361,69 | 365,57 | 346,4 | 357,9 |
| N. 100 | 0,149 | 116,34 | 145,72 | 105,32 | 122,5 |
| N. 200 | 0,074 | 116,77 | 132,7 | 103,74 | 117,7 |
| PASA N. 200 | | 281,6 | 72 | 405,37 | 253,0 |

TABLA 2.6: Granulometría Masa Retenida Parcial Promedio del Agregado

## 2.2 – Gravedad Específica Del Agregado.

La gravedad específica de un agregado es útil para determinar la relación peso-volumen del agregado compactado y así calcular el contenido de vacios de las mezclas asfálticas en caliente compactada. Por definición, la gravedad específica de un agregado es la relación del peso por unidad de volumen de un material respecto del mismo volumen de agua a una temperatura determinada.

Se determina el peso específico de los áridos por dos razones: para permitir el cálculo de los vacios de las mezclas asfálticas compactadas; y, para corregir las cantidades de áridos empleados en una mezcla para pavimentación cuando su peso específico varía apreciablemente.

Podemos calcular diferentes pesos específicos como son:

*Peso específico Total:* éste incluye todos los poros de la muestra, y asume que todos los poros que absorben agua no absorben asfalto.

*Peso específico Efectivo:* éste excluye del volumen de la muestra todos los poros y espacios capilares que absorben asfalto.

*Peso específico Aparente:* éste no incluye como parte del volumen de la muestra, los poros y espacios capilares que se llenarían de agua, y los poros que se llenarían de asfalto.

De igual manera que para la granulometría, se han realizado tres veces el ensayo de gravedad específica para poder calcular un promedio de los resultados obtenidos. La gravedad específica se ensayó dividiendo a la porción total en dos partes; fino (todo aquello que pasa el tamiz N.4) y grueso (todo aquello que es de un tamaño mayor al tamiz N.4).

### 2.2.1 Gravedad Especifica porción Finos. "ASTM C 128-04"

**Equipo**[8]

- Balanza (capacidad 1 Kg. O más, sensibilidad 0,1 g.)
- Matriz (capacidad 500 cm3)
- Molde cónico (30 mm. de diámetro en la parte superior, 89 mm. de diámetro en la parte inferior y 73 mm. de altura)

[8] Lara: 30

- Barra compactadora (340 g. de masa, con un extremo de superficie plana circular de 25 mm.. de diámetro)
- Horno (temperatura uniforme 105 ± 5°C)
- Recipiente

## PROCEDIMIENTO[9]

- Se toma una muestra de 500 g. de masa
- Se determina la masa de matraz (**Fotografía 2.3**)



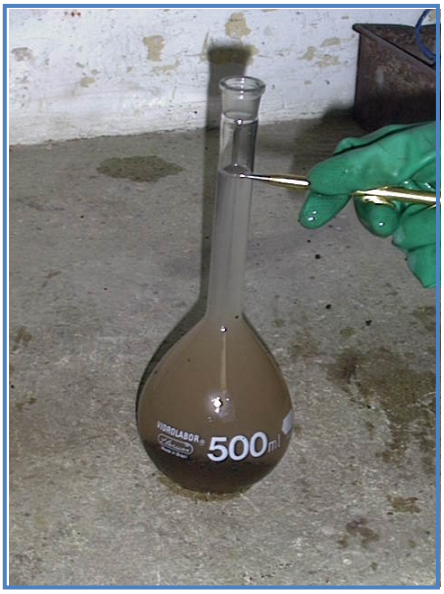

**FOTOGRAFÍA N° 2.3**[10] Determinación masa del matraz

[9] Lara: 33
[10] Lara:33

❖ Se introduce la muestra en el matraz (**Fotografía 2.4**), luego se llena de agua hasta alcanzar casi la marca de 500 cm3 a una temperatura de 20°C (**Fotografía 2.5**).




FOTOGRAFÍA N° 2.4[11] Introducción de muestra en matraz




FOTOGRAFÍA N° 2.5[12] Llenado con agua 500cc.

[11] Lara:34
[12] Lara:34

- Con el fin de eliminar las burbujas de aire se hace rodar el matraz sobre sí mismo en una superficie plana (Fotografía N° 2.6), luego se coloca en un baño de temperatura constante, manteniéndolo a 20°C.



FOTOGRAFÍA N° 2.6[13] Eliminación de vacíos

- Cuando se observa que no existen burbujas de aire, se llena con agua hasta la marca de 500 cm3 y se determina la masa del conjunto matraz, agua y muestra.
- Se saca el agregado fino del matraz, y se seca la muestra en el horno a una temperatura uniforme (105 $\pm$ 5°C)
- Se determina la masa de muestra cada intervalo de dos horas, cuando no existe variación de masa en la muestra durante dos

[13] Lara:35

intervalos consecutivos, se saca la muestra del horno y se deja enfriar.

- Se determinó la masa de la muestra seca.

## Cálculos y resultados[14]

- Se determina la masa de agua añadida al matraz, con la siguiente relación:

$$Ma = Mmw - (Mm + B)$$

En donde:

Ma = Masa de agua añadida al matraz (g.)

Mm = Masa del matraz (g.)

Mmw = Masa del conjunto matraz, agua y muestra (g.)

B = Masa de la muestra saturada con superficie seca (g.)

- Se calcula la gravedad específica Bulk, con la siguiente relación:

$$G_e = \frac{A}{500 - Ma}$$

En donde:

Ge = Gravedad especifica Bulk

A = Masa de la muestra seca (g.)

[14] Lara:36

- La gravedad específica saturada con superficie seca se calcula con la siguiente relación:

$$G_{es} = \frac{B}{500 - Ma}$$

En donde:

Ges = gravedad especifica del material saturado con superficie seca.

- La gravedad específica aparente se calcula con la siguiente fórmula:

$$G_{ea} = \frac{A}{500 + A + Mm - Mmw}$$

En donde:

Gea = gravedad específica aparente.

- Se calcula el porcentaje de absorción con la siguiente relación:

$$A_b = \frac{B - A}{A} * 100$$

En donde:

Ab = Porcentaje de absorción.

Los resultados obtenidos en los ensayos se publican en las siguientes tablas:

| ***Ensayo de Gravedades y Absorción Fino N° 1*** | | |
|---|---|---|
| MASA MATRAZ (gr) | Mm= | 173.610 |
| MASA CONJUNTO (gr) | Mmw= | 777.900 |
| MASA MUESTRA S.S.S. (gr) | B= | 250.000 |
| MASA MUESTRA SECA (gr) | A= | 186.000 |
| MASA AGUA ANADIDA (gr) | Ma= | 354.290 |
| GRAVEDAD BULK | Ge= | 1.783 |
| GRAVEDAD SSS | Ges= | 2.397 |
| GRAVEDAD APARENTE | Gea= | 1.105 |
| PORCENTAJE DE ABSORCION | Abs%= | 34.409 |

TABLA 2.7 Gravedades y Absorción. Ensayo N° I

| ***Ensayo de Gravedades y Absorción Fino N° 2*** | | |
|---|---|---|
| MASA MATRAZ (gr) | Mm= | 173.630 |
| MASA CONJUNTO (gr) | Mmw= | 780.800 |
| MASA MUESTRA S.S.S. (gr) | B= | 250.020 |
| MASA MUESTRA SECA (gr) | A= | 185.370 |
| MASA AGUA ANADIDA (gr) | Ma= | 357.150 |
| GRAVEDAD BULK | Ge= | 1.730 |
| GRAVEDAD SSS | Ges= | 2.334 |
| GRAVEDAD APARENTE | Gea= | 1.079 |
| PORCENTAJE DE ABSORCION | Abs%= | 34.876 |

TABLA 2.8 Gravedades y Absorción. Ensayo N°2

| ***Ensayo de Gravedades y Absorción Fino N° 3*** | | |
|---|---|---|
| MASA MATRAZ (gr) | Mm= | 173.620 |
| MASA CONJUNTO (gr) | Mmw= | 787.200 |
| MASA MUESTRA S.S.S. (gr) | B= | 250.000 |
| MASA MUESTRA SECA (gr) | A= | 196.200 |
| MASA AGUA ANADIDA (gr) | Ma= | 363.580 |
| GRAVEDAD BULK | Ge= | 1.727 |
| GRAVEDAD SSS | Ges= | 2.201 |
| GRAVEDAD APARENTE | Gea= | 1.172 |
| PORCENTAJE DE ABSORCION | Abs%= | 27.421 |

TABLA 2.9 Gravedades y Absorción. Ensayo N°3

Una vez que se realizaron los tres ensayos para la determinación de Gravedades Específicas y de Porcentaje de Absorción se calculó el promedio de cada uno y de lo cual se publica la siguiente tabla de resumen de promedios:

| | GRAVEDAD ESPECIFICA FINO | | | |
|---|---|---|---|---|
| | N° 1 | N° 2 | N° 3 | PROMEDIO |
| GRAVEDAD BULK | 1.783 | 1.730 | 1.727 | 1.747 |
| GRAVEDAD SSS | 2.397 | 2.334 | 2.201 | 2.311 |
| GRAVEDAD APARENTE | 1.105 | 1.079 | 1.172 | 1.119 |
| PORCENTAJE DE ABSORCION | 34.409 | 34.876 | 27.421 | 32.235 |

TABLA 2.10 Gravedades y Absorción Promedio

### 2.2.2 Gravedad Específica porción Grueso. "ASTM C 127 - 04 "

Equipo [15]

- Balanza hidrostática (capacidad de 5 Kg o más sensibilidad de 0,5 g. o menos)
- Cesta cilíndrica de alambre (de malla con abertura No. 8 de aproximadamente 20 cm. de diámetro y 20 cm. de altura)
- Recipiente cilíndrico (capacidad suficiente para sumergir la cesta de alambre en agua)
- Bandeja

Preparación de la muestra[16]

- La muestra se obtendrá por cuarteo, y deberá ser de 5 Kg más o menos; debe ser de tal naturaleza que todas las partículas se retengan en el tamiz No. 4 (4.76 mm.)
- Se lava completamente la muestra para eliminar el polvo u otras impurezas superficiales de las partículas.
- Se seca la muestra en el horno a una temperatura uniforme (110 $\pm$ 5°C), durante un período de 24 horas.

[15] Lara, 39
[16] Lara, 40

- Se saca la muestra del horno, se coloca dentro de un recipiente lleno de agua y se deja reposar la muestra por un período de 24 horas.

- Se saca la muestra del agua y se la hace rodar sobre un paño grande absorbente, hasta que la película de agua haya desaparecido de la superficie (**Fotografía 2.7**). Durante esta operación se debe evitar la evaporación.



**FOTOGRAFÍA N° 2.7**[17] Secado manual para obtener Superficie Saturada con Superficie Seca

[17] Lara, 40

Procedimiento[18]

- Se determina la masa de la muestra saturada con superficie seca (Fotografía 2.8).



FOTOGRAFÍA N° 2.8 Determinación masa Saturada con Superficie Seca

- Se toma la muestra y se coloca en la cesta de alambre; luego se sumerge la muestra en el agua y se determina la masa de la muestra sumergida (Fotografía 2.9).

[18] Lara, 41



**FOTOGRAFÍA N° 2.9** Determinación masa sumergida

- Se saca la muestra del agua y se seca en el horno a temperatura uniforme (110 $\pm$ 5°C).
- Se determina la masa de la muestra cada intervalo de dos horas; cuando no existe variación de masa en la muestra durante dos intervalos consecutivos, se saca la muestra del horno y se deja enfriar.
- Se determina la masa de la muestra seca.

Cálculos y resultados [19]

- La gravedad específica Bulk, se calcula con la siguiente relación:

$$G_e = \frac{A}{B - C}$$

En donde:

Ge = Gravedad específica Bulk

A = Masa de la muestra seca (g.)

B = Masa de la muestra saturada con superficie seca (g.)

C = Masa de la muestra sumergida en el agua (g.)

- La gravedad específica saturada con superficie seca, se calcula con la siguiente fórmula:

$$G_{es} = \frac{B}{B - C}$$

En donde:

Ges = gravedad específica del material saturado con superficie seca.

- La gravedad específica aparente, se calcula con la siguiente relación:

$$G_a = \frac{A}{A - C}$$

En donde:

Gea = Gravedad específica aparente

[19] Lara, 42

- Se calcula el porcentaje de absorción con la siguiente relación:

$$AB\% = \frac{B - A}{A} * 100$$

En donde:

Ab = Porcentaje de absorción

- Se calcula los valores de densidad relativa promedio con la siguiente expresión :

$$G = \frac{1}{\frac{P1}{100 * G_1} - \frac{P2}{100 * G_2} + \frac{Pn}{100 * G_n}}$$

En donde:

G = densidad promedio o densidad relativa (gravedad específica)

G1, G2,.... Gn = densidad promedio apropiada para cada tamaño de Fracción dependiendo el tipo de densidad relativa.

P1, P2,..... Pn = porcentaje en masa de cada tamaño de fracción en la muestra original.

❖ Se calcula el valor de absorción promedio con la siguiente expresión:

$$AB = \frac{P1 * A1}{100} + \frac{P2 * A2}{100} + \frac{Pn * An}{100}$$

En donde:

Ab = absorción promedio (%)

A1, A2,.....An = porcentaje de absorción para cada tamaño de fracción.

P1, P2,.....Pn = porcentajes en masa de cada tamaño de fracción presente en la muestra original.

Se realizaron tres ensayos de Gravedad Específica de la porción gruesa del agregado Pétreo y los resultados son los siguientes:

| ***Ensayo de Gravedades y Absorción Grueso N°1*** | | |
|---|---|---|
| MASA MUESTRA S.S.S. (gr) | B= | 2006.900 |
| MASA MUESTRA SECA (gr) | A= | 1258.560 |
| MASA SUMERGIDA EN AGUA (gr) | C= | 476.000 |
| GRAVEDAD BULK | Ge= | 0.822 |
| GRAVEDAD SSS | Ges= | 1.311 |
| GRAVEDAD APARENTE | Gea= | 1.608 |
| PORCENTAJE DE ABSORCION | Abs%= | 59.460 |

TABLA 2.11 Gravedades y Absorción. Ensayo N°1

| ***Ensayo de Gravedades y Absorción Grueso N°2*** | | |
|---|---|---|
| MASA MUESTRA S.S.S. (gr) | B= | 1809.700 |
| MASA MUESTRA SECA (gr) | A= | 1146.300 |
| MASA SUMERGIDA EN AGUA (gr) | C= | 362.000 |
| GRAVEDAD BULK | Ge= | 0.792 |
| GRAVEDAD SSS | Ges= | 1.250 |
| GRAVEDAD APARENTE | Gea= | 1.462 |
| PORCENTAJE DE ABSORCION | Abs%= | 57.873 |

TABLA 2.12 Gravedades y Absorción. Ensayo N°2

| ***Ensayo de Gravedades y Absorción Grueso N°3*** | | |
|---|---|---|
| MASA MUESTRA S.S.S. (gr) | B= | 1964.520 |
| MASA MUESTRA SECA (gr) | A= | 1238.540 |
| MASA SUMERGIDA EN AGUA (gr) | C= | 390.230 |
| GRAVEDAD BULK | Ge= | 0.787 |
| GRAVEDAD SSS | Ges= | 1.248 |
| GRAVEDAD APARENTE | Gea= | 1.460 |
| PORCENTAJE DE ABSORCION | Abs%= | 58.616 |

TABLA 2.13 Gravedades y Absorción. Ensayo N°3

Se realizaron los 3 ensayos de Gravedad específica y Absorción. Con los resultados mostrados anteriormente se ha calculado un promedio tanto de gravedad específica como porcentaje de absorción y se publican los resultados en la siguiente tabla:

| | GRAVEDAD ESPECIFICA GRUESO | | | |
|---|---|---|---|---|
| | N° 1 | N° 2 | N° 3 | PROMEDIO |
| GRAVEDAD BULK | 0.822 | 0.792 | 0.787 | 0.800 |
| GRAVEDAD SSS | 1.311 | 1.250 | 1.248 | 1.270 |
| GRAVEDAD APARENTE | 1.608 | 1.462 | 1.460 | 1.510 |
| PORCENTAJE DE ABSORCION | 59.460 | 57.873 | 58.616 | 58.650 |

**TABLA 2.14** Gravedades y Absorción Promedio

A continuación se determina el porcentaje de absorción del agregado total (fino y grueso), basándose en la masa de cada porción como se indica en la tabla 2.15 con su porcentaje correspondiente indicada en la tabla 2.16:

$$\%\,de\ Absorción\ del\ agregado = \frac{(32{,}94\ x\ 360{,}395) + (58{,}65 * 139{,}605)}{500}$$

$$\%\,de\ Absorción\ del\ agregado = 39{,}61\ \%$$

| Tamaño | Masa (gr) | Masa de porción (gr) | |
|---|---|---|---|
| 1 | 0,433 | 139,605 | Grueso |
| 3/4 | 1,875 | | |
| 1/2 | 19,426 | | |
| 3/8 | 25,019 | | |
| N. 4 | 92,852 | | |
| N. 8 | 124,767 | 360,395 | Finos |
| Pasa N. 8 | 235,627 | | |
| ***TOTAL*** | ***500*** | ***500*** | |

TABLA 2.15 Masas de cada porción del agregado total.

| | Porcentaje de absorción (%) | Porcentaje de absorción del agregado (%) |
|---|---|---|
| Finos | 32,24 | 39,61 |
| Grueso | 58,65 | |

TABLA 2.16 Porcentaje de absorción del agregado total.

## 2.3 - Desgaste del Agregado Grueso en la Máquina de los Ángeles (Abrasión). "*ASTM C-131-03*"



**FOTOGRAFIA N° 2.10:** Máquina de los Ángeles

En los agregados gruesos una de las propiedades físicas en los cuales su importancia y su conocimiento son indispensables en el diseño de mezclas es la RESISTENCIA A LA ABRASIÓN O DESGASTE de los agregados.

El ensayo que se ha aplicado da a conocer el porcentaje de desgaste del agregado grueso que éste sufrirá en condiciones de roce continuo de las partículas y las esferas de acero. Esto nos indica si el agregado grueso a utilizar es el adecuado para el diseño de la mezcla asfáltica ya que su desgaste proporciona una medida de resistencia a la rodadura constante de vehículos sobre la capa de pavimento.

Los agregados deben ser capaces de resistir el desgaste irreversible y degradación durante la producción colocación y compactación de las obras de pavimentación, y sobre todo durante la vida de servicio del pavimento.

Por esta razón los agregados que están en, o cerca de la superficie como son los materiales de base y carpeta asfáltica deben ser más resistentes que los agregados de las capas inferiores, sub-base, de la estructura de pavimento, la razón se debe a que las capas superficiales reciben los mayores esfuerzos y mayor desgaste por parte de cargas del tránsito.

Este método describe el procedimiento para determinar el porcentaje de desgaste de los agregados de tamaños menores a 37.5mm (1½") y agregados gruesos de tamaños mayores de 19.0mm (¾"), por medio de la Máquina de los Ángeles. La cantidad de material a ensayar y el número de esferas a incluir dependen de la gradación del agregado grueso.

La Muestra que se usa para el ensayo de abrasión deberá estar de acuerdo con una de las gradaciones dadas en la Tabla 2.18; La gradación que se use debe ser aquella que representa más próximamente la gradación natural del material. De acuerdo a la tabla 2.6 indicada anteriormente, se observa que el tamiz que pasa N° 4 y retiene el N° 8 es donde se retiene mayor masa por lo tanto el tipo de gradación de la muestra para el ensayo de abrasión es tipo D.

| TAMAÑO DEL TAMIZ | | | | MASA DE LOS TAMAÑOS INDICADOS (g.) GRADACION | | | |
|---|---|---|---|---|---|---|---|
| PASA | | RETIENE | | A | B | C | D |
| 1 ½ | 38.1 | 7 | 25.4 | 1250±25 | | | |
| 1 | 25.4 | ¾ | 19.0 | | | | |
| ¾ | 19.0 | ½ | 12.7 | 1250±25 | 2500±10 | | |
| ½ | 12.7 | 3/8 | 9.5 | | | | |
| 3/8 | 9.5 | No. 3 | 6.3 | 1250±10 | 2500±10 | 2500±10 | |
| No. 3 | 6.3 | No. 4 | 4.76 | 1250±10 | | | |
| No. 4 | 4.76 | No. 8 | 2.36 | | | 2500±10 | 5000±10 |
| TOTAL | | | | 5000±10 | 5000±10 | 5000±10 | 5000±10 |

TABLA 2.18[20]: Tipos de Gradación

## Equipo

- **Maquina de los ángeles** : Tambor de acero de 710 ± 6 mm de diámetro interior y de 510 ± 6 mm de longitud interior montado horizontalmente por sus vástagos axiales con una tolerancia de inclinación de 1 en 100, uno de los cuales debe tener un dispositivo de polea o similar, para acoplar el motor. En su manto cilíndrico debe tener una abertura para introducir la muestra, con una tapa provista de dispositivos para fijarla firmemente en su lugar y que asegura una estanqueidad al polvo.
- **Balanza**: Con una capacidad superior a 10 kg. Y una precisión igual o mayor al 0.1%. De la pesada.
- **Tamices** : De malla y alambre y abertura cuadrada.

[20] Lara, 69

- **Bandeja**
- **Esferas**: (Carga abrasiva), Un juego de esferas de acero de 45 a 50 mm de diámetro.

Una carga abrasiva consiste en esfera de acero de unos 48 mm de diámetro, cuya cantidad depende del material que se ensaya, para este ensayo se ha determinado la gradación tipo D, tal como se indica en la siguiente tabla 2.19:

| *TIPO* | *NÚMEROS DE ESFERAS* | *MASA DE LAS ESFERAS (grs)* |
|---|---|---|
| *A* | *12* | *5000 ± 25* |
| *B* | *11* | *4584 ± 25* |
| *C* | *8* | *3330 ± 25* |
| *D* | *6* | *2500 ± 15* |

**TABLA 2.19**[21]**:** Número de esferas

## Procedimiento

1. Se pesa 5000 gramos de muestra seca con una aproximación de 1 gramo y se coloca junto con la carga abrasiva dentro del cilindro; se hace girar este con una velocidad entre 30 y 33 rpm, girando hasta completar 500 vueltas teniendo en cuenta que la velocidad angular es constante.

[21] Lara, 69

2. A continuación se retira el material del cilindro y luego se hace pasar por el tamiz # 12 según lo establecido en la Norma. El material retenido en el tamiz #12 debe ser lavado y secado en el horno a una temperatura comprendida entre 105 °C y 110 °C. Al día siguiente se cuantifico la muestra eliminando los finos y luego fue pesada.

## Cálculos [22]

Se calcula la masa de material que pasa el tamiz No. 12, después del ensayo, utilizando la siguiente fórmula:

$$C = A - B$$

En donde:

C = Material que pasa el tamiz No. 12 (g.)

A = Masa inicial de la muestra (g.)

B = Masa sostenida en el tamiz No. 12 (g.)

Luego se calcula el porcentaje de desgaste del agregado, con la siguiente fórmula:

$$\text{Porcentaje de desgaste} = \frac{C \times 100}{A}$$

[22] Lara, 72

A continuación se presentan los resultados obtenidos:

| | |
|---|---|
| Tipo de Gradación | D |
| Número de Esferas | 6 |
| (A) Masa Inicial gr. | 5000 |
| (B) Masa sostenida en el tamiz N°12 gr. | 3355 |
| (C) Material que pasa el Tamiz N°12 gr. | 1645 |

| | |
|---|---|
| % de Desgaste | 32.90% |

TABLA 2.20: Resultado del ensayo de Abrasión

## 2.4 – Durabilidad de los Agregados a la Acción del Sulfato de Sodio. *"ASTM C-088 – 99 a"*

Es el porcentaje de pérdidas del material en una mezcla de agregados durante el ensayo de durabilidad de los áridos sometidos al ataque con sulfato de sodio o sulfato de magnesio. Éste ensayo estima la resistencia del agregado al deterioro por acción de los agentes climáticos durante la vida útil de la obra. Puede aplicarse tanto en agregado grueso como fino.

El ensayo se realiza exponiendo una muestra de agregado a ciclos alternativos de baño de inmersión en una solución de sulfato de sodio y secado en horno. Una inmersión y un secado se consideran un ciclo de durabilidad. Durante la fase de secado, las sales precipitan en los vacíos del agregado. En la re-inmersión las sales se rehidratan y ejercen fuerzas de expansión internas que simulan las fuerzas de expansión del agua congelada. El resultado del ensayo es el porcentaje total de pérdida de peso sobre varios tamices para un número requerido de ciclos. Los valores máximos de pérdida son aproximadamente de 10 a 20% para cinco ciclos de inmersión- secado.

El método describe el procedimiento que debe seguirse para determinar la resistencia a la desintegración de los agregados por la acción de soluciones de sulfato de sodio o de magnesio.

Equipo

1. Tamices

   Para ensayar agregado grueso: 3 /8", ½"

   Para ensayar agregado fino: Nº 50, Nº 30, Nº 16, Nº 8 y Nº 4

2. **Recipientes:** Cestas de mallas metálicas que permiten sumergir las muestras en la solución utilizada, facilitando el flujo de la solución e impidiendo la salida de las partículas del agregado. El volumen de la solución en la cual se sumergen las muestras será, por lo menos, cinco veces el volumen de la muestra sumergida.

3. **Balanza.** Capacidad de 500 gr. y sensibilidad de 0.1 gr. para el caso del agregado fino y otro de capacidad no menor a 5000 gr. y sensibilidad de 1 gr. para el caso del agregado grueso

4. **Horno**. Capaz de mantener una temperatura de 110± 5ºC

*Solución de Sulfato de Sodio*

Si se va emplear sulfato de sodio de forma anhidra, se disuelve 700 gr. en un litro de agua a la temperatura de 25 a 30ºC. Luego se deja reposar la preparación por 48 horas a 21 ± 1ºC, antes de su empleo.

## Procedimiento

1. Se sumerge las muestras preparadas en la solución de sulfato de sodio por un período de 16 a 18 horas, de manera que el nivel de la solución quede por lo menos 13 mm por encima de la muestra. Tapar el recipiente para evitar la evaporación y contaminación con sustancias extrañas. Mantener la temperatura en 21 ± 1ºC durante el período de inmersión.



**FOTOGRAFIA Nº 2.11**[23]**:** Muestra sumergida en solución sulfato de sodio.

2. Se retira la muestra de la solución dejándola escurrir durante 15±5 min., se seca en el horno a 110º±5ºC hasta obtener peso constante a la temperatura indicada. Para verificar el peso se sacará la muestra a

[23] Lara, 77

intervalos no menores de 4 horas ni mayores de 18 horas. Se considerará que se alcanzó un peso constante cuando dos pesadas sucesivas de una muestra, no difieren más de 0.1 gr. en el caso del agregado fino, o no difieren más de 1.0 gr. en el caso del agregado grueso.

3. Obtenido el peso constante se deja enfriar a temperatura ambiente y se vuelve a sumergir en la solución para continuar con los ciclos que se especifiquen.

4. Al final de los ciclos se lava la muestra hasta eliminar los sulfatos de sodio, los últimos lavados deben efectuarse con agua destilada.

5. Se seca a peso constante a una temperatura de 110±5ºC y se pesa.

6. Se tamiza el agregado fino sobre los tamices en que fue retenido antes del ensayo, y el agregado grueso sobre los tamices establecidos, según el tamaño de las partículas.

Cálculos[24]

1. Se calcula el porcentaje retenido parcial con respecto a la granulometría original del agregado, el cálculo se realiza para cada fracción y con la siguiente relación:

$$\% \text{ Retenido Parcial} = \frac{\text{Masa retenida parcial} \times 100}{\text{Masa total de muestra}}$$

2. Se calcula el porcentaje que pasa el tamiz más fino después del ensayo; este valor se calcula para cada fracción, con la siguiente fórmula:

$$\% \text{ que pasa} = \frac{\text{Masa inicial} - \text{Masa retenida después del ensayo} \times 100}{\text{Masa inicial}}$$

3. Se calcula el porcentaje de desgaste parcial, con la siguiente relación:

$$\% \text{ desgaste parcial} = \frac{\text{Porcentaje retenido parcial} \times \% \text{ que pasa}}{100}$$

4. El porcentaje de desgaste total del agregado a la acción de los sulfatos, es igual a la suma de los porcentajes de desgaste parcial.

[24] Lara, 79

De acuerdo a la especificación establecida por el M.O.P. se determina que el porcentaje de desgaste a los sulfatos debe ser menor al 12%. A continuación se presentan los resultados del ensayo en la tabla 2.21:

| Numero de tamiz | | % Ret. Parcial del agregado | M. de las fracciones antes de ensayo | M. de las fracciones despues de ensayo | % Pasa(el tamiz+fino despues del ensayo) | % de desgaste parcial |
|---|---|---|---|---|---|---|
| Pasa | Retiene | | | | | |
| 1/2 | 3/8 | 4.84% | 330 | 314.7 | 4.64% | 0.22% |
| 3/8 | N.4 | 17.67% | 300 | 278.23 | 7.26% | 1.28% |
| N.4 | N.8 | 24.74% | 100 | 88.24 | 11.76% | 2.91% |
| N.8 | N.16 | 22.52% | 100 | 89.97 | 10.03% | 2.26% |
| N.16 | N.30 | 16.27% | 100 | 81.54 | 18.46% | 3.00% |
| N.30 | N.50 | 3.66% | 100 | 78.43 | 21.57% | 0.79% |
| | | | | | % de Desgaste Total | 10.47% |

TABLA 2.21: Resultados del ensayo Durabilidad de los Agregados a la Acción del Sulfato de Sodio.

## 2.5 – Equivalente de Arena *"ASTM D2419 - 02"*



**FOTOGRAFIA N° 2.12:** *Equipo para equivalente de arena*

Este método de ensayo asigna un valor empírico a la cantidad relativa, finura y características del material fino presente en una muestra de ensayo formado por suelo granular que pasa el tamiz de 4.75mm (N°4). El término "Equivalente de Arena" transmite el concepto de que la mayoría de suelos granulares y agregados finos son mezcla de partículas gruesas, arenas y generalmente finos. Este método proporciona una manera rápida de campo para determinar cambios en la calidad de agregados durante la producción o colocación.

Para determinar el porcentaje de finos en una muestra, se incorpora una medida de suelo y solución en una probeta plástica graduada que luego de ser agitada separa el recubrimiento de finos de las partículas de arena; después de un período de tiempo, se pueden leer las alturas de arcilla y

arena en la probeta. El equivalente de arena es la relación de la altura de arena respecto a la altura de arcilla, expresada en porcentaje.

Este método proporciona una manera rápida de campo para determinar cambios en la calidad de agregados durante la producción o colocación.

Los resultados que se exponen a continuación son obtenidos como el porcentaje de alturas de arcilla y arena medidas en una probeta graduada tal como lo dicta la norma.

$$\text{EQUIVALENTE DE ARENA} = \frac{\text{SEDIMENTO: Lectura B}}{\text{Suspension: Lectura A}}$$

| | | |
|---|---|---|
| A = | 3.3 | |
| B = | 2.9 | |
| **EQUIVALENTE DE ARENA** | = | **88%** |

TABLA 2.22: Resultados del ensayo Equivalente de Arena

## 2.6 – Determinación de Deletéreos *"ASTM C 142 - 97"*

Este método describe el procedimiento para la determinación de los terrones de arcilla y de partículas friables o deleznables en los agregados naturales.

En la especificación establecida por el M.O.P. determina que el porcentaje de partículas livianas (Deletéreos) tiene que ser menor al 1%.

Como se menciono anteriormente el agregado no tiene distinción de las porciones, de acuerdo a la norma la mezcla de agregado fino y grueso, se los debe separar utilizando el tamiz No. 4

Para el agregado fino su masa inicial no debe ser menor a 100 gr, que está conformado por el material que se retenga en el tamiz N° 16 y para el agregado grueso, se debe separar por tamaños, y la masa de muestra para cada tamaño no debe ser menor a la indicada en la Tabla 2.23.

| *TAMAÑO DEL TAMIZ* | | | | *MASA MINIMA* |
|---|---|---|---|---|
| *PASA* | | *RETIENE* | | |
| *Pulg.* | *mm.* | *Pulg.* | *Mm.* | *Kg* |
| *3/8* | *9.5* | *No. 4* | *4.76* | *1.0* |
| *¾* | *19.0* | *3/8* | *9.50* | *2.03.0* |
| *1 ½* | *38.1* | *3/4* | *19.00* | *5.0* |
| *Más de 1 ½"(38,1mm* | | | | |

**TABLA 2.23:** Requisitos del MOP para masa mínima para agregado grueso.

Como se explico anteriormente para este ensayo se ha separado la porción fina de la gruesa según lo indica la norma siendo los resultados los siguientes:

| | $W_i$ (gr) | $W_f$ (gr) |
|---|---|---|
| Porción Finos | 286.98 | 148.76 |
| Porción Grueso | 2648.00 | 2310 |

| | |
|---|---|
| % DELETEREOS FINOS | 48.2% |
| % DELETEREO GRUESO | 12.8% |

**TABLA 2.24:** Resultados obtenidos del ensayo Deletéreos.

# 3. – CARATERIZACION DE CEMENTO ASFÁLTICO

Una mezcla asfáltica en caliente consiste en la combinación uniforme de agregados con cemento asfaltico. Alrededor de un 5% del total de una mezcla asfáltica está constituido por el cemento asfáltico, y como se verá posteriormente, las características de una mezcla y su comportamiento son sensibles ante la mínima alteración de este contenido de asfalto y sus propiedades. Es por ésta razón que es importante determinar las características mecánicas del cemento asfáltico que se ha usado para ésta investigación.

El concreto asfaltico es un tipo de mezcla en caliente que cumple con estrictos requisitos de control de calidad, resultando una carpeta de alta calidad, con buena calidad de agregados y bien compactada, es por eso que es necesario realizar ensayos de caracterización del cemento asfáltico que se ha utilizado en ésta investigación. El cemento asfaltico utilizado es el AP3 y se lo obtuvo de la planta asfáltica ubicada a orillas del Río Guayllabamba.

De acuerdo a las especificaciones del MOP TOMO II para caminos y puentes el cemento asfaltico debe cumplir con las siguientes especificaciones:

| ENSAYOS | 60-70 | | 85-100 | |
|---|---|---|---|---|
| **Betún original** | mínimo | máximo | mínimo | máximo |
| Penetración (25 ?C, 100 gr, 5 s), mm/10. | 60 | 70 | 85 | 100 |
| Punto de ablandamiento A y B, °C. | 48 | 57 | 45 | 53 |
| Indice de penetración (*). | –1,5 | +1,5 | -1,5 | +1,5 |
| Ductilidad (25 ?C, 5 cm/minuto), cm. | 100 | --- | 100 | --- |
| Contenido de agua (en volumen), % . | --- | 0,2 | --- | 0,2 |
| Solubilidad en Tricloroetileno, %. | 99 | --- | 99 | --- |
| Punto de inflamación, Copa Cleveland, ?C. | 232 | --- | 232 | --- |
| Densidad relativa, 25 °C/ 25 °C | 1,00 | --- | 1,00 | --- |
| Ensayo de la mancha (**) | NEGATIVO | | NEGATIVO | |
| Contenido de parafinas, %. | --- | 2.2 | --- | 2.2 |
| **Ensayos al residuo del TFOT:** | | | | |
| Variación de masa, %. | --- | 0,8 | --- | 1,0 |
| Penetración, % de penetración original. | 54 | --- | 50 | --- |
| Ductilidad , cm | 50 | --- | 75 | --- |
| Resistencia al endurecimiento (***). | --- | 5,0 | --- | 5,0 |

TABLA 3.1 [25] Requisitos presentados por el MOP en tabla 810.2.1

A continuación se presentan los ensayos realizados con sus respectivos resultados.

## *3.1 Gravedad Específica "ASTM: D 3142 - 97"*

La gravedad específica de un material, tal como se explicó en el capitulo anterior, es la relación entre el peso en aire a una temperatura determinada al peso de un volumen igual de agua a la misma temperatura.

Para la determinación de la gravedad específica para cementos asfalticos se tienen algunos métodos de ensayo. Para esta investigación se ha utilizado el Método de la Balanza Analítica o Hidrostática con su procedimiento para bitúmenes sólidos y duros la cual se la realizó de la siguiente manera:

[25] MOP, VIII 68

## Equipo[26]

- Moldes de bronce de ½" (**Fotografía 3.1**)
- Mechero
- Recipiente para calentar el material
- Dextrina con glicerina en partes iguales
- Funda de agua destilada
- Balanza analítica



**FOTOGRAFÍA N° 3.1** Moldes de Bronce

## Procedimiento para bitúmenes sólidos y duros[27]

- Con el material que se va a ensayar se prepara un cubo con una arista aproximada de media pulgada. Para ello, se calienta la muestra aplicando calor lentamente evitando pérdidas por evaporación.

[26] Yánez, Práctica N° 9

[27] Yánez, Práctica N° 9

- Cuando la muestra esté suficientemente fluida, se vacía en un cubo de bronce de media pulgada de arista, el cual debe ser previamente amalgamado con mercurio, evitando la formación de burbujas.

- La muestra se retira del molde una vez que éste se encuentra a la temperatura ambiente. Se pesa la muestra convenientemente, primero en el aire (peso "a") y luego en agua destilada a 25°C recientemente hervida (peso "b"), teniendo cuidado de remover las burbujas de aire que se formen. Las pesadas deben hacerse con una aproximación de 0.1 mg.

Para el cálculo de la Gravedad Específica se utiliza la siguiente expresión:

$$Gs = \frac{a}{a - b}$$

Los resultados obtenidos de este ensayo son los siguientes.

| | MUESTRAS | |
|---|---|---|
| | N°1 | N°2 |
| Peso al Aire [gr.] | 9.25 | 8.36 |
| P. Sumergido [gr.] | 0.12 | 0.11 |
| Grav. Espec. Gs [g/cm³] | 1.013 | 1.013 |
| Gs PROMEDIO [g/cm³] | 1.013 | |

**TABLA 3.2** Gravedades de Muestras N°1 y N°2 - Gravedad Específica Promedio

## *3.2 Penetración "ASTM D5 - 05"*

El ensayo de penetración determina la dureza y la consistencia relativa de un betún asfáltico, midiendo la distancia que una aguja normalizada penetra verticalmente en una muestra del asfalto en condiciones especificadas de temperatura, carga y tiempo.

La penetración se expresa como el promedio de por lo menos tres lecturas (expresadas en la cifra entera más cercana) cuyos valores no difieren de este promedio en más de la Tolerancia. Las bases de procedimiento y cálculo de resultados de este ensayo son los siguientes:

### Equipo requerido[28]

- Penetrómetro estándar, incluyendo aguja, peso, vástago y soporte (**Fotografía 3.2**).
- Recipiente para asfaltos, de diámetro 55 mm y 35 mm.
- Recipiente para agua de diámetro 9.0 cm y 5.5 cm de altura, de vidrio.
- Baño de agua, con control para mantener una temperatura constante de 25°C (**Fotografía 3.3**).
- Mechero a gas.

[28] Yánez, Práctica N° 10

- Cronómetro.
- Par de guantes de asbesto.
- Trapo limpio



**FOTOGRAFÍA N° 3.2** Penetrómetro estándar.



**FOTOGRAFÍA N° 3.3** Baño María para mantener temperatura constante.

Procedimiento[29]

- Luego de obtener el material de los depósitos se calienta la muestra hasta que, su consistencia sea suficientemente fluida para transferirla al recipiente apropiado. Nunca se debe calentar a más de 150 °C (320° F).
- Se aplica ligeramente la llama del mechero, a la superficie del producto bituminoso para eliminar las posibles burbujas. Luego se tapa el recipiente con su contenido y se deja enfriar por un período de 1 a 1½ horas.
- Al terminarse el período de enfriamiento, se coloca el recipiente con su contenido en un baño de agua a temperatura constante de 25° C (77° F) por un período de 1 a 1½ horas. Al mismo tiempo, se coloca también el recipiente de diámetro 9 cm dentro del baño de agua a temperatura constante de 25° C.
- Al terminar el período de reposo dentro del baño de agua de 25° C, se retira el recipiente de diámetro 9 cm con una cantidad de la misma agua del baño a 25° C. Es suficiente llenar este recipiente hasta una altura de 2 cm.
- Se retira el recipiente con la muestra, se quita su tapa y se lo coloca dentro del otro recipiente con agua. Se pone el conjunto sobre la plataforma del penetrómetro e inmediatamente se baja la aguja cuidadosamente hasta que la punta esté tocando la superficie de la

[29] Yánez, Práctica N° 10

muestra. Esto se logra poniendo la punta de la aguja en contacto con su imagen reflejada en la muestra. Para visualizar la unión de la aguja con su imagen, se utiliza una fuente luminosa.

- Luego de ajustar el indicador en cero, se deja caer la aguja por 5 segundos, hasta penetrar la muestra y por medio del indicador se mide la distancia de penetración. Se debe hacer por lo menos tres ensayos. La penetración debe hacerse en puntos distantes un centímetro del borde del recipiente y un centímetro entre sí. Para cada penetración se limpia la aguja con un trapo limpio y no se usa solventes.

## Cálculo[30]

La penetración se expresa como el promedio de por lo menos tres lecturas (expresadas en la cifra entera más cercana) cuyos valores no difieren de este promedio en más de la Tolerancia.

$$\pm \text{ TOLERANCIA } = \frac{PROMEDIO\ DE\ PENETRACION}{100} + 1$$

La tolerancia se expresa en la cifra entera más cercana.

[30] Yánez, Práctica N° 10

Se obtuvieron los siguientes resultados:

| Puntos | Lectura Penetración |
|---|---|
| P 1 | 60 |
| P 2 | 59 |
| P 3 | 58 |
| **Penetración promedio** | 59 |

**TABLA 3.2** Lecturas de Penetración

| | centésimas de cm |
|---|---|
| **Tolerancia** | 1,581 |
| **T. Redondeada** | 2 |

**TABLA 3.3** Tolerancia en Penetración

## 3.3 Punto de ablandamiento o reblandecimiento "ASTM: D2398-68"

El punto de ablandamiento nos ayuda a determinar el cambio de consistencia del asfalto que sucede gradualmente a medida que la temperatura aumenta.

Existen varios métodos de ensayo para determinar el punto de ablandamiento y el utilizado para esta investigación es el reconocido por la ASTM como el método del anillo y bola.

Se define el punto de ablandamiento, como la temperatura a la cual una probeta del material en forma de disco, mantenida horizontalmente dentro de un anillo, es obligada a deformarse por el peso de una bola de acero y toca una superficie de un baño situada a una 1 pulgada (2,54 cm) cuando se calienta a una velocidad determinada dentro del baño con agua destilada y glicerina.

Los procedimientos de análisis del presente ensayo se establecen de la siguiente manera:

### Equipo requerido.-[31]

1. Anillo de bronce
2. Bola de acero de 9,53mm(3/8) de diámetro y con un peso entre 3,45 a 3,55 gramos
3. Guía de la bola
4. Termómetro con escala de -2 °c a + 80 °c
5. Baño (consistente en un vaso de vidrio resistente al calor, de diámetro mayor que 8,5 cm y altura mayor que 10,5 cm.)

[31] Yánez, Práctica N° 11

6. Agua destilada

7. Agitador




**FOTOGRAFÍA N° 3.4** Equipo para Punto de Reblandecimiento

## Preparación de la muestra [32]

1. El material bituminoso se calentara a una temperatura inferior a 100 °C por encima de su punto de fluido y homogéneo y no tenga burbujas de aire.

2. Se calienta el anillo de broce a una temperatura que sea más o menos la del material bituminoso. Se coloca un poco de material

[32] Yánez, Práctica N° 11

sobre una placa de bronce amalgamada, en cantidad suficiente para que, una vez frío su nivel quede por encima del anillo.

3. Se deja enfriar durante una hora al material en estudio y a la temperatura ambiente, eliminando el exceso de material por medio de una espátula caliente.

Procedimiento para materiales bituminosos con punto de reblandecimiento menor a 80°c.[33]

1. Se monta el aparato colocando sobre el soporte los anillos, las guías y el termómetro en su correcta posición, introduciendo el conjunto en recipiente y llenando éste con agua destilada hasta que el nivel de la superficie quede por lo menos 5 cm por encima de la parte superior del anillo. Se introduce también la bola, pero no se la coloca sobre la muestra.
2. Se mantiene el baño a la temperatura de 25 °C durante 15 minutos, colocando después la bola centrada por la guía sobre la muestra.
3. Se aplica calor al baño agitando ligeramente el líquido de manera que la temperatura aumente 5 ± 0.5 °C por minuto, hasta que el material se

[33] Yánez, Práctica N° 11

reblandezca y, arrastrado por la bola , llegue a tocar la superficie situada a una pulgada (2.54 cm).

4. La temperatura que marca el termómetro en el instante en que la muestra toca el fondo del baño, se toma como punto de reblandecimiento del material.

5. Se harán varios ensayos de un mismo material, teniendo en cuenta que la velocidad a la que se eleva la temperatura sea uniforme durante todos y cada uno de los ensayos.

Las variaciones máximas permitidas para un minuto, después de los tres primeros, serán de ±0.5 °C. Todos los ensayos en los que la velocidad exceda este límite no se considerarán válidos.

## Cálculos[34]

1. La media de las determinaciones (ensayos) con aproximación de 0.5 °C será el Punto de Reblandecimiento del material.
2. La precisión del ensayo es de ±0.5 °C.

[34] Yánez, Práctica N° 11

Los resultados de éste ensayo en las dos muestras evaluadas se publican en la siguiente tabla:

| MUESTRA N° | TEMPERATURA °C |
|---|---|
| **1** | 40 |
| **2** | 40,5 |
| **PROMEDIO** | **40,25** |

**TABLA 3.4** Punto de Reblandecimiento. Ensayo N°1 y N°2 Promedio del Punto de Reblandecimiento.

## 3.4 Ensayo de Inflamación y combustión "ASTM: D 92"



**FOTOGRAFIA N° 3.5:** Equipo para Inflamación y combustión

Este ensayo nos sirve para determinar la temperatura a la cual el material bituminoso debe ser manipulado con precaución debido a que a dicha temperatura en presencia de fuego puede inflamarse.

Cuando se calienta un asfalto, libera vapores que son combustibles. Existen dos temperaturas como indica el ensayo que son: Punto de Inflamación y Punto de Combustión.

El punto de inflamación, es la temperatura a la cual puede ser calentado con seguridad un asfalto, sin que se produzca la inflamación instantánea de los vapores liberados, en presencia de una llama libre. Esta temperatura, sin embargo, está bastante por debajo, en general, de la que el material entra en combustión permanente. Se la denomina punto de combustión.

El equipo que se ocupo para este ensayo se menciona a continuación: [35]

- 1 Vaso abierto de Cleveland
- 1 Placa de calentamiento de metal
- 1 Fuente de calor, ya sea un mechero de gas, hornillo eléctrico o lámpara de alcohol.
- 1 Termómetro graduado con escala de –6°C a + 400 °C.

## Procedimiento

1. Primero se calienta el material bituminoso a una temperatura comprendida entre 150 y 175 ° C hasta que esté en estado fluido para poder verter en el vaso Cleveland.
2. Luego se llena el vaso con el material bituminoso fluido hasta el ras del menisco tomando en cuenta que en la superficie del material esté libre de burbujas.
3. Se procede a encender el mechero de prueba y se ajusta la llama para que tenga un diámetro comprendido entre 3 a 5 mm según la norma.
4. Se comienza el calentamiento de la muestra con una velocidad inicial de aumento de la temperatura entre 14 y 17 °C por minuto hasta llegar a una temperatura de 56 ° C por debajo del punto de inflamación

[35] Yánez, Práctica N° 12

previsto, se comienza a disminuir el calor para lograr que, en los últimos 28° C, la velocidad de elevación de la temperatura esté comprendida entre 5 y 6 ° C por minuto.

5. A partir de 180 ° C antes del punto de inflamación previsto, se comienza la operación cada 2° C con un movimiento suave y uniforme, la llama de prueba se pasa en un solo sentido cada vez, y en el sentido opuesto la pasada siguiente y no debe tardarse en cada pasada más de un segundo.

6. Cuando se produce el primer destello en algún punto de la superficie de la muestra en el momento de una pasada, se anota la temperatura indicada en el termómetro.

7. Para determinar el punto de combustión, se continúa con el movimiento suave y uniforme cada 2 °C de elevación de temperatura. Cuando la llama dura al menos 5 segundos sobre la muestra, se anota la temperatura que indica en el termómetro.

A continuación se indica los resultados obtenidos del ensayo:

| PRUEBA N. | Punto de Inflamación | Punto de Combustión | |
|---|---|---|---|
| 1 | 234 | 248 | °C |
| | 453 | 478 | °F |

**TABLA 3.5** Resultados del ensayo de Inflamación y combustión

## *3.5 Ensayo de Ductilidad* ***"ASTM: D113 - 99"***



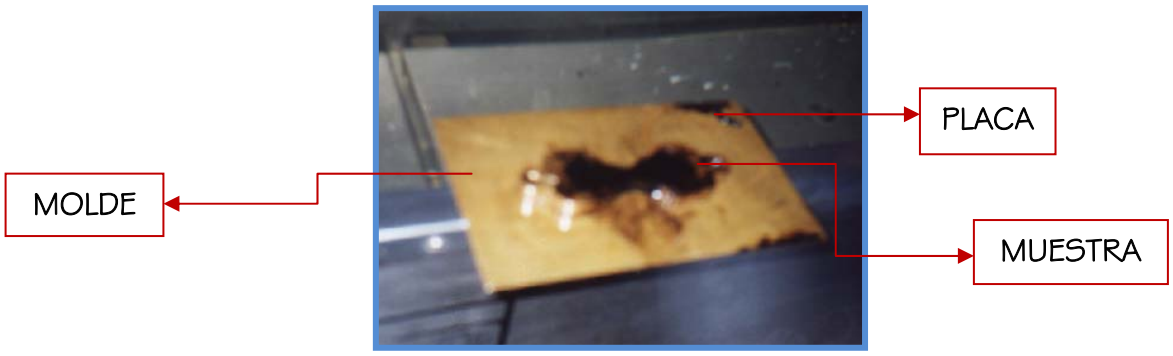
**FOTOGRAFIA Nº 3.6:** Equipo para ductilidad

Este ensayo consiste en medir la máxima distancia a la cual una briqueta de materiales bituminosos, de geometría y bajo condiciones de temperatura y velocidad de deformación específicas, puede ser estirada sin romperse. De alguna manera, la ductilidad muestra la susceptibilidad que tienen los materiales bituminosos a la tensión.

El equipo que se ocupa para este ensayo se indica a continuación: [36]

- Aparato para ductilidad (Fotografía 3.6)
- Moldes para briquetas (Fotografía 3.7)
- Termómetro
- Baño de María
- Platinas de bronce

## Procedimiento[37]




**FOTOGRAFIA N° 3.7:** Muestra para ensayo de Ductilidad.

1. Se prepara las 3 muestras para el ensayo como se indica en la norma, se calienta el asfalto hasta que esté completamente fluido. Luego se vierte el fluido en los moldes hasta el ras del molde, evitando que queden burbujas de aire en la muestra.

[36] Yánez, Práctica N° 13
[37] Yánez, Práctica N° 13

2. Se deja enfriar las muestras a la temperatura ambiente, protegiéndolas del polvo. Después que las muestras se hayan enfriado se retira el exceso del material con una espátula caliente hasta que el molde esté envasado.

3. Se introducen las 3 muestras en conjunto con la placa, molde y la muestra en el baño maría a una temperatura de 25° C durante una hora y media.

4. Se sacan las muestras del baño maría, se separan las piezas laterales del molde y se retiran las muestras de la placa.

5. Se procede con el ensayo, se coloca agua en el aparato de ductilidad a una temperatura de 25 ° C. Luego se colocan las muestras a una distancia de 2.5 cm del fondo.

6. Se enciende el aparato de ductilidad, se debe tener cuidado de que el hilo que se produce al estirarse la muestra no se ponga en contacto con el fondo del aparato de ductilidad y se anota la medida cuando el hilo se rompa.

Los resultados obtenidos de este ensayo son los siguientes:

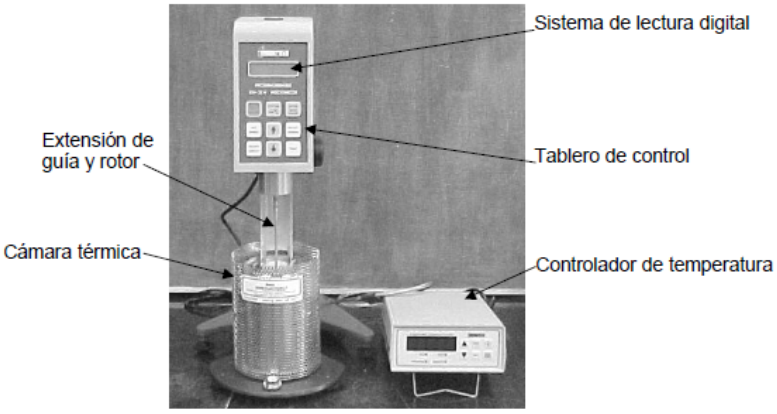
| Muestra N° | Ductilidad (cm) |
|---|---|
| 1 | > 135 |
| 2 | > 135 |
| 3 | > 135 |
| PROMEDIO | > 135 |

TABLA 3.6 Resultados del ensayo de Ductilidad

## *3.6 Ensayo de Viscosidad "ASTM: D4402 - 06"*

Esta prueba permite determinar la consistencia de los cementos asfalticos, en un rango de 38 a 260°C, mediante la determinación de la resistencia que ofrece una muestra de prueba a la deformación. La prueba consiste en determinar el par de torsión que es necesario aplicar en un eje rotacional, en el seno de una muestra de prueba colocada dentro de un contenedor, bajo condiciones controladas de temperatura, para que gire a una cierta velocidad.

*Equipo:*




**FOTOGRAFIA N° 3.8:** Equipo de ensayo de viscosidad.

Los resultados se exponen en la siguiente carta de viscosidad:

**Viscosidad ceménto asfáltico sin polímero**

| Lectura | Temperatura | Visc [cP] | Torque [%] | velocidad [rpm] | husillo |
|---|---|---|---|---|---|
| 1 | 135°C | 322.50 | 12.9 | 100 | SC4-27 |
| 2 | 135°C | 322.50 | 12.9 | 100 | SC4-27 |
| 3 | 135°C | 322.50 | 12.9 | 100 | SC4-27 |
| 1 | 155°C | 128.75 | 10.3 | 200 | SC4-27 |
| 2 | 155°C | 128.75 | 10.3 | 200 | SC4-27 |
| 3 | 155°C | 128.75 | 10.3 | 200 | SC4-27 |

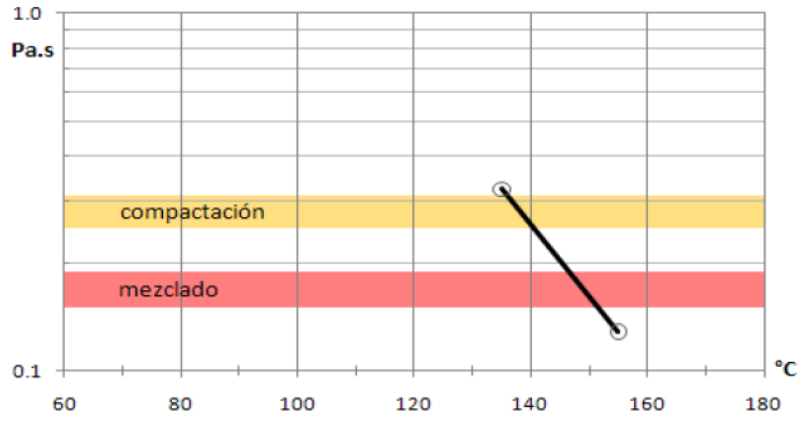



TABLA 3.7 Resultados del ensayo de Viscosidad

# 4.- DISEÑO – MÉTODO MARSHALL "ASTM D 6927 – 04"

## *4.1 Cálculo del Porcentaje Óptimo Teórico (P.O.T.) por medio de expresiones empíricas.*

Para poder dar un paso inicial en la obtención del porcentaje óptimo de asfalto para una mezcla en caliente se debe calcular en primer lugar un porcentaje de asfalto aproximado teórico, para lo cual existen expresiones empíricas o en base a estudios realizados en laboratorio que nos permiten tener un punto de partida en cuanto a cantidades de asfalto en Porcentaje (%), necesarios para conformar el grupo de muestras para ejecutar el ensayo de Diseño usando el Método Marshall.

Para la determinación del porcentaje óptimo teórico o aproximado de una mezcla se ha acudido a las recomendaciones y a la teoría que el autor Gustavo Rivera E. publica en su libro "*EMULSIONES ASFÁLTICAS*" y que dice lo siguiente:

> *""CALCULO DE PORCENTAJE ÓPTIMO TEORICO DE ASFALTO EN UNA MEZCLA*
>
> *El porcentaje óptimo teórico de ligante se puede calcular por medio de varios métodos, sin embargo por su exactitud y facilidad de cálculo se describirán las dos mejores:*

1. *Método del Laboratorio de Puentes y Calzadas de Francia*
2. *Método del Instituto del Asfalto de Estados Unidos.*

1. *Método de Laboratorio de Puentes y Calzadas (L.P.C.)*

*Este cálculo teórico requiere que se evalúe la superficie específica, (S.E.), del material pétreo y conocer el tipo de pavimento donde se va a emplear. Para efectos de este estudio, únicamente se va a considerar el caso de las mezclas más comúnmente empleadas, es decir el valor de riqueza será constante.*

*Para determinar la S.E. (en m²/kg), se usa la siguiente fórmula:*

$$S.E. = \frac{1}{100}(0.237 * G + 1.60 * g + 12.85 * A + 117.8F)$$

*Donde;*

*G : % entre la malla 19.05mm y 4.76mm*

*g : % entre la malla 4.76mm y 0.420mm*

*A : % entre la malla 0.420mm y 0.074mm*

*F : % que pasa la malla 0.074mm*

*Con el valor de la S.E., se entra directamente a la gráfica correspondiente y se obtiene el porcentaje de cemento asfáltico cercano al óptimo, con respecto al agregado. La cantidad así determinada es muy cercana a la que se obtendrá a partir del cálculo práctico elaborando los especímenes.*

*Otra forma de obtener el porcentaje de cemento asfáltico es empleando el porcentaje que pasa la malla 0.074mm (F), y entrando directamente a la grafica correspondiente con este valor. Esta forma de cálculo es menos exacta que la primera donde entran todos los tamaños de partículas.*

## 2. *Método del Instituto del Asfalto (EU)*

*Este método esta publicado en la edición del Manual del Instituto del Asfalto y da directamente el porcentaje óptimo teórico de cemento asfalto con respecto a la mezcla total:*

$$\%E = 0.032 * a + 0.045 * b + k * c + K$$

*Donde:*

*E: % optimo teórico de cemento asfaltico.*

*a : % retenido en la malla 2.0mm.*

*b : % pasa la malla 2.0mm y retiene la 0.074mm.*

*c: % pasa la malla 0.074mm*

*k : 0.20 si el valor (c) está entre 11 y 15%*

*0.18 si el valor (c) está entre 6 y 10%*

*0.15 si el valor de (c) es menor del 5%*

*K : puede variar de 0.0 a 2.0 según el tipo de material pétreo y de su absorción.* [38]

Las gráficas mencionadas en ésta referencia bibliográfica se encuentran en el Capítulo "Anexos" y mediante la utilización de estas formulas empíricas se ha obtenido los porcentajes teóricos de asfalto que han sido tomados como punto de partida para elaboración de briquetas a ensayar usando el Método Marshall para

[38] Rivera E., 1998: 126

determinar el Porcentaje Óptimo de Asfalto para las Muestras Patrón de ésta investigación.

Dadas las expresiones que permitan conocer el porcentaje óptimo teórico, se realizó el cálculo utilizando los datos obtenidos en el *Capítulo 2* y *Capítulo 3* (Caracterización de los Materiales Pétreos y Caracterización de Cemento Asfáltico, respectivamente) y dando como resultado lo siguiente:

### *Porcentaje Óptimo Teórico (L.P.C.)*

Los datos presentados en éste acápite van acorde a los datos que se tiene de granulometría promedio del agregado en la *Tabla 2.5* de esta investigación y la explicación del significado de cada término de la expresión se puede apreciar en punto *4.1*

| DATOS | | |
|---|---|---|
| **G =** | 9.4 | % |
| **g =** | 18.5 | % |
| **A =** | 65.5 | % |
| **a =** | 2.4 | % |
| **f =** | 4.2 | % |
| **M =** | 3,75 - 4,25 | |
| S = | 7.54 | **P (%) = 5.99** |

TABLA 4.1 Datos y cálculos de P.O.T. según el LPC.

Se puede ver que el P.O.T calculado utilizando la expresión dada por el Laboratorio de Puentes y Calzadas es de 6.0 %.

*Método del Instituto del Asfalto*

Los datos presentados en éste acápite van acorde a los datos que se tiene de granulometría promedio del agregado en la ***Tabla 2.5*** de esta investigación y la alta absorción del agregado pétreo usado para las mezclas asfálticas en caliente (***Tablas 2.10 y 2.14***) y la explicación del significado de cada término de la expresión se puede apreciar en punto ***4.1***

$$\%Asfalto = 0.035 * a + 0.045 * b + k * c + F$$

$a = mat.> \#8$
$b = mat. entre \#8 - \#200$
$c = mat. < \#200$
$k = 0.15 \; si \; "c" \; esta \; entre \; 11 \; y \; 15$
$k = 0.18 \; si \; "c" \; esta \; entre \; 6 \; y \; 10$
$k = 0.20 \; si \; "c" < 5\%$
$F = entre \; 0.0 \; y \; 2.0 \; segun \; su \; absorcion$

| | |
|---|---|
| a= | 52.9 % |
| b= | 42.9 % |
| c= | 1.7 % |
| k= | 0.2 |
| F= | 1.5 % |

**% ASFALTO= 5.622 %**

TABLA 4.2 Datos y cálculos de P.O.T. según Instituto del Asfalto.

El resultado obtenido de la expresión dada por el Instituto del asfalto es del 5.60%.

De estos dos datos se puede concluir que un punto de partida para el diseño por el método Marshall para mezclas asfálticas en caliente es el de analizar las mezclas iniciando con un 6% de asfalto, por lo tanto ese será el porcentaje con el cual se inicia la determinación que se describe con el capítulo anterior.

## *4.2 Determinación Del Porcentaje Óptimo De Asfalto Usando El Método Marshall Para El Diseño.*

En el diseño del método Marshall se ha utilizado mezclas asfálticas en caliente. El objetivo del método Marshall es el de determinar el contenido optimo de asfalto para una mezcla especifica de agregado; así como también proporcionar información sobre las características físicas y mecánicas de la mezcla asfáltica en caliente de tal manera que sea posible establecer si cumple parámetros establecidos de densidades y contenidos óptimos de vacios durante la construcción de la capa del pavimento.

El método consiste en ensayar una serie de briquetas cilíndricas, cada una preparada con la misma granulometría y con diferentes contenidos de asfalto.

El MOP TOMO I, establece que para las mezclas asfálticas en caliente deberán emplearse una de las granulometrías indicada en la siguiente tabla 405-5.1 y es por eso necesaria la determinación de la granulometría para conocer si el agregado es apto para las mezclas asfálticas bajo las especificaciones del MOP.

La granulometría que se ha utilizado esta indicada en la ***Tabla 2.5*** que es propia del agregado pétreo ensayado en esta investigación ya que cumple con las especificaciones mínimas y máximas establecidas por el MOP de la ***Tabla 405-5***, de acuerdo al tamaño máximo nominal de la partícula.

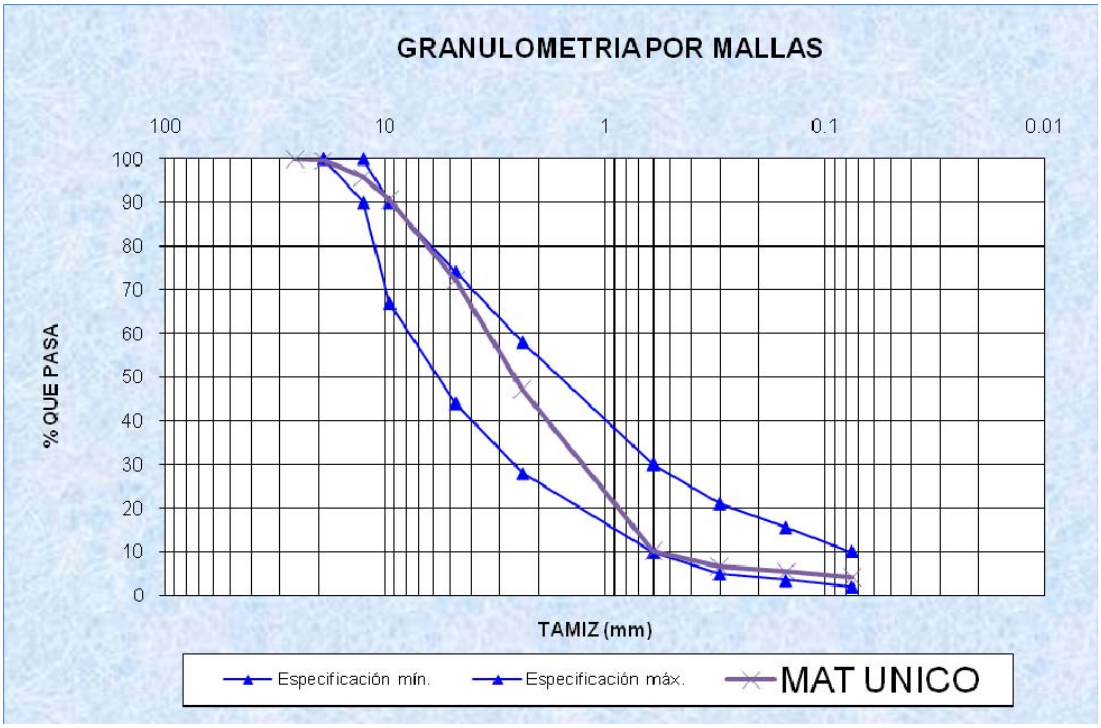
| TAMIZ | Porcentaje en peso que pasa a través de los tamices de malla cuadrada | | | |
|---|---|---|---|---|
| | ¾" | ½" | 3/8" | Nº4 |
| 1" (25.4 mm.) | 100 | -- | -- | -- |
| ¾" (19.0 mm.) | 90 - 100 | 100 | -- | -- |
| ½" (12.7 mm.) | -- | 90 - 100 | 100 | -- |
| 3/8" (9.50 mm.) | 56 - 80 | | 90 - 100 | 100 |
| Nº 4 (4.75 mm.) | 35 – 65 | 44 – 74 | 55 – 85 | 80 - 100 |
| Nº 8 (2.36 mm.) | 23 – 49 | 28 – 58 | 32 – 67 | 65 - 100 |
| Nº 16 (1.18 mm.) | -- | -- | -- | 40 - 80 |
| Nº 30 (0.60 mm.) | -- | -- | -- | 25 - 65 |
| Nº 50 (0.30 mm.) | 5 – 19 | 5 – 21 | 7 - 23 | 7 - 40 |
| Nº 100 (0.15 mm.) | -- | -- | -- | 3 - 20 |
| Nº 200 (0.075 mm.) | 2 – 8 | 2 – 10 | 2 - 10 | 2 - 10 |

**TABLA 405-5(MOP)[39]:** Porcentaje en peso para mezclas asfálticas en caliente

| | | ESPECIF. TAM. MAX 1/2" | | |
|---|---|---|---|---|
| MALLA | ABERTURA (mm) | Máximo | Mínimo | % Pasa |
| 1 | 25.4 | 100 | 100 | 99.9 |
| 3/4 | 19 | 100 | 100 | 99.5 |
| 1/2 | 12.7 | 100 | 90 | 95.7 |
| 3/8 | 9.51 | ---- | ---- | 90.6 |
| N. 4 | 4.76 | 74 | 44 | 72.1 |
| N. 8 | 2.362 | 58 | 28 | 47.1 |
| N. 16 | 1.19 | ---- | ---- | 25.8 |
| N. 30 | 0.595 | ---- | ---- | 10.2 |
| N. 50 | 0.297 | 21 | 5 | 6.6 |
| N. 100 | 0.149 | ---- | ---- | 5.4 |
| N. 200 | 0.074 | 10 | 2 | 4.2 |
| PASA N. 200 | | | | 1.7 |

**TABLA 4.3** Tabla Especificaciones Granulometría Máxima Mínima

[39] MOP, 2001: IV-95




**Gráfica 4.1** Curvas granulométricas Según Especificación MOP 405-5

Al estar acorde a las especificaciones la granulometría del agregado pétreo usado en la investigación, no es necesario realizar ninguna mezcla de materiales para cumplir con dichos límites como lo muestra el ***Gráfico 4.1***.

Todas las briquetas se preparan siguiendo un procedimiento específico para calentar el asfalto y agregados, mezclar y compactar.

Las briquetas preparadas con el método se rompen en la prensa Marshall, determinando su estabilidad (Resistencia) y flujo (Deformación). Si se desea conocer los porcentajes de vacios de las mezclas así fabricadas, se

determinaran previamente los pesos específicos de los materiales empleados y de las briquetas compactadas, antes del ensayo de rotura.

Con la fórmula recomendada por el ***Instituto del Asfalto*** se ha obtenido el porcentaje optimo aproximado de 5.60% y del 6,00% con la expresión dada por la ***L.P.C.*** por lo que se tomo como referencia para iniciar el diseño con el Método Marshall un 6.00%. Se mezclaron 1100 gramos del agregado mineral con el peso equivalente al porcentaje óptimo aproximado del cemento asfaltico. En el momento de la mezcla se observó que debido a la gran absorción del agregado, éste no se cubrió lo suficiente con el asfalto y al compactar la muestra se notó que excedía el rango máximo de la altura de la briqueta que establece la tabla del anexo en la página A 50.

Por esto se decidió disminuir la cantidad del material pétreo a 500 gr. y aumentar el porcentaje de asfalto a 7.5 % pero sin embargo se obtuvo el mismo resultado visual anterior. Sucesivamente se fue aumentando el porcentaje de asfalto en las mezclas a razón de 0.5% por grupo hasta llegar al 12%, y de 1.00% en 1.00% hasta llegar al 14% donde se pudo observar que gran parte del agregado estaba ya cubierto por el cemento asfáltico.

Se utilizó como rango de análisis los porcentajes comprendidos entre 11% y 14% para la elaboración de las briquetas que fueron ensayadas en el Método Marshall para la obtención del porcentaje Óptimo de Asfalto para la Muestra Patrón.

A partir del 11% se procedió a realizar 3 briquetas para ser ensayadas sucesivamente con los siguientes porcentajes: 11.0%, 11.5%, 12%, 13% y 14%.

Tal como se explicó anteriormente de una manera breve, del ensayo del Método Marshall se puede obtener además del porcentaje óptimo de asfalto, las características y relaciones volumétricas referentes a una mezcla asfáltica que son también parámetros que pueden ser útiles para juzgar la aceptabilidad de ésta. Las relaciones de las que se hace referencia son las siguientes:

**Peso Específico Bulk:**

$$Gb = \frac{Wa}{Wss - Ww}$$

Wa = Peso seco en el aire
Wss = Peso saturado con superficie seca
Ww = Peso sumergido en el agua

V = Wss - Ww

1. Esta determinación se realiza tan pronto como las briquetas recién compactadas se han enfriado a la temperatura ambiente.

2. La densidad aparente de las briquetas se determina calculando la relación entre su peso en aire y su volumen. La densidad se puede determinar por tres métodos diferentes de acuerdo a las características que tenga la briqueta en cuanto a su porosidad.

De acuerdo a la mezcla que obtuvimos una vez compactada se la llama "Briqueta Abierta" ya que a simple vista se puede apreciar que la superficie de la misma no es lisa ni uniforme así que se utiliza el método de determinación de densidad aparente usando parafina para cubrir los poros permeables de la briqueta de ensayo.

3. Éste método se aplica a mezclas cuya superficie es abierta y permeable. En este caso el volumen aparente se determina restando del peso de la briqueta en el aire, el peso de la briqueta en el agua, pero habiendo recubierto previamente a ésta de una capa de parafina (**Fotografía 4.1**).



**FOTOGRAFÍA N° 4.1** Parafinado de Briquetas de ensayo.



FOTOGRAFÍA N° 4.2 Briquetas con Parafina

La densidad aparente viene dada por la fórmula:

$$Gb = \frac{P}{V} = \frac{Pa}{Pa - Pbag - \left(\frac{Pba - Pa}{Pb}\right)}$$

Donde:

Pa = Peso de la briqueta en el aire sin parafina en gramos.

Pba = Peso de la briqueta en el aire con parafina en gramos.

Pbag = Peso de la briqueta en el agua con parafina en gramos.

Pb = Peso específico de la parafina empleada.

## Peso Específico Promedio del Agregado Total:

$$Gagre = \frac{100}{P1/G1 + P2/G2 + \ldots + Pn/Gn}$$

P1,n = Porcentajes de la mezcla
G1,n = Peso específico de cada material.

Este peso específico de los agregados en promedio sirve para poder calcular correlaciones de la mezcla asfáltica propiamente dicha con expresiones que se presentan posteriormente. Los datos necesarios para esta fórmula son los publicados en la *Tabla 2.10 y 2.14*

## Peso Específico Máximo Teórico:

$$Gmt = \frac{100}{\%Agre/Gagre + \%Asf/Gasf}$$

%Agre = Porcentaje de agregado en la mezcla
Gagre = Peso específico promedio del agregado
%Asf = Porcentaje de asfalto en la mezcla
Gasf = Gravedad específica del asfalto.

Ésta expresión representa teóricamente el peso especifico que tendría una mezcla asfáltica sin la presencia de vacios, es por eso que se la llama teórica ya que no existe tal mezcla. Su cálculo depende enteramente de la proporción en porcentaje con la cual se haya mezclado cada briqueta de ensayo y del peso específico promedio especificado en el acápite anterior (Peso Específico del agregado Promedio Total).

## Peso Específico Máximo Medido:

$$Gmm = \frac{A}{A - (B - C)}$$

A = Peso de la mezcla
B = Peso frasco + mezcla + agua
C = Peso frasco + agua

*El cálculo de éste parámetro nos muestra parámetros de propiedades fundamentales de cuyos valores son influenciados por la composición de la mezcla en términos de tipos y cantidades de agregados y materiales bituminosos.*

*Éste peso específico calculado es usado para:*

1. *El cálculo de cantidades de vacios en mezclas asfálticas compactadas.*
2. *El cálculo de la cantidad de bitumen absorbido por el agregado, y;*
3. *Para proveer valores objetivos para la compactación de mezclas asfálticas.*[40]

Entre el equipo necesario para este ensayo (ASTM D2041-03) se encuentran recipientes para vacío, extractor de aire o generador de vacío, barómetro, agitador mecánico, entre otros. (**Fotografía 4.3**)

[40] ASTM, 2004: D2041-03



**FOTOGRAFÍA N° 4.3** Equipo para Determinación "Gmm"

Las expresiones que se muestran de aquí en adelante son valores igualmente teóricos los cuales se calculan con los resultados de las fórmulas dadas previamente y muestran parámetros o características de las mezclas asfálticas que dan parámetros de comparación y fundamentos para poder escoger un Porcentaje Óptimo de diseño.

% en Volumen agregado vs Volumen total:

$$Vagre = \frac{\%Agre * Gb}{Gagre}$$

% Vacios con aire:

$$Vv = \left( 1 - \frac{Gb}{Gmm} \right) * 100$$

Volumen asfalto efectivo:

$$Vae = 100 - Vagre - Vv$$

% Vacios agregado mineral:

$$Vam = 100 - Vagre$$

A continuación se indicara la siguiente tabla 4.4 con los resultados del Método Marshall de donde se ha obtenido el porcentaje óptimo para la muestra patrón.

| % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | W seco (gr) | W con parafina (gr) | W sumergido (gr) | Wsss (gr) | "BULK" (gr/cm³) | Densidad media | Gmt | Gmm | Volumen | Factor | VOLUMENES | | | VAM | ESTABILIDAD (lb) | FLUJO (1/100") | ESTABILIDAD corregido | ESTABILIDAD Prom. | FLUJO PROM. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Vagre | Vv | Vae | | | | | | |
| 11.0 | 7 | 573.24 | 70.85 | 630.69 | 651.82 | 68.50 | 659.19 | 1.12 | 1.12 | 1.475 | 1.648 | 590.69 | 0.81 | 63.65 | 32.15 | 4.20 | 36.35 | 1469 | 15 | 1189.89 | 1124.49 | 15.33 |
| | 8 | 555.00 | 68.60 | 610.31 | 632.51 | 59.86 | 637.70 | 1.11 | | 1.563 | | 577.84 | 0.83 | | | | | 1276 | 16 | 1059.08 | | |
| | 9 | 557.41 | 68.89 | 606.73 | 624.33 | 65.25 | 628.40 | 1.12 | | 1.563 | | 563.15 | 0.86 | | | | | 1546 | 15 | 1329.56 | | |
| 11.5 | 10 | 556.83 | 72.36 | 616.09 | 632.56 | 57.14 | 640.88 | 1.10 | 1.09 | 1.471 | 1.616 | 583.74 | 0.83 | 61.98 | 32.27 | 5.75 | 38.02 | 1450 | 15 | 1203.50 | 1214.92 | 14.33 |
| | 11 | 557.40 | 72.43 | 614.43 | 641.85 | 56.20 | 647.43 | 1.10 | | 1.563 | | 591.23 | 0.81 | | | | | 1514 | 15 | 1226.34 | | |
| | 12 | 555.60 | 72.20 | 611.78 | 632.22 | 44.40 | 638.38 | 1.08 | | 1.563 | | 593.98 | 0.81 | | | | | 1454 | 13 | 1177.74 | | |
| 12.0 | 13 | 563.70 | 76.87 | 538.86 | 552.47 | 87.86 | 557.61 | 1.20 | 1.10 | 1.467 | 1.634 | 469.75 | 1.19 | 61.91 | 32.70 | 5.38 | 38.09 | 1845 | 13 | 2195.55 | 1339.34 | 12.67 |
| | 14 | 559.40 | 76.28 | 630.47 | 649.52 | 64.17 | 655.65 | 1.11 | | 1.563 | | 591.48 | 0.81 | | | | | 1669 | 12 | 1351.89 | | |
| | 15 | 562.72 | 76.73 | 625.45 | 645.98 | 48.74 | 650.43 | 1.09 | | 1.563 | | 601.69 | 0.78 | | | | | 1701 | 13 | 1326.78 | | |
| 13.0 | 16 | 501.60 | 74.95 | 561.55 | 610.94 | 42.13 | 610.29 | 1.08 | 1.07 | 1.460 | 1.642 | 568.16 | 0.86 | 59.42 | 34.96 | 5.61 | 40.58 | 1152 | 17 | 990.72 | 1068.06 | 16.00 |
| | 17 | 500.87 | 74.84 | 564.06 | 614.13 | 26.57 | 614.16 | 1.05 | | 1.563 | | 587.59 | 0.81 | | | | | 1144 | 15 | 926.64 | | |
| | 18 | 501.64 | 74.96 | 568.44 | 619.54 | 35.18 | 619.57 | 1.07 | | 1.563 | | 584.39 | 0.83 | | | | | 1380 | 16 | 1145.40 | | |
| 14.0 | 19 | 502.18 | 81.75 | 571.7 | 619.36 | 42.63 | 619.36 | 1.08 | 1.09 | 1.453 | 1.66 | 576.73 | 0.83 | 59.92 | 34.59 | 5.49 | 40.08 | 1208.00 | 18.00 | 1002.64 | 938.31 | 19.50 |
| | 20 | 499.3 | 81.28 | 566.76 | 612.91 | 57.17 | 613.22 | 1.11 | | 1.563 | | 556.05 | 0.89 | | | | | 982.00 | 14.00 | 873.98 | | |
| | 21 | 500.12 | 81.41 | 570.77 | 635.34 | 36.01 | 635.55 | 1.07 | | 1.563 | | 599.54 | 0.78 | | | | | 929.00 | 21.00 | 724.62 | | |

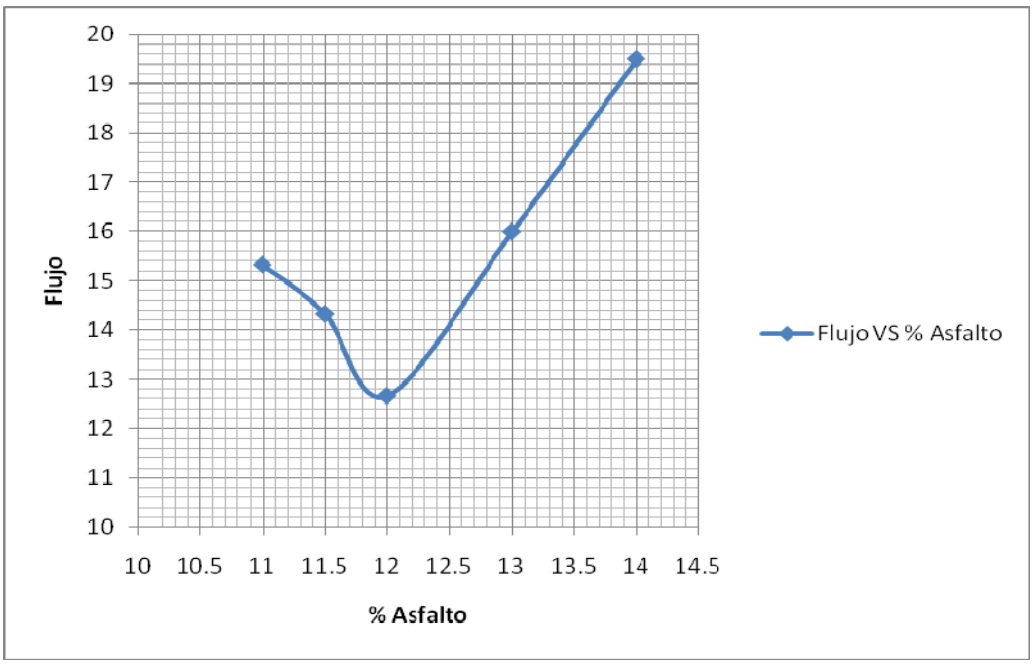
TABLA 4.4 Datos y cálculos Diseño por el Método Marshall.

## 4.2.1 Interpretación de resultados Método Marshal de Diseño.

Además de la Tabla 4.3 se deben preparar los siguientes gráficos que unan con curvas aproximadas a los puntos obtenidos y dichas curvas serán usadas para determinar el contenido de asfalto de diseño de la mezcla.

> *Mediante el analisis de estas curvas de propiedades, se puede aprender mucho sobre la sensibilidad de la mezcla al contenido de asfalto. Estas curvas de propiedades han demostrado seguir un patron rasonablemente consistente para mezclas asfalticas, pero variaciones pueden y ocurrirán, sin embargo, los resultados obtenidos y las relaciones que rige en cada una de las curvas de propiedades estan establecidas y explicadas a continuación:* [41]

a) *Flujo Vs. Contenido de Asfalto.*

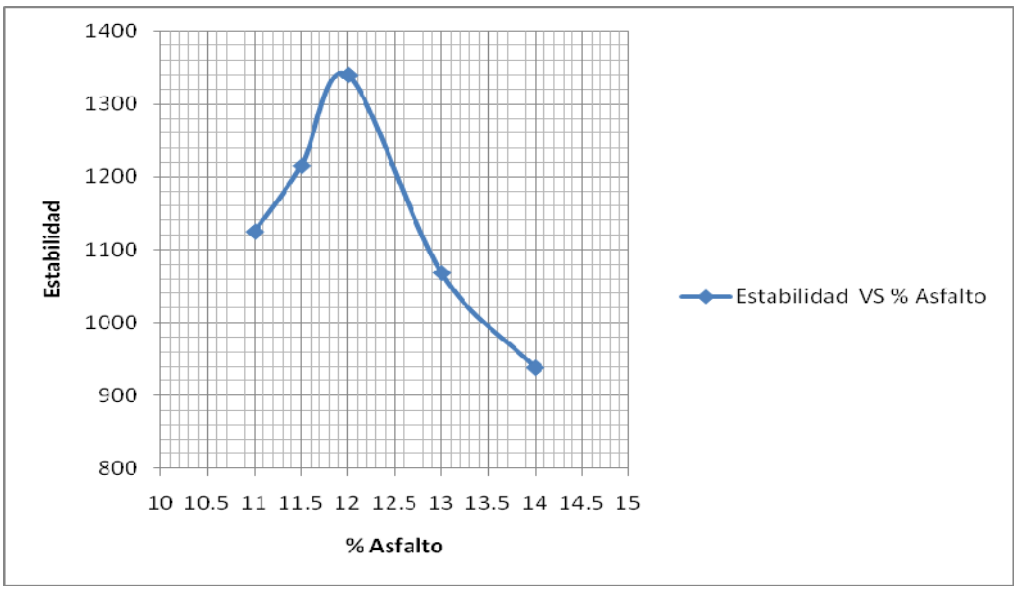



**Curva 4.1** Curva de análisis Flujo vs. % Asfalto}

[41] Asphalt Institute, 1997:

El valor del flujo incrementa consistentemente a medida que aumenta el contenido de asfalto.

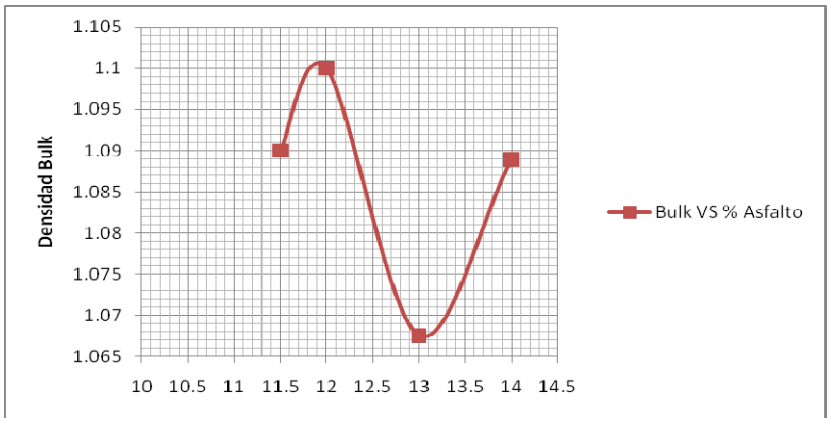
b) *Estabilidad Vs. Contenido de Asfalto*




**Curva 4.2** Curva de análisis Estabilidad vs. % Asfalto

El valor de la estabilidad aumenta con el incremento del contenido de asfalto hasta un máximo, de ahí en adelante este disminuye.

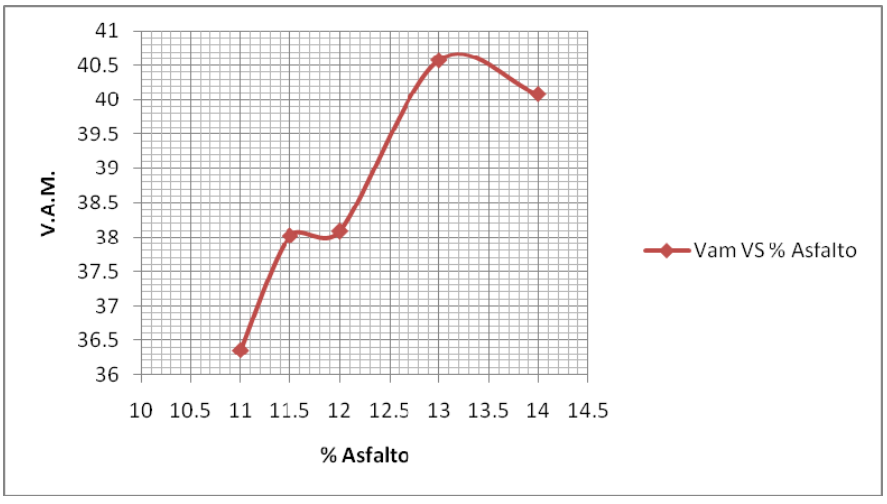
c) *Gravedad Específica Bulk de la Mezcla Vs. Contenido de Asfalto.*




**Curva 4.3** Curva de análisis Bulk vs. % Asfalto

Esta curva sigue un patrón similar a la curva de estabilidad, excepto que para el máximo peso específico normalmente (pero no siempre) ocurre a un contenido de asfalto apenas mayor que con la máxima estabilidad.

d) *Vacíos de Agregado Mineral (V.A.M.) Vs. Contenido de Asfalto*




**Curva 4.4** Curva de análisis VAM vs. % Asfalto

El porcentaje de vacios en el agregado mineral, VMA, generalmente decrece a un valor mínimo y luego incrementa a medida que sigue aumentando el contenido de asfalto.

| % ASFALTO | Densidad Media | VAM | Estabilidad Promedio | Flujo Promedio. |
|---|---|---|---|---|
| 11 | 1,12 | 36,35 | 1124,49 | 15,33 |
| 11,5 | 1,09 | 38,02 | 1214,92 | 14,33 |
| 12 | 1,1 | 38,09 | 1339,34 | 12,67 |
| 13 | 1,07 | 40,58 | 1068,06 | 16,00 |
| 14 | 1,09 | 40,08 | 938,31 | 19,50 |

TABLA 4.5 Resumen de resultados del Diseño por el Método Marshall

Por medio de las curvas de propiedades de la mezcla asfáltica del ensayo del Método Marshall podemos establecer el comportamiento o sensibilidad de la mezcla a medida que aumenta o disminuye la cantidad de asfalto.

Usando un 12 % de asfalto se puede apreciar en la *Curva 4.1* que se obtiene el menor flujo lo cual es importante ya que ésta característica nos da una medida de la deformabilidad que puede tener una carpeta asfáltica.

Así mismo en la *Curva 4.2* se puede notar que la estabilidad a un porcentaje de asfalto aproximado al 12% es la más alta del ensayo, lo cual significa que en éste porcentaje obtendremos la mayor resistencia a cargas de transito de la carpeta asfáltica.

Estos dos parámetros son de los más esenciales para tomar una decisión en cuanto a Porcentaje Optimo de una Mezcla Asfáltica en caliente y especialmente para esta investigación se han tomado estos valores como referenciales para escoger al ***12%*** como Porcentaje Óptimo para elaboración de Muestras Patrón a ser ensayadas con el método descrito posteriormente en el ***Capítulo 5.***

## *4.3 Elaboración de la muestra patrón previo al ensayo de la centrifuga.*

Como resultado del ensayo de diseño con el Método Marshall se ha llegado a conocer que el porcentaje óptimo de asfalto para la mezcla con el cual se va a trabajar es del **12%** y que la masa de material pétreo para cada briqueta no debe exceder 500gr con el fin de obtener un volumen adecuado ya que las características de peso específico y absorción del agregado mineral utilizado así lo requieren.

Se han usado 100 briquetas en el ensayo de extracción de porcentaje de bitumen con la centrífuga, las cuales se distribuían de la siguiente manera:

| SOLVENTE | PORCENTAJE DE ASFALTO | |
|---|---|---|
| | 12% | 13% |
| Gasolina Extra | 10 | 10 |
| Gasolina Súper | 10 | 10 |
| JP-1 | 10 | 10 |
| AVGas- 130 | 10 | 10 |
| Tricloroetileno | 10 | 10 |
| | 50 | 50 |
| | *100* | *Briquetas* |

**TABLA 4.6:** Número de briquetas para disolvente con su porcentaje correspondiente

Para la elaboración de las muestras patrón se ha procedido a separar el material por tamices. En función de la granulometría se calculó las porciones correspondientes de cada tamaño de partícula del total tomando en cuenta la masa del material pétreo establecida de 500 gr., de esta manera las fundas se hicieron de 500 gr elaborando 50 fundas para el 12% y 50 fundas para el 13% que da un total de 100 fundas.

A continuación se presenta la siguiente tabla donde constan los pesos de cada porción que conforman la muestra patrón:

| Tamaño | Masa (gr) |
|---|---|
| 1 | 0.433 |
| 3/4 | 1.875 |
| 1/2 | 19.426 |
| 3/8 | 25.019 |
| N. 4 | 92.852 |
| N. 8 | 124.767 |
| Pasa N. 8 | 235.627 |
| ***TOTAL*** | ***500*** |

TABLA 4.7: Pesos de cada Tamiz para la elaboración de muestra patrón.

Luego se colocaron diez fundas cada día en el horno por 24 horas (*Fotografía 4.4*) para obtener el peso seco del material pétreo, con este dato se calculó el peso del asfalto para cada funda con su porcentaje correspondiente. Al día siguiente de dejar las 10 muestras en el horno se procede a realizar la mezcla de cada funda calentando el asfalto para que tenga una mejor adherencia con el agregado con el objetivo de tener un buen manejo de mezcla entre el agregado y el asfalto (*Fotografía 4.5*).



**FOTOGRAFÍA N° 4.4** Calentamiento de Material Pétreo previo a la Mezcla



**FOTOGRAFÍA N° 4.5** Mezcla terminada.

Después de hacer la mezcla de cada funda se colocó en un recipiente con su identificación del porcentaje que le corresponde dejándole en reposo por 8 días, posterior a estos días se pesa cada muestra para obtener el peso de la mezcla.

El mismo día que se obtuvo el peso de mezcla se realizó el ensayo de extracción del porcentaje de bitumen con la centrífuga, y así se procedió con las 100 fundas.

# 5.- EXTRACCIÓN DE PORCENTAJE DE BITUMEN EN MEZCLAS ASFÁLTICAS USANDO LA CENTRIFUGA [42] "ASTM - D 2172"

El asfalto es un material ligante de color marrón oscuro a negro, constituido principalmente por betunes que pueden ser naturales u obtenidos por refinación del petróleo.

## 5.1 Introducción

Para fines de diseño de mezclas de pavimento es muy importante determinar el porcentaje de extracción de bitumen adecuado para la mezcla asfáltica.

De acuerdo a la norma se puede realizar con tricloroetileno, bromuro de propílico normal o cloruro de metileno con el equipo de centrifuga con tricloetileno por facilidad de manipulación de este químico ya que los otros son mas tóxicos para el ser humano.

El contenido de bitumen se calcula por diferencia de la masa del agregado extraído, contenido de humedad y materia mineral en el extracto. El contenido de bitumen se expresa como masa por ciento de las mezclas libre de humedad.

## 5.2 Alcance

En el ensayo de centrifuga se determina el porcentaje de bitumen de las mezclas asfálticas en caliente.

[42] Yánez, Ensayo N° 16

Se obtienen mejores resultados cuantitativos cuando el ensayo se efectúa sobre mezclas y pavimentos inmediatamente después de su preparación.

Este método recoge el procedimiento que debe seguirse para la determinación del tanto por ciento del material bituminoso que contiene una mezcla asfáltica, por medio de extracción en frío con un disolvente, siempre que el tamaño máximo del árido sea de 1 pulgada (2,54 cm). El árido recuperado por este método se ensayo, puede ser utilizado para análisis granulométrico, no así el producto bituminoso, el cual no puede ser ensayado posteriormente.

## *5.3 Equipo*

- 1 Centrífuga
- 1 Filtro
- 1 Horno con control de temperatura constante a 110 º C
- 1 Balanza de 5 Kg de capacidad y sensibilidad de 0,1 g
- 1 Probeta graduada de 2000 cc. de capacidad.
- Solventes (a escoger): gasolina extra, Gasolina súper, AVGAS -130, Gasolina de avión JP1 y tricloroetileno
- 1 Solución de carbonato de amonio




**FOTOGRAFÍA N° 5.1** Centrífuga para Extracción De Bitumen.



**FOTOGRAFÍA N° 5.2** Filtro para Centrífuga.

## *5.4 Preparación de la muestra*

Continuando con la explicación del capítulo 4.3, luego que las diez muestras reposaron 8 días se obtuvo el peso de la mezcla y se procedió a verter los solventes mencionados anteriormente (gasolina extra, Gasolina súper, Gasolina de avión: JP1, Gasolina de avión : AVGAS -130 y Tricloroetileno) en los recipientes hasta cubrir la mezcla para los dos porcentajes en estudio. (Porcentaje optimo 12%, y porcentaje de comparación 13%) dejándole reposar el tiempo indicado en la norma de dicho ensayo (***Fotografía 5.3***).



**FOTOGRAFÍA N° 5.3** *Reposo de mezcla en cada Disolvente*

## 5.5 Procedimiento del ensayo

1.- Se coloca la muestra que se dejo en reposo junto con el solvente dentro de la máquina de la centrifuga, luego se pesa el filtro en estado seco para ser colocado sobre la taza. Se coloca la tapa de la centrifuga para ser ajustada junto con el filtro para evitar que se pierda alguna partícula de la muestra.

2.- Por medio del tubo de salida del extractor se coloco el solvente en dosis de 200 mililitros, se prende la máquina de la centrifuga con revoluciones graduales hasta llegar a 3600 RPM, luego de esto se debe parar la maquina esperando que se apague totalmente para poder colocar de nuevo el mismo solvente de 200 mililitros, de esta manera se repite el procedimiento hasta conseguir que la muestra tenga un color café claro.

3.- Obteniendo la muestra del color indicado se procede a retirar la tapa para sacar el filtro cuidadosamente y con una espátula se retira el material adherido al filtro colocándole en un recipiente (***Fotografía 5.4 y Fotografía 5.5***) junto con la muestra lavada que está en la taza de la centrifuga, dicho recipiente se coloca en el horno a 110° hasta que la muestre este seca para obtener un peso constante. Luego se deja secar el filtro al aire para ser pesado (***Fotografía 5.6***).



**FOTOGRAFÍA N° 5.4** Proceso de Centrifugación.



**FOTOGRAFÍA N° 5.5** Proceso de Centrifugación.



**FOTOGRAFÍA N° 5.6** *Secado de Filtros al Aire.*

De esta manera se realizaron todas las muestras con su porcentaje respectivo para cada solvente.

## *5.6 Cálculos*

El porcentaje de bitumen en la muestra se calcula de la siguiente manera:

$$Porcentaje\ de\ Bitumen = \frac{(W_1 - W_2) - (W_2 + 4 + W_5)}{(W_1 - W_2)}$$

Donde:

W1 = Peso inicial de la muestra

W2 = Peso del agua

W3 = Peso del agregado mineral

W4 = Peso de las cenizas

W5 = Aumento del peso en el filtro

# 6.- USO DE LOS RESPECTIVOS DISOLVENTES, RESULTADOS.

Tal como se había mencionado anteriormente, ésta investigación va dirigida al análisis de disolventes comerciales como alternativa al uso del TRICLOROETILENO en la extracción del Porcentaje de Bitumen.

Basados en los procedimientos que dicta el capítulo anterior, se han ensayado 20 muestras para cada disolvente – Gasolina Extra, Gasolina Súper, Gasolina de Avión JP-1 y Gasolina de Avión AVGas130– y 20 muestras con el Tricloroetileno para así tener valores de comparación entre los disolventes comerciales y el que recomienda la norma.

Hay que aclarar que la mitad de las muestras ensayadas con cada disolvente (10 muestras), corresponden a briquetas que han sido mezcladas con el porcentaje óptimo de asfalto, o sea 12%.

Las otras 10 muestras de cada disolvente son briquetas que han sido mezcladas con un 13% de asfalto. Este porcentaje se ha escogido por la siguiente razón:

En el capítulo 4, en el acápite 4.2, se explica que para realizar el diseño con el Método Marshall, al agregado mineral se le fue aumentando paulatinamente el porcentaje equivalente de asfalto hasta que la mezcla luzca casi en su totalidad cubierta por el asfalto y desde ese porcentaje partió el análisis. Debido a esa apreciación y considerando que las mezclas se suelen realizar también en sitio y los obreros pueden verse tentados a mezclar con más asfalto de lo necesario, se escoge un porcentaje superior al óptimo para analizarlo de la misma manera para obtener resultados y conclusiones que nos puedan servir como comparación.

A continuación se presentan los resultados de extracción del Porcentaje de Bitumen con los porcentajes y cantidades expuestas anteriormente:

## *6.1 Extracción con gasolina Extra.*

Los resultados de extracción de Porcentaje de Bitumen con gasolina Extra tanto para el Porcentaje Óptimo de diseño (12%) y el de 13% son:

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Pmezcla | Peso Filtro in | Peso Filtro fin | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| EXTRA | 12.0 | 1 | 498.80 | 68.02 | 558.58 | 28.93 | 29.99 | 497.63 | 10.722 | 10.382 |
| | | 2 | 499.90 | 68.17 | 564.87 | 29.17 | 30.22 | 504.07 | 10.578 | |
| | | 3 | 497.46 | 67.84 | 566.36 | 29.11 | 29.71 | 506.28 | 10.502 | |
| | | 4 | 489.43 | 66.74 | 555.00 | 28.80 | 29.19 | 496.37 | 10.494 | |
| | | 5 | 498.15 | 67.93 | 565.37 | 28.92 | 29.67 | 505.92 | 10.383 | |
| | | 6 | 502.74 | 68.56 | 567.91 | 28.98 | 29.63 | 508.38 | 10.368 | |
| | | 7 | 500.09 | 68.19 | 568.21 | 28.97 | 29.70 | 509.00 | 10.292 | |
| | | 8 | 498.72 | 68.01 | 563.68 | 29.25 | 30.19 | 505.18 | 10.211 | |
| | | 9 | 497.24 | 67.81 | 563.70 | 30.15 | 30.10 | 505.93 | 10.257 | |
| | | 10 | 496.02 | 67.64 | 561.54 | 29.07 | 29.39 | 505.00 | 10.012 | |

**TABLA 6.1** Resultados de Extracción con gasolina Extra para mezclas con 12% de asfalto.

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso Mezcla | Peso Filtro in. | Peso Mez fin | Peso Fil fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| EXTRA | 13.0 | 1 | 500.50 | 74.79 | 572.09 | 29.19 | 506.54 | 29.29 | 11.441 | **11.259** |
| | | 2 | 499.37 | 74.62 | 566.37 | 29.22 | 501.07 | 29.76 | 11.434 | |
| | | 3 | 503.30 | 75.21 | 580.26 | 29.06 | 512.20 | 29.54 | 11.647 | |
| | | 4 | 500.81 | 74.83 | 570.75 | 28.57 | 504.97 | 29.07 | 11.438 | |
| | | 5 | 500.99 | 74.86 | 570.82 | 28.67 | 505.16 | 28.83 | 11.475 | |
| | | 6 | 499.87 | 74.69 | 576.41 | 29.10 | 512.20 | 29.53 | 11.065 | |
| | | 7 | 499.30 | 74.61 | 574.51 | 29.34 | 511.88 | 29.45 | 10.882 | |
| | | 8 | 499.15 | 74.59 | 572.82 | 29.27 | 509.65 | 29.75 | 10.944 | |
| | | 9 | 500.00 | 74.71 | 573.98 | 29.35 | 508.48 | 29.51 | 11.384 | |
| | | 10 | 497.30 | 74.31 | 573.80 | 29.18 | 511.18 | 29.39 | 10.877 | |

**TABLA 6.2** Resultados de Extracción con gasolina Extra para mezclas con 13% de asfalto.

## 6.2 Extracción con gasolina Súper.

Los resultados de extracción de Porcentaje de Bitumen con gasolina Súper tanto para el Porcentaje Óptimo de diseño (12%) y el de 13% son:

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Pmezcla | Peso Filtro in | Peso Filtro fin | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| SUPER | 12.0 | 11 | 503.80 | 68.70 | 570.28 | 30.06 | 30.15 | 508.99 | 10.732 | 10.980 |
| | | 12 | 502.10 | 68.47 | 569.25 | 30.51 | 30.78 | 506.90 | 10.906 | |
| | | 13 | 472.60 | 64.45 | 536.30 | 30.16 | 30.29 | 475.95 | 11.229 | |
| | | 14 | 501.42 | 68.38 | 567.67 | 29.62 | 29.80 | 505.62 | 10.899 | |
| | | 15 | 502.82 | 68.57 | 572.65 | 30.04 | 30.17 | 509.58 | 10.991 | |
| | | 16 | 501.87 | 68.44 | 571.92 | 30.09 | 30.10 | 508.85 | 11.026 | |
| | | 17 | 500.24 | 68.21 | 570.85 | 30.04 | 30.11 | 506.86 | 11.197 | |
| | | 18 | 496.28 | 67.67 | 562.10 | 30.35 | 30.40 | 500.41 | 10.966 | |
| | | 19 | 504.39 | 68.78 | 573.36 | 30.32 | 30.62 | 510.87 | 10.847 | |
| | | 20 | 503.50 | 68.66 | 572.39 | 30.28 | 30.36 | 509.32 | 11.005 | |

**TABLA 6.3** Resultados de Extracción con gasolina Súper para mezclas con 12% de asfalto.

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso Mezcla | Peso Filtro in. | Peso Mez fin | Peso Fil fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| SUPER | 13.0 | 11 | 502.83 | 75.14 | 583.98 | 30.74 | 512.78 | 30.99 | 12.149 | **11.930** |
| | | 12 | 500.21 | 74.74 | 571.61 | 29.86 | 503.20 | 30.06 | 11.933 | |
| | | 13 | 502.68 | 75.11 | 575.93 | 30.25 | 506.56 | 30.31 | 12.034 | |
| | | 14 | 500.71 | 74.82 | 574.42 | 30.18 | 506.74 | 30.19 | 11.781 | |
| | | 15 | 500.37 | 74.77 | 576.72 | 30.15 | 507.88 | 30.00 | 11.962 | |
| | | 16 | 499.50 | 74.64 | 573.85 | 29.65 | 505.50 | 29.72 | 11.899 | |
| | | 17 | 500.36 | 74.77 | 574.53 | 30.39 | 505.78 | 30.71 | 11.911 | |
| | | 18 | 501.60 | 74.95 | 572.48 | 30.77 | 504.90 | 30.94 | 11.775 | |
| | | 19 | 503.30 | 75.21 | 579.20 | 29.66 | 510.07 | 29.72 | 11.925 | |
| | | 20 | 500.30 | 74.76 | 575.25 | 30.55 | 506.65 | 30.53 | 11.929 | |

**TABLA 6.4** Resultados de Extracción con gasolina Súper para mezclas con 13% asfalto.

## 6.3 Extracción con gasolina de avión N.1 "JP-1"

Los resultados de extracción de Porcentaje de Bitumen con gasolina de avión JP-1 tanto para el Porcentaje Óptimo de diseño (12%) y el de 13% son:

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Pmezcla | Peso Filtro in | Peso Filtro fin | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| G. AVION 1 | 12.0 | 21 | 500.48 | 68.25 | 562.85 | 29.67 | 29.94 | 502.55 | 10.665 | 10.758 |
| | | 22 | 500.31 | 68.22 | 569.26 | 28.90 | 29.00 | 506.10 | 11.078 | |
| | | 23 | 501.64 | 68.41 | 571.16 | 28.54 | 28.64 | 510.43 | 10.615 | |
| | | 24 | 500.65 | 68.27 | 569.31 | 28.67 | 28.70 | 507.46 | 10.859 | |
| | | 25 | 504.12 | 68.74 | 572.86 | 28.91 | 29.16 | 510.15 | 10.904 | |
| | | 26 | 503.95 | 68.72 | 572.84 | 29.00 | 29.23 | 511.15 | 10.729 | |
| | | 27 | 502.25 | 68.49 | 571.24 | 28.60 | 28.72 | 507.93 | 11.062 | |
| | | 28 | 502.01 | 68.46 | 569.84 | 28.86 | 29.20 | 508.09 | 10.777 | |
| | | 29 | 500.87 | 68.30 | 569.44 | 29.00 | 29.10 | 510.05 | 10.412 | |
| | | 30 | 503.87 | 68.71 | 570.54 | 28.82 | 28.89 | 510.69 | 10.478 | |

**TABLA 6.5** Resultados de Extracción con JP-1 para mezclas con 12% de asfalto.

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso Mezcla | Peso Filtro in. | Peso Mez fin | Peso Fil fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| G. AVION 1 | 13.0 | 21 | 501.50 | 74.94 | 574.55 | 29.53 | 506.96 | 29.70 | 11.734 | **11.884** |
| | | 22 | 502.40 | 75.07 | 577.90 | 29.37 | 509.19 | 29.89 | 11.800 | |
| | | 23 | 506.24 | 75.65 | 581.83 | 29.13 | 512.85 | 29.48 | 11.796 | |
| | | 24 | 498.30 | 74.46 | 573.22 | 29.28 | 504.70 | 29.44 | 11.926 | |
| | | 25 | 503.50 | 75.24 | 576.20 | 29.34 | 507.00 | 30.06 | 11.885 | |
| | | 26 | 497.50 | 74.34 | 573.72 | 29.34 | 504.11 | 29.86 | 12.042 | |
| | | 27 | 500.69 | 74.82 | 569.43 | 29.33 | 500.93 | 29.99 | 11.914 | |
| | | 28 | 503.46 | 75.23 | 578.72 | 29.31 | 509.87 | 30.10 | 11.760 | |
| | | 29 | 499.60 | 74.65 | 573.72 | 29.27 | 504.43 | 30.14 | 11.926 | |
| | | 30 | 503.46 | 75.23 | 580.63 | 29.04 | 509.73 | 29.95 | 12.054 | |

**TABLA 6.6** Resultados de Extracción con JP-1 para mezclas con 13% de asfalto.

## 6.4 Extracción con gasolina de avión N.2 "AVGas-130"

Los resultados de extracción de Porcentaje de Bitumen con gasolina de avión AVGas-130 tanto para el Porcentaje Óptimo de diseño (12%) y el de 13% son:

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Pmezcla | Peso Filtro in | Peso Filtro fin | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| G. AVION 2 | 12.0 | 31 | 501.61 | 68.40 | 567.76 | 29.00 | 29.34 | 524.84 | 7.500 | 7.573 |
| | | 32 | 499.40 | 68.10 | 568.20 | 28.88 | 29.17 | 525.64 | 7.439 | |
| | | 33 | 500.22 | 68.21 | 565.82 | 29.45 | 29.51 | 521.96 | 7.741 | |
| | | 34 | 498.22 | 67.94 | 564.41 | 29.36 | 29.45 | 519.93 | 7.865 | |
| | | 35 | 500.14 | 68.20 | 569.56 | 29.16 | 29.66 | 525.64 | 7.623 | |
| | | 36 | 497.93 | 67.90 | 566.11 | 29.25 | 29.98 | 524.68 | 7.189 | |
| | | 37 | 498.13 | 67.93 | 568.54 | 29.36 | 29.89 | 523.14 | 7.892 | |
| | | 38 | 498.33 | 67.95 | 566.77 | 29.20 | 29.32 | 524.94 | 7.359 | |
| | | 39 | 498.62 | 67.99 | 567.59 | 29.15 | 29.24 | 522.46 | 7.935 | |
| | | 40 | 496.89 | 67.76 | 563.27 | 28.99 | 29.14 | 522.65 | 7.185 | |

**TABLA 6.7** Resultados de Extracción con AVgas-130 para mezclas con 12% de asfalto.

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso Mezcla | Peso Filtro in. | Peso Mez fin | Peso Fil fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| G. AVION 2 | 13.0 | 31 | 500.58 | 74.80 | 572.53 | 29.34 | 525.10 | 29.63 | 8.234 | **8.651** |
| | | 32 | 500.14 | 74.73 | 572.37 | 29.41 | 521.18 | 29.73 | 8.888 | |
| | | 33 | 500.10 | 74.73 | 576.08 | 29.32 | 526.49 | 29.42 | 8.591 | |
| | | 34 | 501.15 | 74.88 | 574.34 | 29.25 | 524.33 | 29.47 | 8.669 | |
| | | 35 | 499.30 | 74.61 | 575.25 | 29.53 | 525.00 | 29.57 | 8.728 | |
| | | 36 | 496.38 | 74.17 | 571.78 | 29.19 | 523.32 | 29.34 | 8.449 | |
| | | 37 | 504.00 | 75.31 | 577.58 | 29.38 | 526.08 | 29.82 | 8.840 | |
| | | 38 | 499.82 | 74.69 | 573.02 | 29.26 | 521.85 | 29.35 | 8.914 | |
| | | 39 | 500.77 | 74.83 | 579.16 | 29.46 | 529.55 | 29.48 | 8.562 | |
| | | 40 | 497.83 | 74.39 | 573.76 | 29.08 | 524.00 | 29.29 | 8.636 | |

**TABLA 6.8** Resultados de Extracción con AVgas-130 para mezclas con 13% de asfalto.

## 6.5 Extracción con TRICLOROETILENO

Los resultados de extracción de Porcentaje de Bitumen con gasolina de avión AVGas-130 tanto para el Porcentaje Óptimo de diseño (12%) y el de 13% son:

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Pmezcla | Peso Filtro in | Peso Filtro fin | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| TRICLORO ETILENO | 12.0 | 41 | 502.20 | 68.48 | 569.23 | 29.84 | 30.95 | 505.00 | 11.089 | 10.985 |
| | | 42 | 505.26 | 68.90 | 572.80 | 29.97 | 30.74 | 509.35 | 10.943 | |
| | | 43 | 473.65 | 64.59 | 539.33 | 29.55 | 30.33 | 480.14 | 10.830 | |
| | | 44 | 511.95 | 69.81 | 579.98 | 29.84 | 30.79 | 514.65 | 11.100 | |
| | | 45 | 502.95 | 68.58 | 573.07 | 29.46 | 30.44 | 508.66 | 11.068 | |
| | | 46 | 503.30 | 68.63 | 572.13 | 29.83 | 30.37 | 507.89 | 11.134 | |
| | | 47 | 504.70 | 68.82 | 573.11 | 29.34 | 30.12 | 509.25 | 11.007 | |
| | | 48 | 501.67 | 68.41 | 570.78 | 29.33 | 30.14 | 507.80 | 10.892 | |
| | | 49 | 509.60 | 69.49 | 579.33 | 29.21 | 30.11 | 515.68 | 10.831 | |
| | | 50 | 506.93 | 69.13 | 575.57 | 29.42 | 30.11 | 511.82 | 10.956 | |

**TABLA 6.9** Resultados de Extracción con T.C.E. para mezclas con 12% de asfalto.

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso Mezcla | Peso Filtro in. | Peso Mez fin | Peso Fil fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| TRICLORO ETILENO | 13.0 | 41 | 504.16 | 75.33 | 577.16 | 28.28 | 508.10 | 28.76 | 11.882 | **11.768** |
| | | 42 | 506.70 | 75.71 | 581.09 | 28.44 | 510.95 | 29.33 | 11.917 | |
| | | 43 | 505.38 | 75.52 | 582.41 | 28.30 | 512.94 | 28.82 | 11.839 | |
| | | 44 | 501.56 | 74.95 | 575.91 | 28.36 | 508.00 | 29.31 | 11.627 | |
| | | 45 | 505.56 | 75.54 | 579.40 | 29.66 | 511.26 | 29.92 | 11.716 | |
| | | 46 | 502.52 | 75.09 | 577.88 | 29.57 | 507.87 | 30.16 | 12.013 | |
| | | 47 | 503.10 | 75.18 | 578.66 | 29.45 | 510.15 | 29.81 | 11.777 | |
| | | 48 | 505.15 | 75.48 | 581.61 | 29.55 | 513.78 | 30.01 | 11.583 | |
| | | 49 | 502.47 | 75.08 | 576.50 | 29.68 | 509.05 | 29.90 | 11.662 | |
| | | 50 | 501.70 | 74.97 | 579.33 | 29.79 | 511.48 | 30.05 | 11.667 | |

**TABLA 6.10** Resultados de Extracción con T.C.E. para mezclas con 13% de asfalto.

# 7.- EVALUACIÓN DE RESULTADOS

## 7.1 Relación entre disolventes

En la siguiente tabla 7.1 se indica una comparación de promedios de los porcentajes de la extracción de bitumen de cada disolvente, por lo tanto se ha logrado comparar entre los porcentajes promedios obtenidos de las muestras que se han extraído el porcentaje de bitumen con diferentes disolventes pero teniendo el mismo porcentaje de asfalto.

| Porcentaje de Asfalto | Gasolina Extra (%) | Gasolina Súper (%) | Gasolina Avión JP1 (%) | Gasolina AVGAS-130 (%) | Tricloroetileno (%) |
|---|---|---|---|---|---|
| 12% | 10.382 | 10.980 | 10.758 | 7.573 | 10.985 |
| 13% | 11.259 | 11.930 | 11.884 | 8.651 | 11.768 |

**TABLA 7.1:** Promedio de los porcentajes de cada disolvente.

Con ayuda de esta tabla se realizaron gráficos de barras comparativas con cada disolvente alterno versus con el Tricloroetileno.

A continuación se indica el gráfico 7.1 comparativo entre Gasolina Extra y Tricloroetileno del 12 % de contenido de asfalto que da como resultado un porcentaje de variación del 5.81%

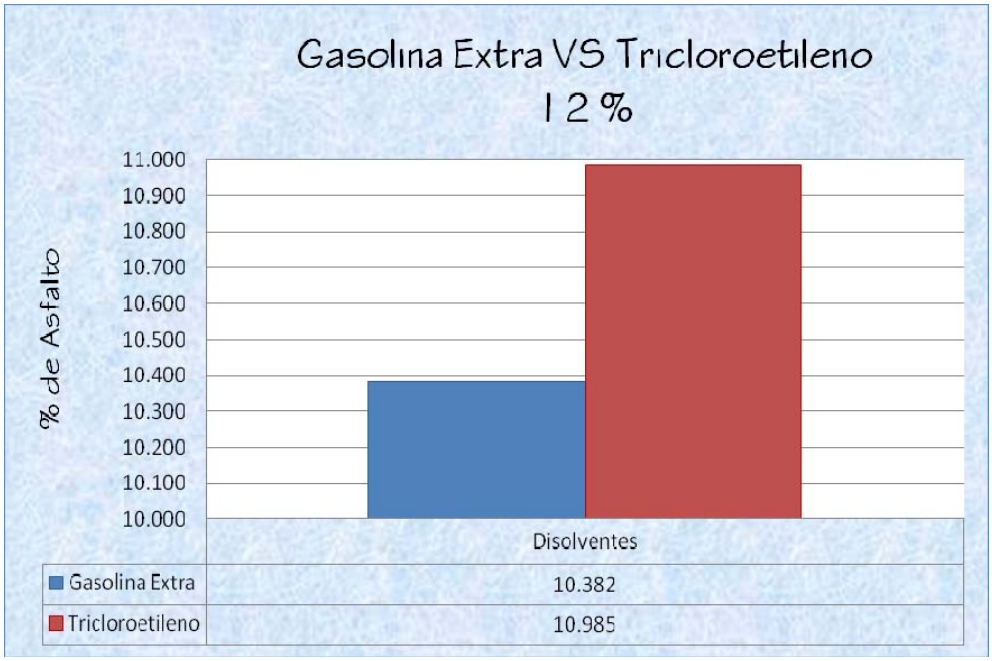



**Gráfico 7.1 :** Comparación de disolventes, Gasolina Extra VS Tricloroetileno del 12 % de contenido de asfalto

En este siguiente gráfico 7.2 se indica la comparación entre los disolventes Extra Vs Tricloroetileno del 13% del contenido de asfalto obteniendo como resultado un porcentaje de variación de 4.52 %.

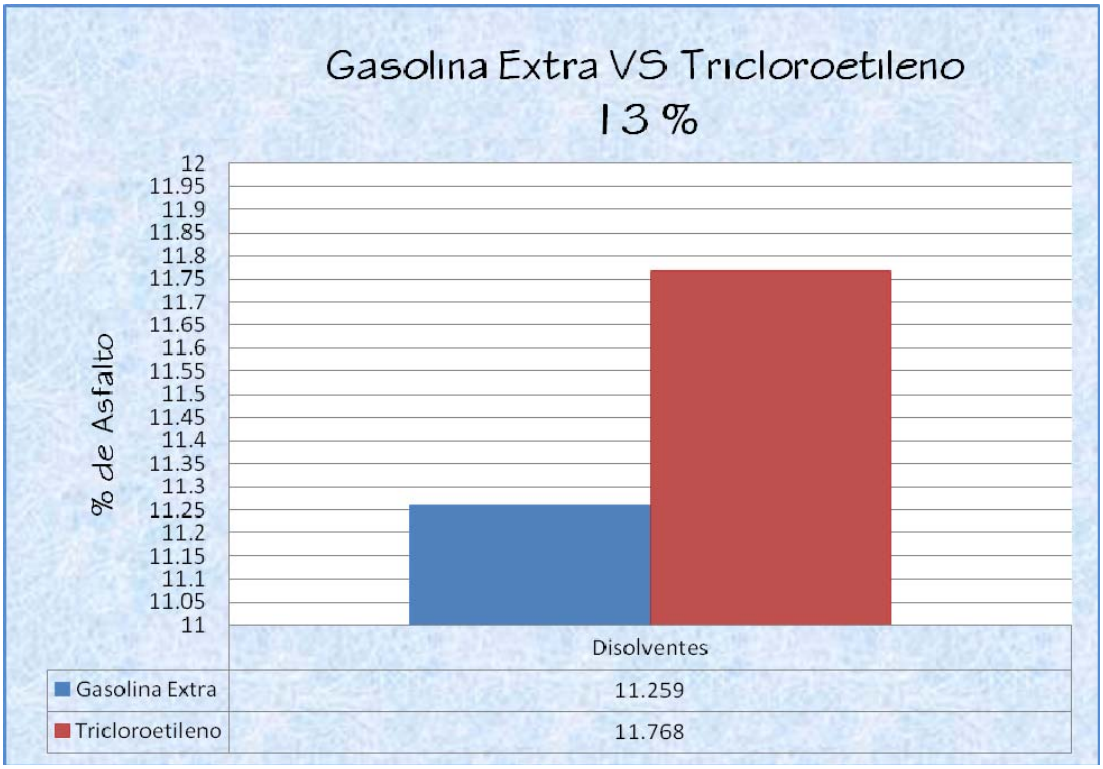



**Gráfico 7.2:** Comparación de disolventes, Gasolina Extra VS Tricloroetileno del 13 % de contenido de asfalto

En el siguiente gráfico 7.3 se presenta la comparación del segundo disolvente alterno entre Gasolina Súper Vs Tricloroetileno con el 12% de contenido de asfalto obteniendo como resultado el porcentaje de variación de 0.05%.

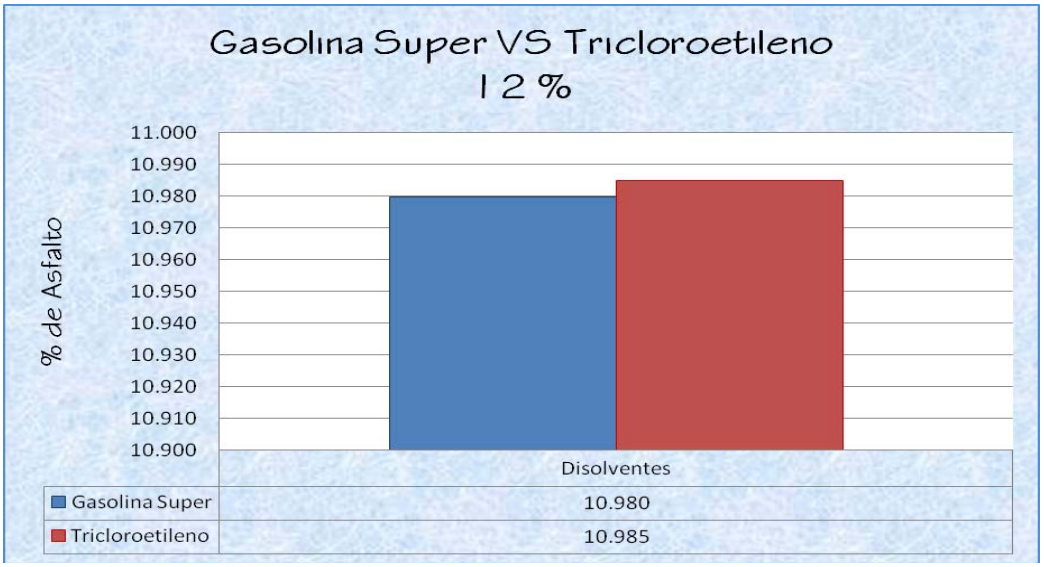



**Gráfico 7.3:** Comparación de disolventes, Gasolina Súper VS Tricloroetileno del 12 % de contenido de asfalto

A continuación se presenta el gráfico comparativo 7.4 entre los disolventes Gasolina Súper Vs Tricloroetileno del 13% de contenido de asfalto dando como resultado un porcentaje de variación del -1.36.

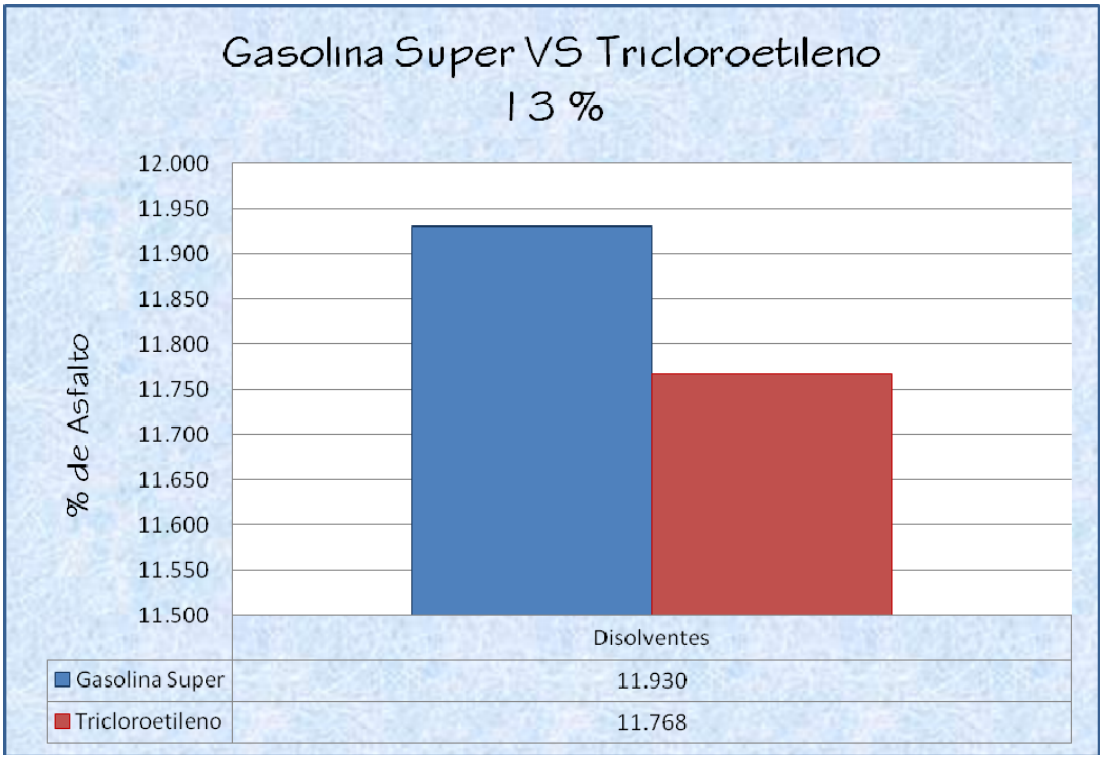



**Gráfico 7.4:** Comparación de disolventes, Gasolina Súper VS Tricloroetileno del 13 % de contenido de asfalto

Con el tercer disolvente alterno también se realizó gráficos de barras comparativos entre Gasolina de avión JP1 VS Tricloroetileno para cada porcentaje.

A continuación se presenta el gráfico 7.5 comparativo de mezclas asfálticas del 12% entre los disolventes mencionados y dando como resultado un porcentaje de variación del 2.11 %

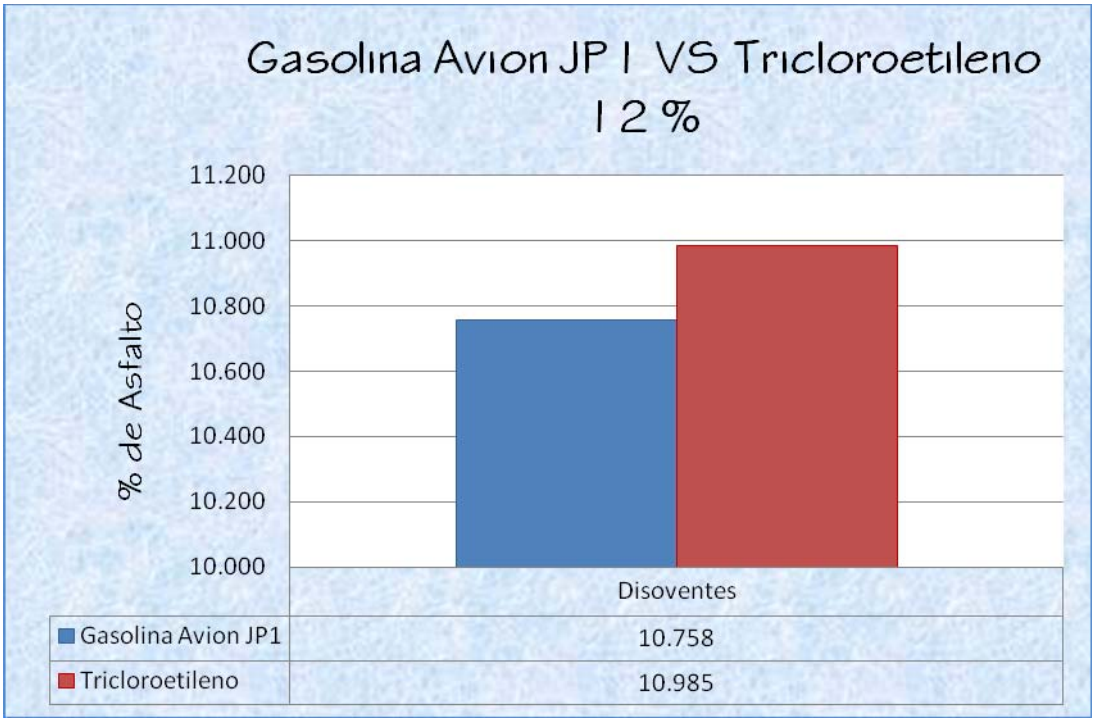



**Gráfico 7.5:** Comparación de disolventes, Gasolina de avión JP I VS Tricloroetileno del I 2 % de contenido de asfalto

En el gráfico 7.6 se indica la comparación de los disolventes Gasolina de avión JP I Vs Tricloroetileno del I 3% obteniendo como resultado un porcentaje de variación del -0.98 %

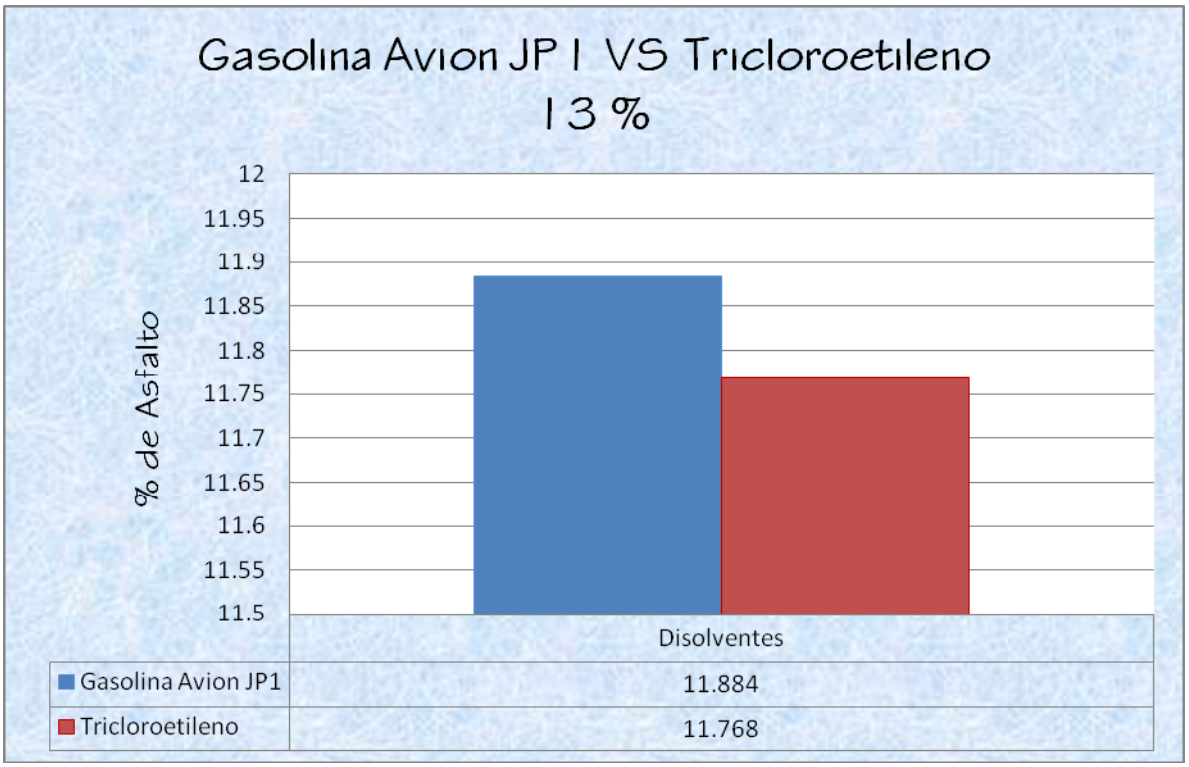



**Gráfico 7.6:** Comparación de disolventes, Gasolina de avión JP1 VS Tricloroetileno del 12 % de contenido de asfalto

Con el cuarto disolvente se ha realizado la comparación de mezclas asfálticas entre los disolventes Gasolina AVGAS-130 VS Tricloroetileno que tienen 12 % de contenido de asfalto, se obtiene el siguiente gráfico 7.7 que da como resultado un porcentaje de variación del 45.05 %.

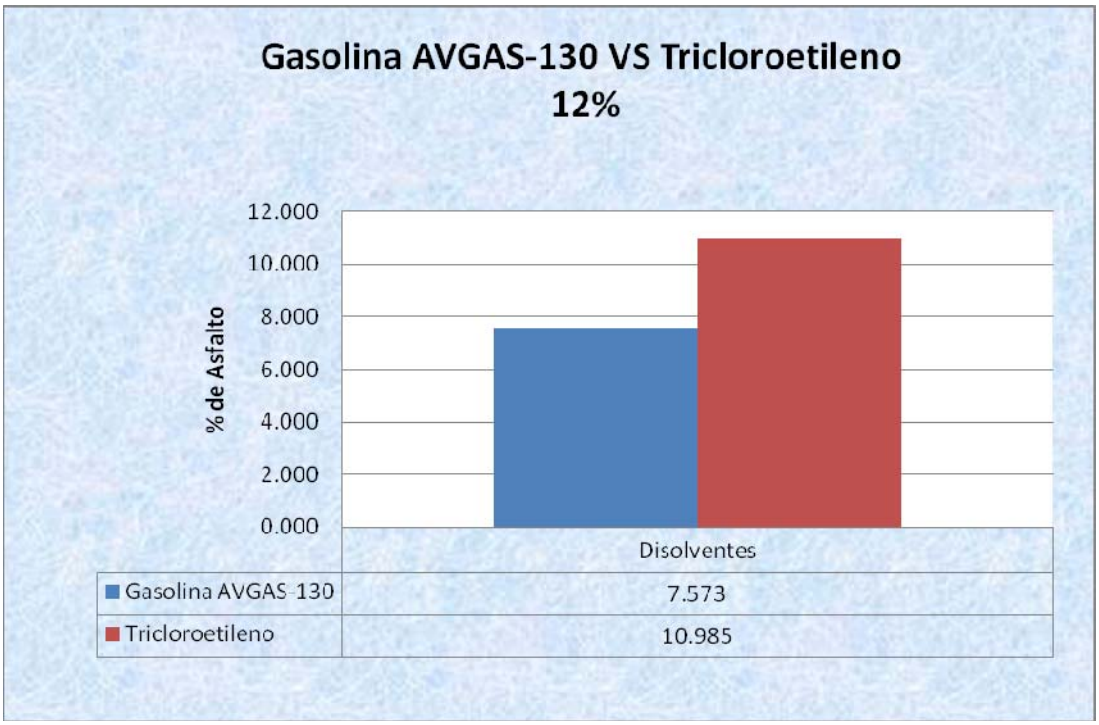



**Gráfico 7.7:** Comparación de disolventes, Gasolina AVGAS-130 VS Tricloroetileno del 12 % de contenido de asfalto

A continuación se indica el gráfico 7.8 comparativo entre los disolventes Gasolina AVGAS-130 VS Tricloroetileno del 13% de contenido de asfalto que dio como resultado un porcentaje de variación del 36.03 %

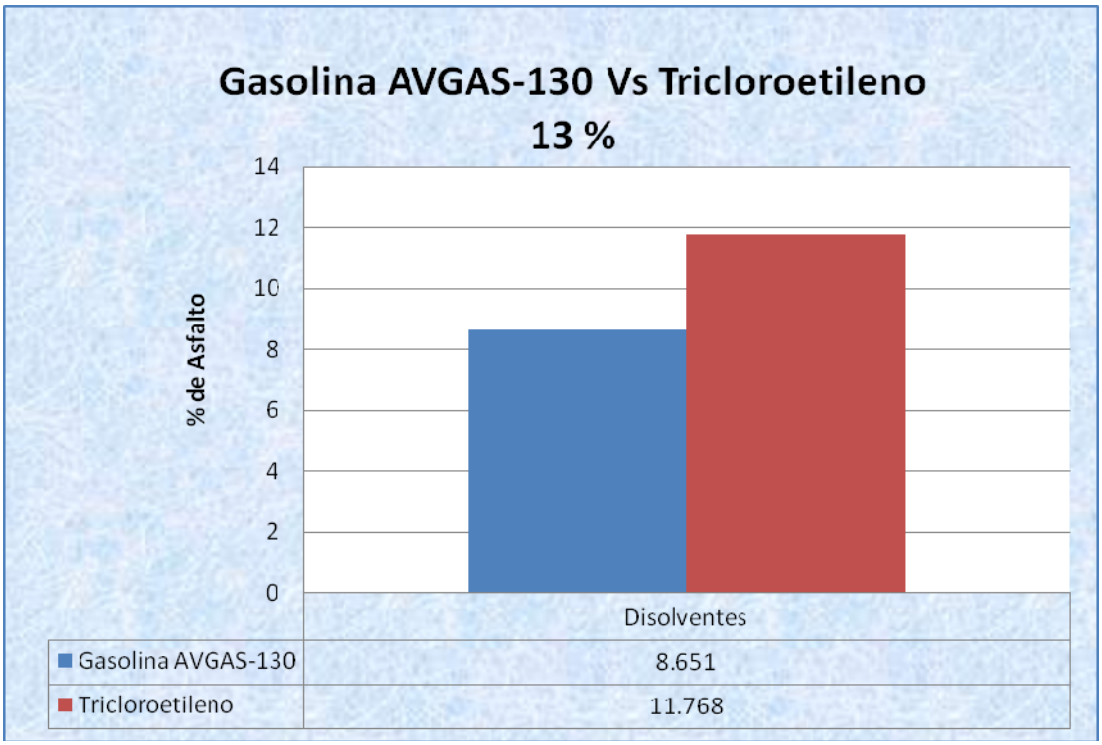



**Gráfico 7.8:** Comparación de disolventes, Gasolina AVGAS-130 VS Tricloroetileno del 13 % de contenido de asfalto

Finalmente, en la siguiente tabla se indica la síntesis del los **porcentajes de variación** de cada disolvente con sus porcentajes correspondientes en relación al *Tricloroetileno*:

| PORCENTAJE DE VARIACIÓN | | | | |
|---|---|---|---|---|
| % de Asfalto | Gasolina Extra | Gasolina Súper | Gasolina JP I | Gasolina AVGAS-130 |
| 12% | 5.81 | 0.05 | 2.11 | 45.05 |
| 13% | 4.52 | -1.36 | -0.98 | 36.03 |

**TABLA 7.2:** Porcentajes de variación de los disolventes.

En la siguiente tabla 7.3 y tabla 7.4 se indica una comparación de los resultados obtenidos de la extracción de bitumen de las muestras de cada disolvente con relación al porcentaje real de la mezcla del 12% y del 13%:

| | | DISOLVENTES | | | | |
|---|---|---|---|---|---|---|
| | | EXTRA | SUPER | JP-1 | AVGas-130 | Tricloroetileno |
| PORCENTAJES | REAL | 12% | | | | |
| | EXTRAIDO | 10,382 | 10,980 | 10,758 | 7,573 | 10,985 |
| | INDICE EXT. | 0,8652 | 0,9150 | 0,8965 | 0,6311 | 0,9154 |

**TABLA 7.3:** Comparación de los porcentajes del 12%.

| | | DISOLVENTES | | | | |
|---|---|---|---|---|---|---|
| | | EXTRA | SUPER | JP-1 | AVGas-130 | Tricloroetileno |
| PORCENTAJES | REAL | 13% | | | | |
| | EXTRAIDO | 11,259 | 11,930 | 11,884 | 8,651 | 11,768 |
| | INDICE EXT. | 0,8661 | 0,9177 | 0,9142 | 0,6655 | 0,9052 |

**TABLA 7.4:** Comparación de los porcentajes del 13%.

## 7.2 Evaluación estadística de resultados

*"La desviación estándar es una medida del grado de dispersión de los datos con respecto al valor promedio. Dicho de otra manera, la desviación estándar es simplemente el promedio o variación esperada con respecto a la media aritmética".*

*La deviación estándar puede ser interpretada como una medida de incertidumbre. La desviación estándar de un grupo repetido de medidas nos da la precisión de estas. Cuando se va determinar si un grupo de medidas está de acuerdo con el modelo teórico, la desviación estándar de esas medidas es de vital importancia: si la media de las medidas está demasiada alejada de la predicción (Con la distancia medida en desviaciones estándar), entonces consideramos que las medidas contradicen la teoría. Esto es coherente ya que las mediciones caen fuera del rango de valores en el cual sería razonable esperar que ocurrieran si el modelo teórico fuera correcto. La desviación estándar es uno de tres parámetros de ubicación central; muestra la agrupación de los datos alrededor de un valor central (la media o promedio) "*[43]

[43] Internet, www.wikkipedia.com

De acuerdo a la norma ASTM D2172 – 01 de la extracción del porcentaje de bitumen en el numeral 30 correspondiente a precisiones y desviaciones establecen tres rangos de absorción del agregado que sirven para comparar la desviación máxima dada por la norma y la desviación estándar calculada de cada disolvente con su porcentaje correspondiente.

En esta investigación se obtuvo un porcentaje de absorción grueso de 58.65 % y de absorción fino de 32.24 % por lo tanto el rango del porcentaje de absorción según la norma es mayor a 2.5 %.

Para determinar la desviación máxima de la norma se debe establecer las características de operación de la investigación que en este caso se realizó con dos operadores y con el método A (Centrifuga), y bajo estas características de ensayo la norma indica que la desviación estándar no debe ser mayor a 0,37.

A continuación se presentan las desviaciones estándar calculadas de cada disolvente con su porcentaje correspondiente:

## Gasolina Extra:

| GASOLINA EXTRA 12% | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras Nº | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 10,7220 | 10,5780 | 10,5020 | 10,4940 | 10,3830 | 10,3680 | 10,2920 | 10,2110 | 10,2570 | 10,0120 | 10,3820 |
| (Xi - Xmed) | 0,3400 | 0,1958 | 0,1203 | 0,1119 | 0,0008 | -0,0140 | -0,0898 | -0,1703 | -0,1246 | -0,3701 | |
| $(Xi - Xmed)^2$ | 0,1156 | 0,0384 | 0,0145 | 0,0125 | 0,0000 | 0,0002 | 0,0081 | 0,0290 | 0,0155 | 0,1369 | |
| σ | 0,2030 | | | | | | | | | | |

TABLA 7.5: Desviación estándar de Gasolina Extra 12%

| GASOLINA EXTRA 13 % | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras Nº | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 11,441 | 11,434 | 11,647 | 11,438 | 11,475 | 11,065 | 10,882 | 10,994 | 11,384 | 10,877 | 11,259 |
| (Xi - Xmed) | 0,18198 | 0,17569 | 0,38798 | 0,17905 | 0,21619 | -0,19349 | -0,37621 | -0,31443 | 0,12514 | -0,38192 | |
| $(Xi - Xmed)^2$ | 0,03312 | 0,03087 | 0,15053 | 0,03206 | 0,04674 | 0,03744 | 0,14153 | 0,09886 | 0,01566 | 0,14586 | |
| σ | 0,285 | | | | | | | | | | |

TABLA 7.6: Desviación estándar de Gasolina Extra 13 %

## Gasolina Súper:

| GASOLINA SUPER 12% | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras Nº | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 10,732 | 10,906 | 11,229 | 10,899 | 10,991 | 11,026 | 11,197 | 10,966 | 10,847 | 11,005 | 10,980 |
| (Xi - Xmed) | -0,248 | -0,0741 | 0,2491 | -0,0807 | 0,0113 | 0,0464 | 0,2177 | -0,0136 | -0,1331 | 0,0251 | |
| $(Xi - Xmed)^2$ | 0,0615 | 0,0055 | 0,0621 | 0,0065 | 0,001 | 0,0021 | 0,0474 | 0,0002 | 0,0177 | 0,0006 | |
| σ | 0,150 | | | | | | | | | | |

TABLA 7.7: Desviación estándar de Gasolina Súper 12 %

| GASOLINA SUPER 13 % | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 12,149 | 11,933 | 12,034 | 11,781 | 11,962 | 11,899 | 11,911 | 11,775 | 11,925 | 11,929 | 11,930 |
| (Xi - Xmed) | 0,21960 | 0,00317 | 0,10466 | -0,14921 | 0,03269 | -0,03121 | -0,01919 | -0,15471 | -0,00472 | -0,00107 | |
| $(Xi - Xmed)^2$ | 0,04822 | 0,00001 | 0,01095 | 0,02226 | 0,00107 | 0,00097 | 0,00037 | 0,02393 | 0,00002 | 0,00000 | |
| σ | 0,109 | | | | | | | | | | |

TABLA 7.8: Desviación estándar de Gasolina Súper 13 %

## Gasolina de Avión JP1 :

| GASOLINA AVION JP1 12% | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 10,665 | 11,078 | 10,615 | 10,859 | 10,904 | 10,729 | 11,062 | 10,777 | 10,412 | 10,478 | 10,758 |
| (Xi - Xmed) | -0,0924 | 0,3197 | -0,1426 | 0,1010 | 0,1459 | -0,0288 | 0,3041 | 0,0189 | -0,3458 | -0,2800 | |
| $(Xi - Xmed)^2$ | 0,0085 | 0,1022 | 0,0203 | 0,0102 | 0,0213 | 0,0080 | 0,0925 | 0,0004 | 0,1196 | 0,0784 | |
| σ | 0,225 | | | | | | | | | | |

TABLA 7.9: Desviación estándar de Gasolina de Avión JP1 del 12 %

| GASOLINA AVION JP1 13 % | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 11,734 | 11,800 | 11,796 | 11,926 | 11,885 | 12,042 | 11,914 | 11,760 | 11,926 | 12,054 | 11,884 |
| (Xi - Xmed) | -0,14923 | -0,08401 | -0,08809 | 0,04198 | 0,00113 | 0,15883 | 0,03004 | -0,12320 | 0,04205 | 0,17052 | |
| $(Xi - Xmed)^2$ | 0,02227 | 0,00706 | 0,00776 | 0,00176 | 0,00000 | 0,02523 | 0,00090 | 0,01518 | 0,00177 | 0,02908 | |
| σ | 0,111 | | | | | | | | | | |

TABLA 7.10: Desviación estándar de Gasolina de Avión JP1 del 13 %

## Gasolina de Avión AVGAS-130:

| GASOLINA AVION AVGAS-130 12% | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de | 7,5000 | 7,4390 | 7,7410 | 7,8650 | 7,6230 | 7,1890 | 7,8920 | 7,3590 | 7,9350 | 7,1850 | 7,573 |
| (Xi - Xmed) | -0,0733 | -0,1336 | 0,1681 | 0,2919 | 0,0505 | -0,3835 | 0,2177 | -0,0136 | -0,1331 | 0,0251 | |
| $(Xi - Xmed)^2$ | 0,0615 | 0,0055 | 0,0621 | 0,0065 | 0,001 | 0,0021 | 0,0474 | 0,0002 | 0,0177 | 0,0006 | |
| σ | 0,282 | | | | | | | | | | |

TABLA 7.11: Desviación estándar de Gasolina de Avión AVGAS-130 del 12 %

| GASOLINA AVION AVGAS-130 13 % | | | | | | | | | | | Promedio ( Xmed) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Porcentaje de Bitumen | 8,234 | 8,888 | 8,591 | 8,669 | 8,728 | 8,449 | 8,840 | 8,914 | 8,562 | 8,636 | 8,651 |
| (Xi - Xmed) | -0,41752 | 0,23646 | -0,06033 | 0,01793 | 0,07723 | -0,20210 | 0,18918 | 0,26302 | -0,08875 | -0,01513 | |
| $(Xi - Xmed)^2$ | 0,17432 | 0,05591 | 0,00364 | 0,00032 | 0,00596 | 0,04084 | 0,03579 | 0,06918 | 0,00788 | 0,00023 | |
| σ | 0,209 | | | | | | | | | | |

TABLA 7.12: Desviación estándar de Gasolina de Avión AVGAS-130 del 13 %

## TRICLOROETILENO:

| TRICLOROETILENO 12% | | | | | | | | | | | Promedio ( Xmed) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Porcentaje de Bitumen | 11,089 | 10,943 | 10,830 | 11,100 | 11,068 | 11,134 | 11,007 | 10,892 | 10,831 | 10,956 | 10,985 |
| (Xi - Xmed) | 0,1036 | -0,0423 | -0,1549 | 0,1153 | 0,0834 | 0,1488 | 0,0216 | -0,0929 | -0,1536 | -0,0290 | |
| $(Xi - Xmed)^2$ | 0,0107 | 0,0018 | 0,0240 | 0,0133 | 0,0070 | 0,0221 | 0,0005 | 0,0086 | 0,0236 | 0,0008 | |
| σ | 0,112 | | | | | | | | | | |

TABLA 7.13: Desviación estándar de Tricloroetileno del 12 %

| GASOLINA AVION TRICLOROETILENO 13 % | | | | | | | | | | | Promedio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Muestras N° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ( Xmed) |
| Porcentaje de Bitumen | 11,882 | 11,917 | 11,839 | 11,627 | 11,716 | 12,013 | 11,777 | 11,583 | 11,662 | 11,667 | 11,768 |
| (Xi - Xmed) | 0,11404 | 0,14898 | 0,07046 | -0,14147 | -0,05271 | 0,24459 | 0,00893 | -0,18492 | -0,10653 | -0,10136 | |
| $(Xi - Xmed)^2$ | 0,01300 | 0,02219 | 0,00496 | 0,02001 | 0,00278 | 0,05983 | 0,00008 | 0,03420 | 0,01135 | 0,01027 | |
| σ | 0,141 | | | | | | | | | | |

TABLA 7.14: Desviación estándar de Tricloroetileno del 13 %

A continuación en la tabla 7.15 se indica el resumen de la desviación estándar de cada disolvente con su porcentaje correspondiente:

| | Gasolina Extra | | Gasolina Súper | | Gasolina Avión JP1 | | Gasolina AVGAS-130 | | Tricloroetileno | |
|---|---|---|---|---|---|---|---|---|---|---|
| % De Asfalto | 12% | 13% | 12% | 13% | 12% | 13% | 12% | 13% | 12% | 13% |
| Desviación Estándar | 0,203 | 0,285 | 0,150 | 0,109 | 0,225 | 0,111 | 0,282 | 0,209 | 0,112 | 0,141 |

TABLA 7.15: Resumen de las desviaciones estándar

# 8. CONCLUSIONES Y RECOMENDACIONES:

## 8.1 CONCLUSIONES

- En esta investigación se cumplió el objetivo del tema que es la utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfálticas con agregados minerales de ALTA ABSORCIÓN, ya que se obtuvo como resultado un porcentaje de absorción fino de 32.23% y un porcentaje de absorción de grueso de 58,65% dando como promedio de porcentaje de absorción del agregado de 39,61%.

- Basándose con referencias de resultados obtenidos por el Laboratorio de Materiales de construcción de la PUCE, se determina que un porcentaje de absorción de agregados comúnmente utilizados para mezclas asfálticas en caliente varía entre 2 % y 5 % como se puede observar en la siguiente tabla donde se enumera las canteras más usadas en Quito.

| CANTERA/MINA | Absorcion % |
|---|---|
| Guayllabamba | 2.45 |
| Pifo | 4.38 |
| Pintag | 2.4 |

Por esta razón se concluye que el porcentaje de absorción del agregado usado en esta investigación es alto comparado con los agregados mencionados en la tabla anterior.

- En los ensayos para las características de los materiales minerales se obtuvieron los siguientes resultados como se indica en la tabla, donde se realizo la comparación entre los resultados de los ensayos y la tabla de especificaciones del MOP TOMO II para el diseño y fabricación de carpetas asfálticas.

| Ensayo | Especificación del MOP | Resultado Obtenido | CUMPLE |
|---|---|---|---|
| Abrasión | < 40 % | 32.90% | SI |
| Desgaste a los sulfatos | < 12 % | 10.06% | SI |
| Deletéreos | < 1 % | 12.80% | NO |

Los agregados minerales que fueron usados para la investigación no cumplieron con las especificaciones porque el ensayo de Deletéreos no cumple con la especificación del MOP, por lo tanto este agregado no es apto para la fabricación de carpetas asfálticas.

- Para la determinación de la característica del cemento asfáltico usado en la investigación se obtuvieron algunos resultados que no cumplen con los requisitos del MOP TOMO II TABLA 810.2.1. para la construcción de caminos y puentes, que son los tres primeros

ensayos que se indica en la tabla pero los tres ensayos siguientes si cumplen con los requisitos, sin embargo en el medio de construcciones viales, por falta de disponibilidad de un buen material asfáltico se utiliza el que se dispone en el momento de la ejecución de la obra.

| ENSAYO | 60 - 70 | | 85 - 100 | | Resultados Obtenidos | Conclusión |
|---|---|---|---|---|---|---|
| BETUN ORIGINAL | Mínimo | Máximo | Mínimo | Máximo | | |
| Penetración ( 25°C, 100 gr,5 s) mm/10 | 60 | 70 | 85 | 100 | 59 | No cumple |
| Punto de ablandamiento A, B Y °C | 48 | 57 | 45 | 43 | 40,25 | No cumple |
| Índice de penetración (*) | -1,5 | 1,5 | -1,5 | 1,5 | 1,58 | No cumple |
| Ductilidad (25 °C, 5 cm/minuto) | 100 | ----- | 100 | ----- | > 135 | Cumple |
| Punto de inflamación, Copa Cleveland, °C. | 232 | ----- | 232 | ----- | 234 | Cumple |
| Densidad relativa, 25 °C/ 25 °C | 1 | ----- | 1 | ----- | 1,013 | Cumple |

MOP – TOMO II - TABLA 810.2.1.

- A pesar de que los elementos constitutivos de la mezcla asfáltica no cumplen en su totalidad con las especificaciones y requisitos establecidos por el MOP, hay que recordar que el principal objetivo de ésta investigación es el de *evaluar* el comportamiento de los disolventes comerciales y obtener elementos de juicio que nos permita recomendar o *no* el uso de éstos en la práctica y no el realizar una mezcla asfáltica cuyo diseño sea el óptimo en cuanto a cumplimiento de requisitos o normas.

- Se pudo comprobar que las expresiones empíricas recomendadas por El Instituto del Asfalto y por el Laboratorio de Puentes y Calzadas para el cálculo del porcentaje Óptimo Teórico de asfalto de una mezcla no son aplicables a aquellas que tengan estas características en cuanto absorción de agregados ya que como se puede notar en el *Capítulo 4.1*, el porcentaje obtenido de las fórmulas mencionadas, llegan a representar apenas un 50% del Porcentaje Óptimo real obtenido después del diseño por medio del Método Marshall.

- Una vez realizado el ensayo de Extracción de Porcentaje de Bitumen usando la Centrífuga, se pudo determinar que el cemento asfáltico puede ser disuelto por los disolventes comerciales usados (Gasolina Extra, Gasolina Súper, Gasolina de avión JP-1 y AvGas-130) pero que cada uno tiene su respectiva eficacia y aproximación al optimo de la mezcla.

  Para evaluar estos resultados de la presente investigación se ha usado un ***Índice de Extracción***, el cual se lo determinó mediante la relación entre el Porcentaje obtenido mediante centrifugación y el Óptimo de la mezcla, considerando al de mayor índice el más eficiente. Se presentan los resultados e índices mencionados en las siguientes tablas tanto para mezclas de 12% (Porcentaje Óptimo) y del 13%.

| | | DISOLVENTES | | | | |
|---|---|---|---|---|---|---|
| | | EXTRA | SUPER | JP-1 | AVGas-130 | Tricloroetileno |
| PORCENTAJES | REAL | 12% | | | | |
| | EXTRAIDO | 10.382 | 10.980 | 10.758 | 7.573 | 10.985 |
| | INDICE EXT. | 0.8652 | 0.9150 | 0.8965 | 0.6311 | 0.9154 |

| | | DISOLVENTES | | | | |
|---|---|---|---|---|---|---|
| | | EXTRA | SUPER | JP-1 | AVGas-130 | Tricloroetileno |
| PORCENTAJES | REAL | 13% | | | | |
| | EXTRAIDO | 11.259 | 11.930 | 11.884 | 8.651 | 11.768 |
| | INDICE EXT. | 0.8661 | 0.9177 | 0.9142 | 0.6655 | 0.9052 |

- Se concluye que el disolvente comercial más eficiente para la Extracción de Porcentaje de Bitumen con el método de la Centrífuga es la ***Gasolina Súper*** ya que se puede apreciar en las tablas anteriores que dicho disolvente es el que mayor Índice de Extracción obtiene en los ensayos e inclusive para las mezclas con un 13% de contenido de asfalto, resulta más eficiente que el Tricloroetileno.

- Por medio de una comparación entre los resultados obtenidos de cada disolvente versus el del que dicta la norma que es el Tricloroetileno (T.C.E.), se ha podido demostrar que se obtienen variaciones de menos del 6% para la Gasolina Extra, Súper y JP-1 por lo cual se los podría catalogar como *Recomendables* para sustituir al T.C.E., pero si se observa la variación para la gasolina de avión AVGas-130 se encuentra entre el 35% y 50% dejándolo así fuera de un rango aceptable de confiabilidad en cuanto precisión y confiabilidad para resultados que un Laboratorio podría necesitar.

| PORCENTAJE DE VARIACIÓN | | | | |
|---|---|---|---|---|
| % de Asfalto | Gas. Extra | Gas. Súper | Gas. JP-1 | Gas. AVGAS-130 |
| 12% | 5.81 | 0.05 | 2.11 | 45.05 |
| 13% | 4.52 | -1.36* | -0.98* | 36.03 |

* Significa que dio mejores resultados que el T.C.E.

- Se aceptan los resultados de extracción de porcentaje de bitumen como válidos gracias a la evaluación estadística realizada con los mismos, para la cual se tomó en consideración los parámetros de análisis para el ensayo de la norma *ASTM 2172* que para muestras ensayadas bajo el Método A (Centrífuga), precisión para ensayos con operadores múltiples y en mezclas con agregados pétreos cuya absorción sea mayor a 2.5%, la desviación estándar (**σ**) debe ser menor a 0.37. La siguiente tabla muestra las desviaciones estándar para cada grupo de muestras de acuerdo a los disolventes usados y se puede apreciar que *todos* los resultados se pueden catalogar como válidos.

| | Gasolina Extra | | Gasolina Súper | | Gasolina Avión JP1 | | Gasolina AVGAS-130 | | Tricloroetileno | |
|---|---|---|---|---|---|---|---|---|---|---|
| % De Asfalto | 12% | 13% | 12% | 13% | 12% | 13% | 12% | 13% | 12% | 13% |
| Desviación Estándar | 0.203 | 0.285 | 0.150 | 0.109 | 0.225 | 0.111 | 0.282 | 0.209 | 0.112 | 0.141 |

## 8.2 *RECOMENDACIONES:*

Una vez terminada ésta investigación y obteniéndose conclusiones claras sobre la utilización de disolventes comerciales para el ensayo de Extracción de Porcentaje de Bitumen con la Centrífuga, se ha podido publicar recomendaciones o acotaciones que, para el juicio de los investigadores, es necesario tomar en cuenta si es que se desea usar éste texto como referencia de cualquier índole.

Las recomendaciones son las siguientes:

- Por ningún motivo se recomienda usar agregados pétreos de las características de absorción indicadas ya que no cumplen con las especificaciones y requisitos dados por el MOP mostrados anteriormente y además se ha podido constatar que las cantidades de cemento asfáltico que se usarían para satisfacer el diseño con este agregado exceden las cantidades de una mezcla común, haciéndola además una mezcla antieconómica.

- Cualquier comparación que se desee hacer con respecto a los resultados obtenidos en ésta investigación deben ser realizados *solamente* con mezclas asfálticas de las mismas características las cuales dependen de la calidad y características de los agregados pétreos utilizados y también del cemento asfáltico. De ninguna manera se recomienda usar los resultados de ésta publicación como factores de corrección o parámetros de correlación con otras mezclas que no entren dentro de las características descritas en el desarrollo de éste texto.

- ***Se recomienda como Disolvente Comercial Alterno la Gasolina Súper***, ya que además de ser la que mejor resultados arrojó en el ensayo principal de ésta investigación, cuenta con ventajas notables como la alta disponibilidad y bajo costo, sin embargo los cuidados que se debe tener al momento de manipularlo son altos ya que es un material inflamable y tóxico si se está expuesto por tiempo prolongado a ésta gasolina. A continuación se presenta un cuadro comparativo en precios, ventajas y cuidados de los 5 disolventes utilizados en esta investigación:

| | | COSTO (USD)/gal. | TOXICIDAD | DISPONIB. | INFLAMABLE |
|---|---|---|---|---|---|
| DISOLVENTES | SUPER | 2.00 | 3 | 3 | 3 |
| | EXTRA | 1.50 | 3 | 3 | 3 |
| | JP - 1 | 2.39 | 3 | 2 | 2 |
| | AVGas - 130 | 7.00 | 3 | 2 | 4 |
| | Tricloroetileno** | 2.56 | 4 | 1 | 2 |

** El costo del Tricloroetileno se lo considera en USD/kg consumido

| | LEYENDA | |
|---|---|---|
| TOXICIDAD | 1 | Nada Tóxico |
| | 2 | Poco Tóxico |
| | 3 | Medianamente Tóxico |
| | 4 | Muy Tóxico |
| DISPONIBILIDAD | 1 | Baja Disponibilidad |
| | 2 | Mediana Disponibilidad |
| | 3 | Alta Disponibilidad |
| INFLAMABLE | 1 | No Inflamable |
| | 2 | Poco Inflamable |
| | 3 | Medianamente Inflamable |
| | 4 | Muy Inflamable |

- Finalmente hay que recomendar que todos los ensayos que se realicen en el laboratorio se deben ejecutar bajo las normas especificadas de seguridad lo que incluye protección personal para manipular materiales nocivos y equipo que puede facilitar la prevención y dado el caso la mitigación de cualquier inconveniente o accidente de trabajo dentro del laboratorio como un incendio o contaminación del ambiente. Dentro de los equipos recomendados para estos propósitos y en especial para el ensayo de Extracción con Centrífuga es necesario contar con campanas de extracción de gases, extintores que deben estar ***cargados y dentro de la fecha recomendada de uso*** para evitar accidentes, sistemas de ventilación de los quipos como hornos de secado deben estar en pleno funcionamiento y los equipos de protección personal como guantes, mascarillas, mandiles de trabajo, entre otros. (*Fotografía 8.1 y Fotografía 8.2*).



*Fotografía 8.1*



*Fotografía 8.2*

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# ANEXOS CORRESPONDIENTES AL CAPÍTULO 2

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Granulometría N° 1

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASMT C 136-01

| GRANULOMETRIA N° 1 | | | | | |
|---|---|---|---|---|---|
| **MALLA** | **ABERTURA (mm)** | **MASA RET PAR. (gr)** | **MASA RET ACUM. (gr)** | **% RETENIDO (gr)** | **% PASA (gr)** |
| 2 | 50.8 | - | - | - | 100,0 |
| 1 1/2 | 58.1 | - | - | - | 100,0 |
| 1 | 25.4 | 10,00 | 10,00 | 0,10 | 99,9 |
| 3/4 | 19 | 12,00 | 22,00 | 0,22 | 99,8 |
| 1/2 | 12.7 | 350,00 | 372,00 | 3,72 | 96,3 |
| 3/8 | 9.51 | 506,00 | 878,00 | 8,78 | 91,2 |
| N. 4 | 4.76 | 1.830,00 | 2.708,00 | 27,08 | 72,9 |
| N. 8 | 2.362 | 2.437,94 | 5.145,94 | 51,46 | 48,5 |
| N. 16 | 1.19 | 2.154,34 | 7.300,28 | 73,00 | 27,0 |
| N. 30 | 0.595 | 1.535,59 | 8.835,87 | 88,35 | 11,6 |
| N. 50 | 0.297 | 361,69 | 9.197,56 | 91,97 | 8,0 |
| N. 100 | 0.149 | 116,34 | 9.313,90 | 93,13 | 6,9 |
| N. 200 | 0.074 | 116,77 | 9.430,67 | 94,30 | 5,7 |
| PASA N. 200 | | 281,60 | 9.712,27 | 97,12 | 2,9 |
| SUMAN | | 9.712,27 | | | |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfaltícas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Granulometría N° 2

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASMT C 136-01

| GRANULOMETRIA N° 2 | | | | | |
|---|---|---|---|---|---|
| **MALLA** | **ABERTURA (mm)** | **MASA RET PAR. (gr)** | **MASA RET ACUM. (gr)** | **% RETENIDO (gr)** | **% PASA (gr)** |
| 2 | 50.8 | 0 | 0 | 0,00 | 100,0 |
| 1 1/2 | 58.1 | 0 | 0 | 0,00 | 100,0 |
| 1 | 25.4 | 10 | 10 | 0,10 | 99,9 |
| 3/4 | 19 | 66,52 | 76,52 | 0,77 | 99,2 |
| 1/2 | 12.7 | 457,72 | 534,24 | 5,34 | 94,7 |
| 3/8 | 9.51 | 484,13 | 1018,37 | 10,18 | 89,8 |
| N. 4 | 4.76 | 1767,2 | 2785,57 | 27,86 | 72,1 |
| N. 8 | 2.362 | 2474,09 | 5259,66 | 52,60 | 47,4 |
| N. 16 | 1.19 | 2252,16 | 7511,82 | 75,12 | 24,9 |
| N. 30 | 0.595 | 1626,71 | 9138,53 | 91,39 | 8,6 |
| N. 50 | 0.297 | 365,57 | 9504,1 | 95,04 | 5,0 |
| N. 100 | 0.149 | 145,72 | 9649,82 | 96,50 | 3,5 |
| N. 200 | 0.074 | 132,7 | 9782,52 | 97,83 | 2,2 |
| PASA N. 200 | | 72 | 9854,52 | 98,55 | 1,5 |
| SUMAN | | 9854,52 | | | |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Granulometría N° 3

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASMT C 136-01

| GRANULOMETRIA N° 3 | | | | | |
|---|---|---|---|---|---|
| **MALLA** | **ABERTURA (mm)** | **MASA RET PAR. (gr)** | **MASA RET ACUM. (gr)** | **% RETENIDO (gr)** | **% PASA (gr)** |
| 2 | 50.8 | - | - | - | 100,0 |
| 1 1/2 | 58.1 | - | - | - | 100,0 |
| 1 | 25.4 | 6,00 | 6,00 | 0,06 | 99,9 |
| 3/4 | 19 | 34,00 | 40,00 | 0,40 | 99,6 |
| 1/2 | 12.7 | 357,87 | 397,87 | 3,98 | 96,0 |
| 3/8 | 9.51 | 511,04 | 908,91 | 9,09 | 90,9 |
| N. 4 | 4.76 | 1.974,00 | 2.882,91 | 28,83 | 71,2 |
| N. 8 | 2.362 | 2.574,16 | 5.457,07 | 54,57 | 45,4 |
| N. 16 | 1.19 | 2.003,83 | 7.460,90 | 74,61 | 25,4 |
| N. 30 | 0.595 | 1.512,50 | 8.973,40 | 89,73 | 10,3 |
| N. 50 | 0.297 | 346,40 | 9.319,80 | 93,20 | 6,8 |
| N. 100 | 0.149 | 105,32 | 9.425,12 | 94,25 | 5,7 |
| N. 200 | 0.074 | 103,74 | 9.528,86 | 95,29 | 4,7 |
| PASA N. 200 | | 405,37 | 9.934,23 | 99,34 | 0,7 |
| SUMAN | | 9.934,23 | | | |

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REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Granulometría Promedio

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASMT C 136-01

| | | Granulometria N° 1 | Granulometria N° 2 | Granulometria N° 3 | |
|---|---|---|---|---|---|
| MALLA | ABERTURA (mm) | MASA RET PAR. (gr) | MASA RET PAR. (gr) | MASA RET PAR. (gr) | MASA RET. PAR. |
| 2 | 50.8 | - | - | - | - |
| 1 1/2 | 58.1 | - | - | - | - |
| 1 | 25.4 | 6,00 | 10,00 | 6,00 | 7,3 |
| 3/4 | 19 | 34,00 | 66,52 | 34,00 | 44,8 |
| 1/2 | 12.7 | 357,87 | 457,72 | 357,87 | 391,2 |
| 3/8 | 9.51 | 511,04 | 484,13 | 511,04 | 502,1 |
| N. 4 | 4.76 | 1.974,00 | 1.767,20 | 1.974,00 | 1.905,1 |
| N. 8 | 2.362 | 2.574,16 | 2.474,09 | 2.574,16 | 2.540,8 |
| N. 16 | 1.19 | 2.003,83 | 2.252,16 | 2.003,83 | 2.086,6 |
| N. 30 | 0.595 | 1.512,50 | 1.626,71 | 1.512,50 | 1.550,6 |
| N. 50 | 0.297 | 346,40 | 365,57 | 346,40 | 352,8 |
| N. 100 | 0.149 | 105,32 | 145,72 | 105,32 | 118,8 |
| N. 200 | 0.074 | 103,74 | 132,70 | 103,74 | 113,4 |
| PASA N. 200 | | 405,37 | 72,00 | 405,37 | 294,2 |

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REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Finos N° 1

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 128-01

| ***Ensayo de Gravedades y Absorción N ° 1*** | | |
|---|---|---|
| MASA MATRAZ (gr) | Mm= | 173,610 |
| MASA CONJUNTO (gr) | Mmw= | 777,900 |
| MASA MUESTRA S.S.S. (gr) | B= | 250,000 |
| MASA MUESTRA SECA (gr) | A= | 186,000 |
| MASA AGUA ANADIDA (gr) | Ma= | 354,290 |
| GRAVEDAD BULK | Ge= | 1,783 |
| GRAVEDAD SSS | Ges= | 2,397 |
| GRAVEDAD APARENTE | Gea= | 1,105 |
| PORCENTAJE DE ABSORCION | Abs%= | 34,409 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Finos N° 2

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 128-01

| ***Ensayo de Gravedades y Absorción N ° 2*** | | |
|---|---|---|
| MASA MATRAZ (gr) | Mm= | 173,630 |
| MASA CONJUNTO (gr) | Mmw= | 780,800 |
| MASA MUESTRA S.S.S. (gr) | B= | 250,020 |
| MASA MUESTRA SECA (gr) | A= | 185,370 |
| MASA AGUA ANADIDA (gr) | Ma= | 357,150 |
| GRAVEDAD BULK | Ge= | 1,730 |
| GRAVEDAD SSS | Ges= | 2,334 |
| GRAVEDAD APARENTE | Gea= | 1,079 |
| PORCENTAJE DE ABSORCION | Abs%= | 34,876 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Finos N° 3

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 128-01

| ***Ensayo de Gravedades y Absorción N ° 3*** | | |
|---|---|---|
| MASA MATRAZ (gr) | Mm= | 173,620 |
| MASA CONJUNTO (gr) | Mmw= | 787,200 |
| MASA MUESTRA S.S.S. (gr) | B= | 250,000 |
| MASA MUESTRA SECA (gr) | A= | 196,200 |
| MASA AGUA ANADIDA (gr) | Ma= | 363,580 |
| GRAVEDAD BULK | Ge= | 1,727 |
| GRAVEDAD SSS | Ges= | 2,201 |
| GRAVEDAD APARENTE | Gea= | 1,172 |
| PORCENTAJE DE ABSORCION | Abs%= | 27,421 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Fino Promedio

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 128-01

| | GRAVEDAD ESPECIFICA FINO | | | |
|---|---|---|---|---|
| | N° 1 | N° 2 | N° 3 | PROMEDIO |
| GRAVEDAD BULK | 1,783 | 1,730 | 1,727 | 1,747 |
| GRAVEDAD SSS | 2,397 | 2,334 | 2,201 | 2,311 |
| GRAVEDAD APARENTE | 1,105 | 1,079 | 1,172 | 1,119 |
| PORCENTAJE DE ABSORCION | 34,409 | 34,876 | 27,421 | 32,235 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Grueso N° 1

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 127 -04

| ***Ensayo de Gravedades y Absorción Grueso N °1*** | | |
|---|---|---|
| MASA MUESTRA S.S.S. (gr) | B= | 2006,900 |
| MASA MUESTRA SECA (gr) | A= | 1258,560 |
| MASA SUMERGIDA EN AGUA (gr) | C= | 476,000 |
| GRAVEDAD BULK | Ge= | 0,822 |
| GRAVEDAD SSS | Ges= | 1,311 |
| GRAVEDAD APARENTE | Gea= | 1,608 |
| PORCENTAJE DE ABSORCION | Abs%= | 59,460 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Grueso N° 2

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 127 -04

| ***Ensayo de Gravedades y Absorción Grueso N °2*** | | |
|---|---|---|
| MASA MUESTRA S.S.S. (gr) | B= | 1809,700 |
| MASA MUESTRA SECA (gr) | A= | 1146,300 |
| MASA SUMERGIDA EN AGUA (gr) | C= | 362,000 |
| GRAVEDAD BULK | Ge= | 0,792 |
| GRAVEDAD SSS | Ges= | 1,250 |
| GRAVEDAD APARENTE | Gea= | 1,462 |
| PORCENTAJE DE ABSORCION | Abs%= | 57,873 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Grueso N° 3

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 127 -04

| ***Ensayo de Gravedades y Absorción Grueso N °3*** | | |
|---|---|---|
| MASA MUESTRA S.S.S. (gr) | B= | 1964,520 |
| MASA MUESTRA SECA (gr) | A= | 1238,540 |
| MASA SUMERGIDA EN AGUA (gr) | C= | 390,230 |
| GRAVEDAD BULK | Ge= | 0,787 |
| GRAVEDAD SSS | Ges= | 1,248 |
| GRAVEDAD APARENTE | Gea= | 1,460 |
| PORCENTAJE DE ABSORCION | Abs%= | 58,616 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Gravedad Especifica Grueso Promedio

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 127 -04

| | GRAVEDAD ESPECIFICA GRUESO | | | |
|---|---|---|---|---|
| | N° 1 | N° 2 | N° 3 | PROMEDIO |
| GRAVEDAD BULK | 0,822 | 0,792 | 0,787 | 0,800 |
| GRAVEDAD SSS | 1,311 | 1,250 | 1,248 | 1,270 |
| GRAVEDAD APARENTE | 1,608 | 1,462 | 1,460 | 1,510 |
| PORCENTAJE DE ABSORCION | 59,460 | 57,873 | 58,616 | 58,650 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Abrasión

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 131 - 03

$$C = (A - B)$$

$$\%\ Desgaste = \frac{C}{A}\ 100$$

| Tipo de Gradación | D |
|---|---|
| Número de Esferas | 6 |
| (A) Masa Inicial gr. | 5000 |
| (B) Masa sostenida en el tamiz N°12 gr. | 3355 |
| (C) Material que pasa el Tamiz N°12 gr. | 1645 |

| % de Desgaste | 32,90% |
|---|---|

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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Durabilidad de los agregados a la accion de los sulfatos

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM C 88 - 99

| Numero de tamiz | | % Ret. Parcial del agregado | M. de las fracciones antes de ensayo | M. de las fracciones despues de ensayo | % Pasa(el tamiz+fino despues del ensayo) | % de desgaste parcial |
|---|---|---|---|---|---|---|
| Pasa | Retiene | | | | | |
| 1/2 | 3/8 | 1,46% | 330 | 314,7 | 4,64% | 0,07% |
| 3/8 | N.4 | 1,33% | 300 | 293,94 | 2,02% | 0,03% |
| N.4 | N.8 | 0,72% | 100 | 88,24 | 11,76% | 0,08% |
| N.8 | N.16 | 98,55% | 100 | 89,97 | 10,03% | 9,88% |
| N.16 | N.30 | 0,00% | 100 | 93,1 | 6,90% | 0,00% |
| N.30 | N.50 | 0,00% | 100 | 78,43 | 21,57% | 0,00% |

| % de Desgaste Total | 10,06% |
|---|---|

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo,2010

ENSAYO: Equivalente de Arena

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM D2419-02

$$\text{EQUIVALENTE DE ARENA} = \frac{\text{SEDIMENTO: Lectura B}}{\text{Suspension: Lectura A}}$$

A = 3,3

B = 2,9

$$\text{EQUIVALENTE DE ARENA} = 88\%$$

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**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Marzo,2010

**ENSAYO:** Deletéreos

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** ASTM C142-97

| | $W_i$ (gr) | $W_f$ (gr) |
|---|---|---|
| Porción Finos | 286,98 | 148,76 |
| Porción Grueso | 2648,00 | 2310 |

| | |
|---|---|
| % DELETEREOS FINOS | 48,2% |

| | |
|---|---|
| % DELETEREO GRUESO | 12,8% |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

## TABLA DE ESPECIFICACIONES PARA AGREGADOS PÉTREOS

**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**DIRIGIDO POR:** Ing. Gustavo Yánez

| Ensayo | Especificación del MOP | Resultado Obtenido | CUMPLE |
|---|---|---|---|
| Abrasión | < 40 % | 32,90% | SI |
| Desgaste a los sulfatos | < 12 % | 10,06% | SI |
| Deletéreos | < 1 % | 12,80% | NO |

# ANEXOS CORRESPONDIENTES AL CAPÍTULO 3

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo, 2010

ENSAYO: Gravedad Especifica del Cemento Asfáltico

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM D3142-97

| | MUESTRAS | |
|---|---|---|
| | N°1 | N°2 |
| Peso al Aire [gr.] | 9.25 | 8.36 |
| P. Sumergido [gr.] | 0.12 | 0.11 |
| Grav. Espec. Gs [g/cm³] | 1.013 | 1.013 |
| Gs PROMEDIO [g/cm³] | 1.013 | |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo, 2010

ENSAYO: Penetración del cemento asfáltico

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM D5-97

| Puntos | Lectura Penetración |
|---|---|
| P 1 | 60 |
| P 2 | 59 |
| P 3 | 58 |
| **Penetracion promedio** | 59 |

| | centesimas de cm |
|---|---|
| **Tolerancia** | 1.581 |
| **T. Redondeada** | 2 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

DIRIGIDO POR: Ing. Gustavo Yánez

FECHA: Marzo, 2010

ENSAYO: Punto de ablandamiento

ESPECIFICACIÓN: ASTM D-36

| MUESTRA N° | TEMPERATURA °C |
|---|---|
| 1 | 40 |
| 2 | 40.5 |
| PROMEDIO | 40.25 |

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REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

DIRIGIDO POR: Ing. Gustavo Yánez

FECHA: Marzo, 2010

ENSAYO: Punto de inflamacion y combustión

ESPECIFICACIÓN: ASTM D92 - 66

| *PRUEBA N.* | *Pto de Inflamacion* | *Pto de Conbustion* | |
|---|---|---|---|
| 1 | 234 | 248 | °C |
| | 453 | 478 | °F |

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INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo, 2010

ENSAYO: Ductilidad

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM D113-99

| Muestra N° | Ductilidad (cm) |
|---|---|
| 1 | > 135 |
| 2 | > 135 |
| 3 | > 135 |
| **PROMEDIO** | **> 135** |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo, 2010

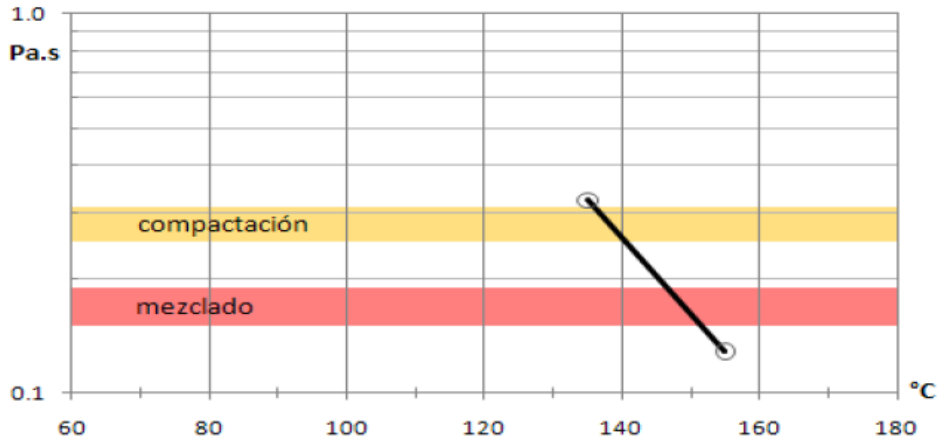
ENSAYO: Viscosidad

DIRIGIDO POR: Ing. Gustavo Yánez

ESPECIFICACIÓN: ASTM D4402-06

**Viscosidad ceménto asfáltico sin polímero**

| Lectura | Temperatura | Visc [cP] | Torque [%] | velocidad [rpm] | husillo |
|---|---|---|---|---|---|
| 1 | 135°C | 322.50 | 12.9 | 100 | SC4-27 |
| 2 | 135°C | 322.50 | 12.9 | 100 | SC4-27 |
| 3 | 135°C | 322.50 | 12.9 | 100 | SC4-27 |
| 1 | 155°C | 128.75 | 10.3 | 200 | SC4-27 |
| 2 | 155°C | 128.75 | 10.3 | 200 | SC4-27 |
| 3 | 155°C | 128.75 | 10.3 | 200 | SC4-27 |



PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**DIRIGIDO POR:** Ing. Gustavo Yánez

## TABLA DE ESPECIFICACIONES PARA CEMENTO ASFÁLTICO

| ENSAYO | 60 - 70 | | 85 - 100 | | Resultados Obtenidos | Conclusión |
|---|---|---|---|---|---|---|
| BETUN ORIGINAL | Mínimo | Máximo | Mínimo | Máximo | | |
| Penetracion ( 25°C, 100 gr, 5 s) mm/10 | 60 | 70 | 85 | 100 | 59 | No cumple |
| Punto de ablandamiento A, B Y °C | 48 | 57 | 45 | 43 | 40.25 | No cumple |
| Indice de penetración (*) | -1.5 | 1.5 | -1.5 | 1.5 | 1.58 | No cumple |
| Ductilidad (25 °C, 5 cm/minuto) | 100 | ----- | 100 | ----- | > 135 | Cumple |
| Punto de inflamación, Copa Cleveland, °C. | 232 | ----- | 232 | ----- | 234 | Cumple |
| Densidad relativa, 25 °C/ 25 °C | 1 | ----- | 1 | ----- | 1.013 | Cumple |
| Viscosidad | | | | | | |

# ANEXOS CORRESPONDIENTES AL CAPÍTULO 4

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

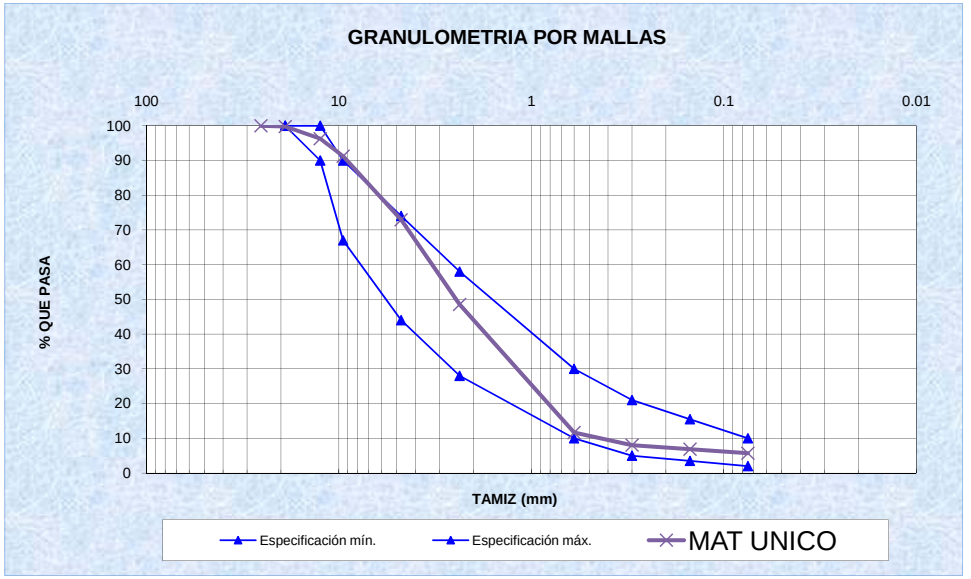
**FECHA:** Marzo, 2010

**ENSAYO:** Granulometria por Tamices

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** ASTM C 136-01

| | | ESPECIF. TAM. MAX 1/2" | | |
|---|---|---|---|---|
| MALLA | ABERTURA (mm) | Máximo | Mínimo | % Pasa |
| 1 | 25.4 | 100 | 100 | 99.9 |
| 3/4 | 19 | 100 | 100 | 99.5 |
| 1/2 | 12.7 | 100 | 90 | 95.7 |
| 3/8 | 9.51 | ---- | ---- | 90.6 |
| N. 4 | 4.76 | 74 | 44 | 72.1 |
| N. 8 | 2.362 | 58 | 28 | 47.1 |
| N. 16 | 1.19 | ---- | ---- | 25.8 |
| N. 30 | 0.595 | ---- | ---- | 10.2 |
| N. 50 | 0.297 | 21 | 5 | 6.6 |
| N. 100 | 0.149 | ---- | ---- | 5.4 |
| N. 200 | 0.074 | 10 | 2 | 4.2 |
| PASA N. 200 | | | | 1.7 |



PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

DIRIGIDO POR: Ing. Gustavo Yánez

## PESOS DE AGREGADO POR TAMIZ PARA ELABORACION DE MUESTRAS

| Tamaño | Masa (gr) |
|---|---|
| 1 | 0.433 |
| 3/4 | 1.875 |
| 1/2 | 19.426 |
| 3/8 | 25.019 |
| N. 4 | 92.852 |
| N. 8 | 124.767 |
| Pasa N. 8 | 235.627 |
| ***TOTAL*** | ***500*** |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

DIRIGIDO POR: Ing. Gustavo Yánez

## CALCULO DE PORCENTAJE ÓPTIMO TEORICO DE ASFALTO EN UNA MEZCLA (Según L.P.C.)

$$S.E. = \frac{1}{100}(0.237 * G + 1.60 * g + 12.85 * A + 117.8F)$$

Donde;

G : % entre la malla 19.05mm y 4.76mm

g : % entre la malla 4.76mm y 0.420mm

A : % entre la malla 0.420mm y 0.074mm

F : % que pasa la malla 0.074mm

| | | | | |
|---|---|---|---|---|
| G = | 8.78 | 0.0878 | M = | 3,75 - 4,25 |
| g = | 18.3 | 0.183 | | |
| A = | 64.89 | 0.6489 | | |
| a = | 2.33 | 0.0233 | | |
| f = | 5.7 | 0.057 | | |

| | | | |
|---|---|---|---|
| ***S =*** | ***9.542*** | ***P (%) =*** | ***6.28*** |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGAC Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO Sebastián Baquero M.
Nashyra Cabrera M.

DIRIGIDO P Ing. Gustavo Yánez

## CALCULO DE PORCENTAJE ÓPTIMO TEORICO DE ASFALTO EN UNA MEZCLA (Según I.A.)

$$\%Asfalto = 0.035 * a + 0.045 * b + k * c + F$$

$a$ = mat. > #8
$b$ = mat. entre #8 – #200
$c$ = mat. < #200
$k$ = 0.15 si "c" esta entre 11 y 15
$k$ = 0.18 si "c" esta entre 6 y 10
$k$ = 0.20 si "c" < 5%
$F$ = entre 0.0 y 2.0 segun su absorcion

| | | |
|---|---|---|
| a= | 51.46 | % |
| b= | 42.84 | % |
| c= | 2.88 | % |
| k= | 0.2 | |
| F= | 1.5 | % |

**% ASFALTO= 5.8049 %**

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGACIÓN: Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados mineralesde alta absorción.

REALIZADO POR: Sebastián Baquero M.
Nashyra Cabrera M.

DIRIGIDO POR: Ing. Gustavo Yánez

## PESOS DE ASFALTO PARA ELABORACIÓN DE MUESTRA PATRÓN

$$\text{Peso Asfalto} = \frac{\text{Peso seco} * \%\,\text{Asfalto}}{100 - \%\,\text{Asfalto}}$$

| % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) |
|---|---|---|---|
| 10.0 | 1 | 561.17 | 62.35 |
| | 2 | 555.93 | 61.77 |
| | 3 | 558.30 | 62.03 |
| 10.5 | 4 | 530.90 | 62.28 |
| | 5 | 562.76 | 66.02 |
| | 6 | 554.80 | 65.09 |
| 11.0 | 7 | 573.24 | 70.85 |
| | 8 | 555.00 | 68.60 |
| | 9 | 557.41 | 68.89 |
| 11.5 | 10 | 556.83 | 72.36 |
| | 11 | 557.40 | 72.43 |
| | 12 | 555.60 | 72.20 |
| 12.0 | 13 | 563.70 | 76.87 |
| | 14 | 559.40 | 76.28 |
| | 15 | 562.72 | 76.73 |
| 13.0 | 16 | 501.60 | 74.95 |
| | 17 | 500.87 | 74.84 |
| | 18 | 501.64 | 74.96 |
| 14.0 | 19 | 502.18 | 81.75 |
| | 20 | 499.3 | 81.28 |
| | 21 | 500.12 | 81.41 |

# ANEXOS CORRESPONDIENTES AL CAPÍTULO 6

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Marzo, 2010

**ENSAYO:** Extracción de porcentaje de Bitumen

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** ASTM D2172

## EXTRA 12 %

| | % DE ASFALTO | MUESTRA # | PESO SECO | PESO ASFALTO | Peso mezcla | Peso Filtro | Peso Filtro | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| EXTRA | 12 | 1 | 498.8 | 68.018 | 558.58 | 28.93 | 29.99 | 497.63 | 10.722 | 10.382 |
| | | 2 | 499.9 | 68.168 | 564.87 | 29.17 | 30.22 | 504.07 | 10.578 | |
| | | 3 | 497.46 | 67.835 | 566.36 | 29.11 | 29.71 | 506.28 | 10.502 | |
| | | 4 | 489.43 | 66.74 | 555 | 28.80 | 29.19 | 496.37 | 10.494 | |
| | | 5 | 498.15 | 67.93 | 565.37 | 28.92 | 29.67 | 505.92 | 10.383 | |
| | | 6 | 502.74 | 68.555 | 567.91 | 28.98 | 29.63 | 508.38 | 10.368 | |
| | | 7 | 500.09 | 68.194 | 568.21 | 28.97 | 29.7 | 509 | 10.292 | |
| | | 8 | 498.72 | 68.007 | 563.68 | 29.25 | 30.19 | 505.18 | 10.211 | |
| | | 9 | 497.24 | 67.805 | 563.7 | 30.15 | 30.1 | 505.93 | 10.257 | |
| | | 10 | 496.02 | 67.639 | 561.54 | 29.07 | 29.39 | 505 | 10.012 | |

## SUPER 12 %

| | % DE ASFALTO | MUESTRA # | PESO SECO | PESO ASFALTO | Peso mezcla | Peso Filtro | Peso Filtro | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| SUPER | 12 | 1 | 503.80 | 5.09 | 570.28 | 30.06 | 30.15 | 508.99 | 10.732 | 10.980 |
| | | 2 | 502.10 | 5.07 | 569.25 | 30.51 | 30.78 | 506.90 | 10.906 | |
| | | 3 | 472.60 | 4.77 | 536.30 | 30.16 | 30.29 | 475.95 | 11.229 | |
| | | 4 | 501.42 | 5.06 | 567.67 | 29.62 | 29.80 | 505.62 | 10.899 | |
| | | 5 | 502.82 | 5.08 | 572.65 | 30.04 | 30.17 | 509.58 | 10.991 | |
| | | 6 | 501.87 | 5.07 | 571.92 | 30.09 | 30.10 | 508.85 | 11.026 | |
| | | 7 | 500.24 | 5.05 | 570.85 | 30.04 | 30.11 | 506.86 | 11.197 | |
| | | 8 | 496.28 | 5.01 | 562.10 | 30.35 | 30.40 | 500.41 | 10.966 | |
| | | 9 | 504.39 | 5.09 | 573.36 | 30.32 | 30.62 | 510.87 | 10.847 | |
| | | 10 | 503.50 | 5.09 | 572.39 | 30.28 | 30.36 | 509.32 | 11.005 | |

## Gasolina de Avión JP1 12 %

| | % DE ASFALTO | MUESTRA # | PESO SECO | PESO ASFALTO | Peso mezcla | Peso Filtro | Peso Filtro | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasolina de Avión JP1 | 12 | 1 | 500.48 | 68.25 | 562.85 | 29.67 | 29.94 | 502.55 | 10.665 | 10.758 |
| | | 2 | 500.31 | 68.22 | 569.26 | 28.90 | 29.00 | 506.10 | 11.078 | |
| | | 3 | 501.64 | 68.41 | 571.16 | 28.54 | 28.64 | 510.43 | 10.615 | |
| | | 4 | 500.65 | 68.27 | 569.31 | 28.67 | 28.70 | 507.46 | 10.859 | |
| | | 5 | 504.12 | 68.74 | 572.86 | 28.91 | 29.16 | 510.15 | 10.904 | |
| | | 6 | 503.95 | 68.72 | 572.84 | 29.00 | 29.23 | 511.15 | 10.729 | |
| | | 7 | 502.25 | 68.49 | 571.24 | 28.60 | 28.72 | 507.93 | 11.062 | |
| | | 8 | 502.01 | 68.46 | 569.84 | 28.86 | 29.20 | 508.09 | 10.777 | |
| | | 9 | 500.87 | 68.30 | 569.44 | 29.00 | 29.10 | 510.05 | 10.412 | |
| | | 10 | 503.87 | 68.71 | 570.54 | 28.82 | 28.89 | 510.69 | 10.478 | |

## Gasolina de Avión AVGAS-130 12 %

| | % DE ASFALTO | MUESTRA # | PESO SECO | PESO ASFALTO | Peso mezcla | Peso Filtro | Peso Filtro | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasolina de Avión avgas-130 | 12 | 1 | 501.61 | 68.40 | 567.76 | 29.00 | 29.34 | 524.84 | 7.500 | 7.573 |
| | | 2 | 499.40 | 68.10 | 568.20 | 28.88 | 29.17 | 525.64 | 7.439 | |
| | | 3 | 500.22 | 68.21 | 565.82 | 29.45 | 29.51 | 521.96 | 7.741 | |
| | | 4 | 498.22 | 67.94 | 564.41 | 29.36 | 29.45 | 519.93 | 7.865 | |
| | | 5 | 500.14 | 68.20 | 569.56 | 29.16 | 29.66 | 525.64 | 7.623 | |
| | | 6 | 497.93 | 67.90 | 566.11 | 29.25 | 29.98 | 524.68 | 7.189 | |
| | | 7 | 498.13 | 67.93 | 568.54 | 29.36 | 29.89 | 523.14 | 7.892 | |
| | | 8 | 498.33 | 67.95 | 566.77 | 29.20 | 29.32 | 524.94 | 7.359 | |
| | | 9 | 498.62 | 67.99 | 567.59 | 29.15 | 29.24 | 522.46 | 7.935 | |
| | | 10 | 496.89 | 67.76 | 563.27 | 28.99 | 29.14 | 522.65 | 7.185 | |

## TRICLOROETILENO 12 %

| | % DE ASFALTO | MUESTRA # | PESO SECO | PESO ASFALTO | Peso mezcla | Peso Filtro | Peso Filtro | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| Tricloroetileno | 12 | 1 | 502.20 | 0.00 | 569.23 | 29.84 | 30.95 | 505.00 | 11.089 | 10.985 |
| | | 2 | 505.26 | 0.00 | 572.80 | 29.97 | 30.74 | 509.35 | 10.943 | |
| | | 3 | 473.65 | 0.00 | 539.33 | 29.55 | 30.33 | 480.14 | 10.830 | |
| | | 4 | 511.95 | 0.00 | 579.98 | 29.84 | 30.79 | 514.65 | 11.100 | |
| | | 5 | 502.95 | 0.00 | 573.07 | 29.46 | 30.44 | 508.66 | 11.068 | |
| | | 6 | 503.30 | 0.00 | 572.13 | 29.83 | 30.37 | 507.89 | 11.134 | |
| | | 7 | 504.70 | 0.00 | 573.11 | 29.34 | 30.12 | 509.25 | 11.007 | |
| | | 8 | 501.67 | 0.00 | 570.78 | 29.33 | 30.14 | 507.80 | 10.892 | |
| | | 9 | 509.60 | 0.00 | 579.33 | 29.21 | 30.11 | 515.68 | 10.831 | |
| | | 10 | 506.93 | 0.00 | 575.57 | 29.42 | 30.11 | 511.82 | 10.956 | |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Marzo, 2010

**ENSAYO:** Extracción de porcentaje de Bitumen

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** ASTM D2172

EXTRA 13 %

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso mezcla | Peso Filtro inicial | Peso Filtro final | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| EXTRA | 13 | 1 | 500.50 | 0.00 | 572.09 | 29.19 | 506.54 | 29.29 | 11.441 | 11.259 |
| | | 2 | 499.37 | 0.00 | 566.37 | 29.22 | 501.07 | 29.76 | 11.434 | |
| | | 3 | 503.30 | 0.00 | 580.26 | 29.06 | 512.20 | 29.54 | 11.647 | |
| | | 4 | 500.81 | 0.00 | 570.75 | 28.57 | 504.97 | 29.07 | 11.438 | |
| | | 5 | 500.99 | 0.00 | 570.82 | 28.67 | 505.16 | 28.83 | 11.475 | |
| | | 6 | 499.87 | 0.00 | 576.41 | 29.10 | 512.20 | 29.53 | 11.065 | |
| | | 7 | 499.30 | 0.00 | 574.51 | 29.34 | 511.88 | 29.45 | 10.882 | |
| | | 8 | 499.15 | 0.00 | 572.82 | 29.27 | 509.65 | 29.75 | 10.944 | |
| | | 9 | 500.00 | 0.00 | 573.98 | 29.35 | 508.48 | 29.51 | 11.384 | |
| | | 10 | 497.30 | 0.00 | 573.80 | 29.18 | 511.18 | 29.39 | 10.877 | |

SUPER 13 %

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso mezcla | Peso Filtro inicial | Peso Filtro final | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| SUPER | 13 | 1 | 502.83 | 10.26 | 583.98 | 30.74 | 512.78 | 30.99 | 12.149 | **11.930** |
| | | 2 | 500.21 | 10.21 | 571.61 | 29.86 | 503.20 | 30.06 | 11.933 | |
| | | 3 | 502.68 | 10.26 | 575.93 | 30.25 | 506.56 | 30.31 | 12.034 | |
| | | 4 | 500.71 | 10.22 | 574.42 | 30.18 | 506.74 | 30.19 | 11.781 | |
| | | 5 | 500.37 | 10.21 | 576.72 | 30.15 | 507.88 | 30.00 | 11.962 | |
| | | 6 | 499.50 | 10.19 | 573.85 | 29.65 | 505.50 | 29.72 | 11.899 | |
| | | 7 | 500.36 | 10.21 | 574.53 | 30.39 | 505.78 | 30.71 | 11.911 | |
| | | 8 | 501.60 | 10.24 | 572.48 | 30.77 | 504.90 | 30.94 | 11.775 | |
| | | 9 | 503.30 | 10.27 | 579.20 | 29.66 | 510.07 | 29.72 | 11.925 | |
| | | 10 | 500.30 | 10.21 | 575.25 | 30.55 | 506.65 | 30.53 | 11.929 | |

Gasolina de Avión JP1 13 %

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso mezcla | Peso Filtro inicial | Peso Filtro final | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasolina de avión JP1 | 13 | 1 | 501.50 | 74.94 | 574.55 | 29.53 | 506.96 | 29.70 | 11.734 | **11.884** |
| | | 2 | 502.40 | 75.07 | 577.90 | 29.37 | 509.19 | 29.89 | 11.800 | |
| | | 3 | 506.24 | 75.65 | 581.83 | 29.13 | 512.85 | 29.48 | 11.796 | |
| | | 4 | 498.30 | 74.46 | 573.22 | 29.28 | 504.70 | 29.44 | 11.926 | |
| | | 5 | 503.50 | 75.24 | 576.20 | 29.34 | 507.00 | 30.06 | 11.885 | |
| | | 6 | 497.50 | 74.34 | 573.72 | 29.34 | 504.11 | 29.86 | 12.042 | |
| | | 7 | 500.69 | 74.82 | 569.43 | 29.33 | 500.93 | 29.99 | 11.914 | |
| | | 8 | 503.46 | 75.23 | 578.72 | 29.31 | 509.87 | 30.10 | 11.760 | |
| | | 9 | 499.60 | 74.65 | 573.72 | 29.27 | 504.43 | 30.14 | 11.926 | |
| | | 10 | 503.46 | 75.23 | 580.63 | 29.04 | 509.73 | 29.95 | 12.054 | |

Gasolina de Avión AVGAS 13 %

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso mezcla | Peso Filtro inicial | Peso Filtro final | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| Gasolina de avión AVGAS- 130 | 13 | 1 | 500.58 | 74.80 | 572.53 | 29.34 | 525.10 | 29.63 | 8.234 | 8.651 |
| | | 2 | 500.14 | 74.73 | 572.37 | 29.41 | 521.18 | 29.73 | 8.888 | |
| | | 3 | 500.10 | 74.73 | 576.08 | 29.32 | 526.49 | 29.42 | 8.591 | |
| | | 4 | 501.15 | 74.88 | 574.34 | 29.25 | 524.33 | 29.47 | 8.669 | |
| | | 5 | 499.30 | 74.61 | 575.25 | 29.53 | 525.00 | 29.57 | 8.728 | |
| | | 6 | 496.38 | 74.17 | 571.78 | 29.19 | 523.32 | 29.34 | 8.449 | |
| | | 7 | 504.00 | 75.31 | 577.58 | 29.38 | 526.08 | 29.82 | 8.840 | |
| | | 8 | 499.82 | 74.69 | 573.02 | 29.26 | 521.85 | 29.35 | 8.914 | |
| | | 9 | 500.77 | 74.83 | 579.16 | 29.46 | 529.55 | 29.48 | 8.562 | |
| | | 10 | 497.83 | 74.39 | 573.76 | 29.08 | 524.00 | 29.29 | 8.636 | |

Tricloroetileno 13 %

| | % DE ASFALTO | MUESTRA # | PESO SECO (gr) | PESO ASFALTO (gr) | Peso mezcla | Peso Filtro inicial | Peso Filtro final | Peso Mez. Fin | % de Bitumen | PROMEDIO |
|---|---|---|---|---|---|---|---|---|---|---|
| Tricloroetileno | 13 | 1 | 504.16 | 10.29 | 577.16 | 28.28 | 508.10 | 28.76 | 11.882 | 11.768 |
| | | 2 | 506.70 | 10.34 | 581.09 | 28.44 | 510.95 | 29.33 | 11.917 | |
| | | 3 | 505.38 | 10.31 | 582.41 | 28.30 | 512.94 | 28.82 | 11.839 | |
| | | 4 | 501.56 | 10.24 | 575.91 | 28.36 | 508.00 | 29.31 | 11.627 | |
| | | 5 | 505.56 | 10.32 | 579.40 | 29.66 | 511.26 | 29.92 | 11.716 | |
| | | 6 | 502.52 | 10.26 | 577.88 | 29.57 | 507.87 | 30.16 | 12.013 | |
| | | 7 | 503.10 | 10.27 | 578.66 | 29.45 | 510.15 | 29.81 | 11.777 | |
| | | 8 | 505.15 | 10.31 | 581.61 | 29.55 | 513.78 | 30.01 | 11.583 | |
| | | 9 | 502.47 | 10.25 | 576.50 | 29.68 | 509.05 | 29.90 | 11.662 | |
| | | 10 | 501.70 | 10.24 | 579.33 | 29.79 | 511.48 | 30.05 | 11.667 | |

# ANEXOS CORRESPONDIENTES AL CAPÍTULO 7

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Marzo, 2010

**ENSAYO:** Extracción de porcentaje de Bitumen

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** ASTM D2172

## CUADRO DE PROMEDIOS

| Porcentaje de Asfalto | Gasolina Extra (%) | Gasolina Super (%) | Gasolina Avion JP1 (%) | Gasolina AVGAS-130 (%) | Tricloroetileno (%) |
|---|---|---|---|---|---|
| 12% | 10.382 | 10.980 | 10.758 | 7.573 | 10.985 |
| 13% | 11.259 | 11.930 | 11.884 | 8.651 | 11.768 |

## PORCENTAJE DE VARIACIÓN

| PORCENTAJE DE VARIACIÓN | | | | |
|---|---|---|---|---|
| % de Asfalto | Gaso. Extra | Gaso. Super | Gaso. JP1 | Gaso. AVGAS- |
| 12% | 5.81 | 0.05 | 2.11 | 45.05 |
| 13% | 4.52 | -1.36 | -0.98 | 36.03 |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

INVESTIGAC Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

REALIZADO Sebastián Baquero M.
Nashyra Cabrera M.

FECHA: Marzo, 2010

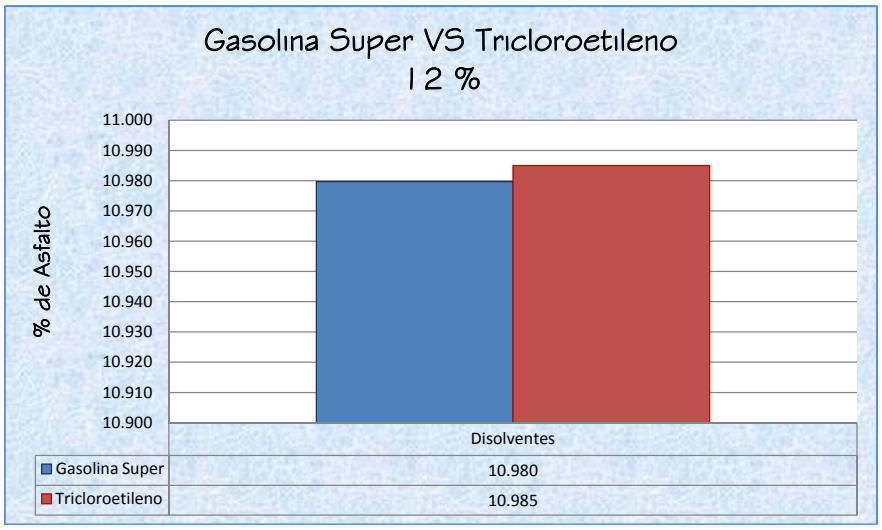
ENSAYO: Extracción de porcentaje de Bitumen

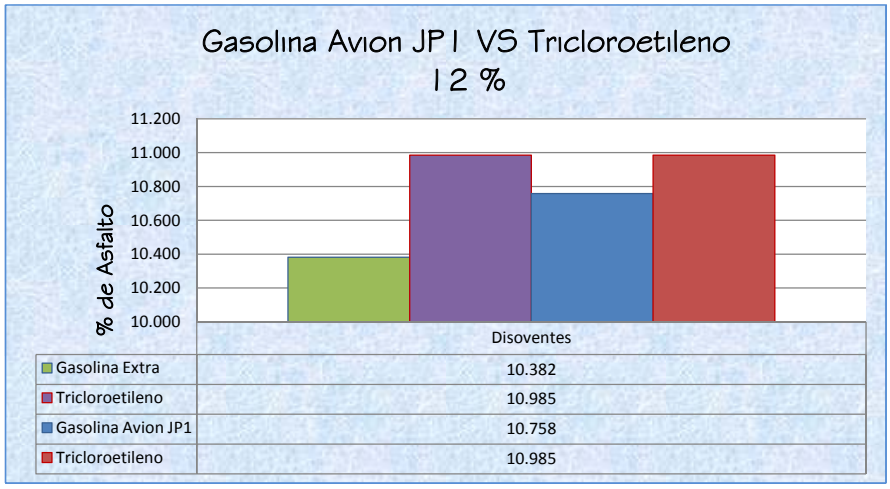
DIRIGIDO P Ing. Gustavo Yánez

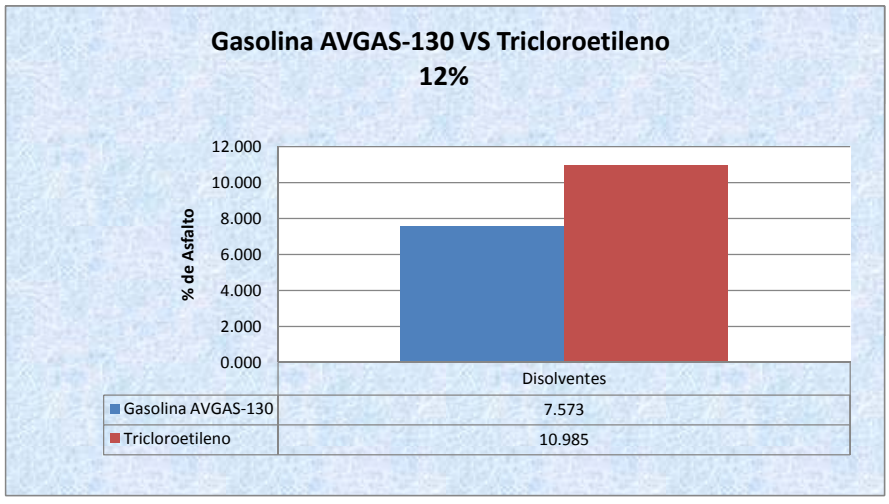
## Comparación de porcentajes de extracción de bitumen Vs Porcentaje Real

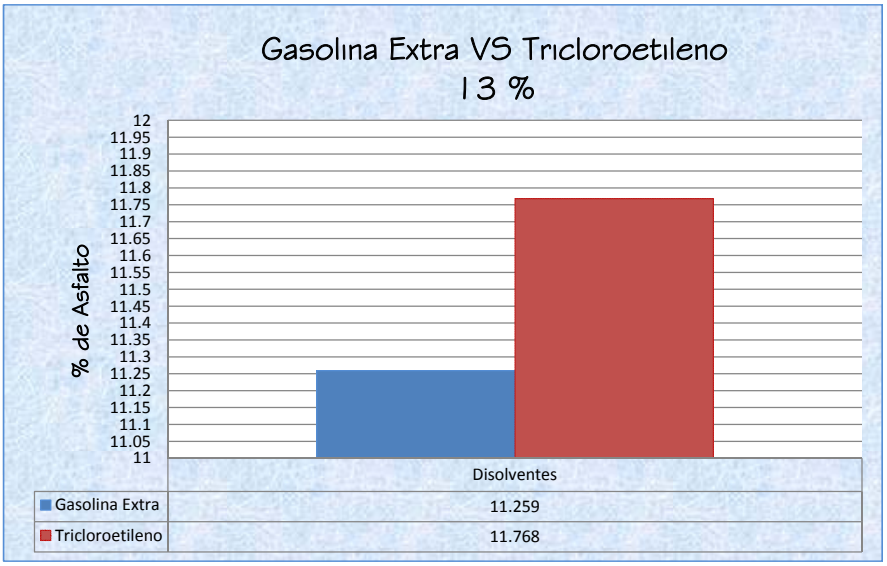
| | | DISOLVENTES | | | | |
|---|---|---|---|---|---|---|
| | | EXTRA | SUPER | JP-1 | AVGas-130 | Tricloroetileno |
| PORCENTAJES | REAL | 12% | | | | |
| | EXTRAIDO | 10,382 | 10,980 | 10,758 | 7,573 | 10,985 |
| | INDICE EXT. | 0,8652 | 0,9150 | 0,8965 | 0,6311 | 0,9154 |

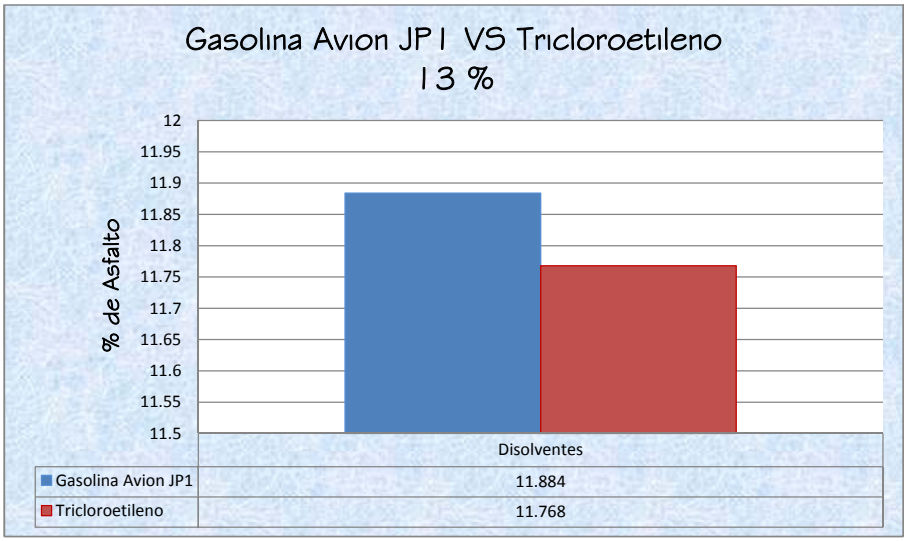
| | | DISOLVENTES | | | | |
|---|---|---|---|---|---|---|
| | | EXTRA | SUPER | JP-1 | AVGas-130 | Tricloroetileno |
| PORCENTAJES | REAL | 13% | | | | |
| | EXTRAIDO | 11,259 | 11,930 | 11,884 | 8,651 | 11,768 |
| | INDICE EXT. | 0,8661 | 0,9177 | 0,9142 | 0,6655 | 0,9052 |

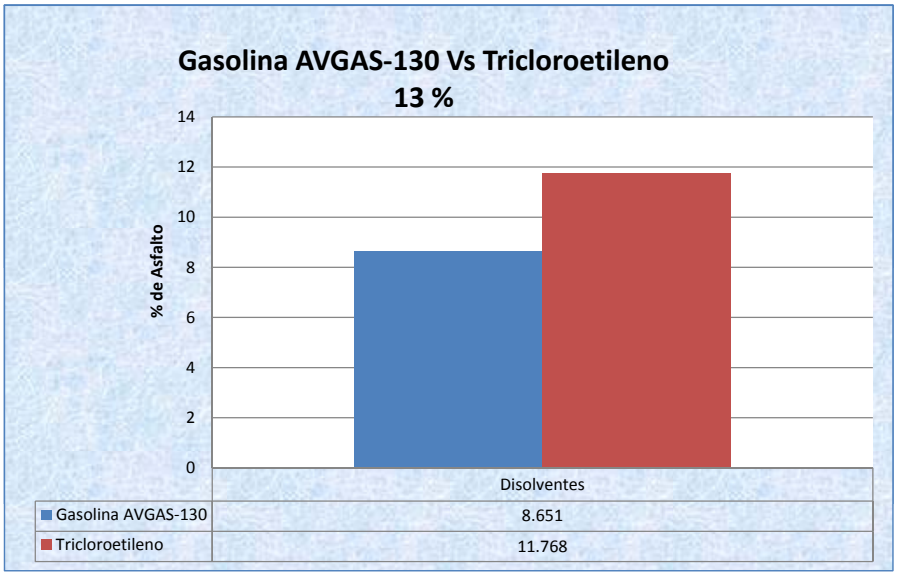

Gasolina Super VS Tricloroetileno
12 %
% de Asfalto
11.000
10.990
10.980
10.970
10.960
10.950
10.940
10.930
10.920
10.910
10.900
Disolventes
Gasolina Super
10.980
Tricloroetileno
10.985


Gasolina Avion JP1 VS Tricloroetileno
12 %
% de Asfalto
11.200
11.000
10.800
10.600
10.400
10.200
10.000
Disoventes
Gasolina Extra
10.382
Tricloroetileno
10.985
Gasolina Avion JP1
10.758
Tricloroetileno
10.985


Gasolina AVGAS-130 VS Tricloroetileno
12%
% de Asfalto
12.000
10.000
8.000
6.000
4.000
2.000
0.000
Disolventes
Gasolina AVGAS-130
7.573
Tricloroetileno
10.985


Gasolina Extra VS Tricloroetileno
13 %
% de Asfalto
12
11.95
11.9
11.85
11.8
11.75
11.7
11.65
11.6
11.55
11.5
11.45
11.4
11.35
11.3
11.25
11.2
11.15
11.1
11.05
11
Disolventes
Gasolina Extra
11.259
Tricloroetileno
11.768


Gasolina Avion JP1 VS Tricloroetileno
13 %
% de Asfalto
12
11.95
11.9
11.85
11.8
11.75
11.7
11.65
11.6
11.55
11.5
Disolventes
Gasolina Avion JP1
11.884
Tricloroetileno
11.768


Gasolina AVGAS-130 Vs Tricloroetileno
13 %
% de Asfalto
14
12
10
8
6
4
2
0
Disolventes
Gasolina AVGAS-130
8.651
Tricloroetileno
11.768

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
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**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Junio, 2010

**ENSAYO:** Desviación Estandar

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** 2172 (30.3)

*Se obtiene la media aritmética o promedio*

*del total de muestras ensayadas usando la siguiente expresión:*

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$$

En donde;

$\bar{X} = media\ aritmética\ o\ promedio.$

$X_i = valor\ de\ muestra\ específica.$

$N = número\ de\ datos\ o\ de\ muestras\ ensayadas.$

*Una vez obtenido el promedio, éste nos sirve para calcular*

*la desviacion estandar* $(\sigma)$ *dada por:*

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})^2}$$

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**ESPECIFICACIÓN:** 2172 (30.3)

Se realizan los ensayos de Extraccion Cuantitativa de Bitumen de las mezclas asfálticas en caliente para la investigación y se obtiene resultados para aquellas muestras que contenían un ***13%*** de asfalto. Estos resultados han sido utilizados para realizar la evaluación estadística de los mismos, con la ayuda de herramientas de cáculo (EXCEL) y usando las anteriores expresiones se ha determinado las desviaciones estandar para cada Disolvente analizado en esta investigación.

| | % DE ASFALTO | MUESTRA # | % de Bitumen | PROMEDIO % DE BITUMEN | (Xi - Xmed) | (Xi - Xmed)² | σ |
|---|---|---|---|---|---|---|---|
| EXTRA | 12.0 | 1 | 11.441 | 11.259 | 0.18198 | 0.03312 | 0.285 |
| | | 2 | 11.434 | | 0.17569 | 0.03087 | |
| | | 3 | 11.647 | | 0.38798 | 0.15053 | |
| | | 4 | 11.438 | | 0.17905 | 0.03206 | |
| | | 5 | 11.475 | | 0.21619 | 0.04674 | |
| | | 6 | 11.065 | | -0.19349 | 0.03744 | |
| | | 7 | 10.882 | | -0.37621 | 0.14153 | |
| | | 8 | 10.944 | | -0.31443 | 0.09886 | |
| | | 9 | 11.384 | | 0.12514 | 0.01566 | |
| | | 10 | 10.877 | | -0.38192 | 0.14586 | |
| SUPER | 12.0 | 11 | 12.149 | 11.930 | 0.21960 | 0.04822 | 0.109 |
| | | 12 | 11.933 | | 0.00317 | 0.00001 | |
| | | 13 | 12.034 | | 0.10466 | 0.01095 | |
| | | 14 | 11.781 | | -0.14921 | 0.02226 | |
| | | 15 | 11.962 | | 0.03269 | 0.00107 | |
| | | 16 | 11.899 | | -0.03121 | 0.00097 | |
| | | 17 | 11.911 | | -0.01919 | 0.00037 | |
| | | 18 | 11.775 | | -0.15471 | 0.02393 | |
| | | 19 | 11.925 | | -0.00472 | 0.00002 | |
| | | 20 | 11.929 | | -0.00107 | 0.00000 | |
| G. AVION 1 | 12.0 | 21 | 11.734 | 11.884 | -0.14923 | 0.02227 | 0.111 |
| | | 22 | 11.800 | | -0.08401 | 0.00706 | |
| | | 23 | 11.796 | | -0.08809 | 0.00776 | |
| | | 24 | 11.926 | | 0.04198 | 0.00176 | |
| | | 25 | 11.885 | | 0.00113 | 0.00000 | |
| | | 26 | 12.042 | | 0.15883 | 0.02523 | |
| | | 27 | 11.914 | | 0.03004 | 0.00090 | |
| | | 28 | 11.760 | | -0.12320 | 0.01518 | |
| | | 29 | 11.926 | | 0.04205 | 0.00177 | |
| | | 30 | 12.054 | | 0.17052 | 0.02908 | |
| G. AVION 2 | 12.0 | 31 | 8.234 | 8.651 | -0.41752 | 0.17432 | 0.209 |
| | | 32 | 8.888 | | 0.23646 | 0.05591 | |
| | | 33 | 8.591 | | -0.06033 | 0.00364 | |
| | | 34 | 8.669 | | 0.01793 | 0.00032 | |
| | | 35 | 8.728 | | 0.07723 | 0.00596 | |
| | | 36 | 8.449 | | -0.20210 | 0.04084 | |
| | | 37 | 8.840 | | 0.18918 | 0.03579 | |
| | | 38 | 8.914 | | 0.26302 | 0.06918 | |
| | | 39 | 8.562 | | -0.08875 | 0.00788 | |
| | | 40 | 8.636 | | -0.01513 | 0.00023 | |
| TRICLORO ETILENO | 12.0 | 41 | 11.882 | 11.768 | 0.11404 | 0.01300 | 0.141 |
| | | 42 | 11.917 | | 0.14898 | 0.02219 | |
| | | 43 | 11.839 | | 0.07046 | 0.00496 | |
| | | 44 | 11.627 | | -0.14147 | 0.02001 | |
| | | 45 | 11.716 | | -0.05271 | 0.00278 | |
| | | 46 | 12.013 | | 0.24459 | 0.05983 | |
| | | 47 | 11.777 | | 0.00893 | 0.00008 | |
| | | 48 | 11.583 | | -0.18492 | 0.03420 | |
| | | 49 | 11.662 | | -0.10653 | 0.01135 | |
| | | 50 | 11.667 | | -0.10136 | 0.01027 | |

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**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Junio, 2010

**ENSAYO:** Desviación Estandar

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** 2172 (30.3)

Se realizan los ensayos de Extraccion Cuantitativa de Bitumen de las mezclas asfálticas en caliente para la investigación y se obtiene resultados para aquellas muestras que contenían un ***12%*** de asfalto. Estos resultados han sido utilizados para realizar la evaluación estadística de los mismos, con la ayuda de herramientas de cáculo (EXCEL) y usando las anteriores expresiones se ha determinado las desviaciones estandar para cada Disolvente analizado en esta investigación.

| | % DE ASFALTO | MUESTRA # | % de Bitumen | PROMEDIO % DE BITUMEN | (Xi - Xmed) | (Xi - Xmed)² | σ |
|---|---|---|---|---|---|---|---|
| EXTRA | 12.0 | 1 | 10.722 | 10.382 | 0.3400 | 0.1156 | 0.203 |
| | | 2 | 10.578 | | 0.1958 | 0.0384 | |
| | | 3 | 10.502 | | 0.1203 | 0.0145 | |
| | | 4 | 10.494 | | 0.1119 | 0.0125 | |
| | | 5 | 10.383 | | 0.0008 | 0.0000 | |
| | | 6 | 10.368 | | -0.0140 | 0.0002 | |
| | | 7 | 10.292 | | -0.0898 | 0.0081 | |
| | | 8 | 10.211 | | -0.1703 | 0.0290 | |
| | | 9 | 10.257 | | -0.1246 | 0.0155 | |
| | | 10 | 10.012 | | -0.3701 | 0.1369 | |
| SUPER | 12.0 | 11 | 10.732 | 10.980 | -0.2481 | 0.0615 | 0.150 |
| | | 12 | 10.906 | | -0.0741 | 0.0055 | |
| | | 13 | 11.229 | | 0.2491 | 0.0621 | |
| | | 14 | 10.899 | | -0.0807 | 0.0065 | |
| | | 15 | 10.991 | | 0.0113 | 0.0001 | |
| | | 16 | 11.026 | | 0.0464 | 0.0021 | |
| | | 17 | 11.197 | | 0.2177 | 0.0474 | |
| | | 18 | 10.966 | | -0.0136 | 0.0002 | |
| | | 19 | 10.847 | | -0.1331 | 0.0177 | |
| | | 20 | 11.005 | | 0.0251 | 0.0006 | |
| G. AVION 1 | 12.0 | 21 | 10.665 | 10.758 | -0.0924 | 0.0085 | 0.225 |
| | | 22 | 11.078 | | 0.3197 | 0.1022 | |
| | | 23 | 10.615 | | -0.1426 | 0.0203 | |
| | | 24 | 10.859 | | 0.1010 | 0.0102 | |
| | | 25 | 10.904 | | 0.1459 | 0.0213 | |
| | | 26 | 10.729 | | -0.0288 | 0.0008 | |
| | | 27 | 11.062 | | 0.3041 | 0.0925 | |
| | | 28 | 10.777 | | 0.0189 | 0.0004 | |
| | | 29 | 10.412 | | -0.3458 | 0.1196 | |
| | | 30 | 10.478 | | -0.2800 | 0.0784 | |
| G. AVION 2 | 12.0 | 31 | 7.500 | 7.573 | -0.0733 | 0.0054 | 0.282 |
| | | 32 | 7.439 | | -0.1336 | 0.0179 | |
| | | 33 | 7.741 | | 0.1681 | 0.0282 | |
| | | 34 | 7.865 | | 0.2919 | 0.0852 | |
| | | 35 | 7.623 | | 0.0505 | 0.0026 | |
| | | 36 | 7.189 | | -0.3835 | 0.1471 | |
| | | 37 | 7.892 | | 0.3192 | 0.1019 | |
| | | 38 | 7.359 | | -0.2137 | 0.0457 | |
| | | 39 | 7.935 | | 0.3624 | 0.1313 | |
| | | 40 | 7.185 | | -0.3881 | 0.1506 | |
| TRICLORO ETILENO | 12.0 | 41 | 11.089 | 10.985 | 0.1036 | 0.0107 | 0.112 |
| | | 42 | 10.943 | | -0.0423 | 0.0018 | |
| | | 43 | 10.830 | | -0.1549 | 0.0240 | |
| | | 44 | 11.100 | | 0.1153 | 0.0133 | |
| | | 45 | 11.068 | | 0.0834 | 0.0070 | |
| | | 46 | 11.134 | | 0.1488 | 0.0221 | |
| | | 47 | 11.007 | | 0.0216 | 0.0005 | |
| | | 48 | 10.892 | | -0.0929 | 0.0086 | |
| | | 49 | 10.831 | | -0.1536 | 0.0236 | |
| | | 50 | 10.956 | | -0.0290 | 0.0008 | |

PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR
FACULTAD DE INGENIERIA

**INVESTIGACIÓN:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfalticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**FECHA:** Junio, 2010

**DIRIGIDO POR:** Ing. Gustavo Yánez

*TABLA DE COSTOS: DISOLVENTES COMERCIALES*

| | | COSTO (USD)/gal. | TOXICIDAD | DISPONIB. | INFLAMABLE |
|---|---|---|---|---|---|
| DISOLVENTES | SUPER | 2.00 | 3 | 3 | 3 |
| | EXTRA | 1.50 | 3 | 3 | 3 |
| | JP - 1 | 2.39 | 3 | 2 | 2 |
| | AVGas - 130 | 7.00 | 3 | 2 | 4 |
| | Tricloroetileno** | 2.56 | 4 | 1 | 2 |

** El costo del Tricloroetileno se lo considera en USD/kg consumido

| | LEYENDA | |
|---|---|---|
| TOXICIDAD | 1 | Nada Tóxico |
| | 2 | Poco Tóxico |
| | 3 | Medianamente Tóxico |
| | 4 | Muy Tóxico |
| DISPONIBILIDAD | 1 | Baja Disponibilidad |
| | 2 | Mediana Disponibilidad |
| | 3 | Alta Disponibilidad |
| INFLAMABLE | 1 | No Inflamable |
| | 2 | Poco Inflamable |
| | 3 | Medianamente Inflamable |
| | 4 | Muy Inflamable |

# ANEXOS
# MOP TOMO II

PONTIFICIA UNIVERSIDAD CATÓLICA DEL ECUADOR
FACULTAD DE INGENIERIA
ESCUELA CIVIL

**INVESTIGACION:** Utilización de disolventes comerciales como alternativa al uso del Tricloroetileno en la extracción de porcentaje de bitumen en mezclas asfálticas con agregados minerales de alta absorción.

**REALIZADO POR:** Sebastián Baquero M.
Nashyra Cabrera M.

**DIRIGIDO POR:** Ing. Gustavo Yánez

**ESPECIFICACIÓN:** MOP-TOMO II (811-2)

## 811-2. Agregados para Mezcla en Planta.

**811-2.01. Descripción.-** Son agregados que se utilizan para la fabricación de hormigón asfáltico empleando una planta de asfaltos o equipo semejante para su mezcla con el asfalto.

**811-2.02. Requisitos.-** Los agregados estarán compuestos de partículas de piedra triturada, grava triturada, grava o piedra natural, arena, etc., de tal manera que cumplan los requisitos de graduación que se establecen en la Tabla 404-5.1 ó 405-5.1 de estas especificaciones según corresponda, y se clasifican en "A", "B" y "C", de acuerdo a lo establecido a continuación:

a) Agregados tipo A: Son aquellos en los cuales todas las partículas que forman el agregado grueso se obtienen por trituración. El agregado fino puede ser arena natural o material triturado y, de requerirse, se puede añadir relleno mineral para cumplir las exigencias de graduación antes mencionadas. Este relleno mineral puede ser inclusive cemento Portland, si así se establece para la obra.

b) Agregados tipo B: Son aquellos en los cuales por lo menos el 50% de las partículas que forman el agregado grueso se obtienen por trituración. El 800 – Materiales VIII-84 agregado fino y el relleno mineral pueden ser triturados o provenientes de depósitos naturales, según la disponibilidad de dichos materiales en la zona del proyecto.

c) Agregados tipo C: Los agregados tipo C para hormigón asfáltico son aquellos provenientes de depósitos naturales o de trituración, según las disponibilidades propias de la región, siempre que se haya verificado que la estabilidad, medida en

el ensayo de Marshall, se encuentre dentro de los límites fijados en la Tabla 405-5.2 de estas especificaciones.

Los agregados serán fragmentos limpios, resistentes y duros, libres de materia vegetal y de exceso de partículas planas, alargadas, blandas o desintegrables, así como de material mineral cubierto de arcilla u otro material inconveniente. Se utilizarán agregados completamente secos y de no poder cumplirse ésto, se instalarán dos secadores en serie, de tal forma que cuando se termine la operación de mezclado, la humedad de los agregados no exceda de 1%.

Además de los requisitos granulométricos y los referentes a su producción, que se indicaron anteriormente, los agregados deben cumplir con las siguientes exigencias:

Los agregados gruesos no deberán tener un desgaste mayor de 40% luego de 500 revoluciones de la máquina de Los Ángeles, cuando sean ensayados a la abrasión, según la norma INEN 860.

La porción de los agregados que pasa el tamiz INEN 0.425 mm. (Nº 40), deberá tener un índice de plasticidad menor a 4, según lo establecido en las Normas INEN 691 y 692.

El agregado no debe experimentar desintegración ni pérdida total mayor del 12%, cuando se lo someta a 5 ciclos de inmersión y lavado con sulfato de sodio, en la prueba de durabilidad, como lo dispone la Norma INEN 863, salvo que las especificaciones especiales indiquen otra cosa.

Los agregados serán de características tales que, al ser impregnados con material bituminoso, más de un 95% de este material bituminoso permanezca impregnando las partículas, después de realizado el ensayo de resistencia a la peladura, según la Norma AASHTO T 182.

El relleno mineral deberá cumplir con los requisitos especificados en la Norma AASHTO M 17.

### 811.2.02 Requisitos

Los agregados gruesos retenidos en el tamiz INEN 4.75 mm. Deben tener cierta angularidad. El 85% de agregado grueso deberá tener por lo menos una cara 800 – Materiales VIII-85 fracturada y el 80% del agregado grueso deberá tener por lo menos dos caras fracturadas, según la Norma ASTM D5821.

La angularidad de los agregados finos es determinada como el porcentaje de vacíos de aire presente en los agregados pasantes el tamiz INEN 2.36 mm. El valor mínimo requerido es de 45% según la Norma ASTM C1252.

El equivalente de arena se realiza en los agregados pasantes el tamiz INEN 4.75 mm. Norma AASHTO T 176 ( ASTM D2419 ). Los valores mínimos recomendados son los siguientes:

| | Equivalente de Arena | |
|---|---|---|
| | Tráfico Liviano y Mediano | Tráfico Pesado |
| Base | 35 | 40 |
| Capa de Rodadura | 45 | 50 |

El máximo porcentaje en peso de partículas alargadas y achatadas retenidas en el tamiz INEN 4.75mm cuya relación entre las dimensiones máximas y mínimas mayor que 5, no deberá ser mayor de un 10% según la Norma ASTM D4791.
El máximo porcentaje de materiales deletéreos en los agregados es de 1% en peso según la Norma ASTM C142.

**811-2.03. Ensayos y Tolerancias.-** Los ensayos de control y verificación que se deben realizar para aceptar o rechazar un agregado, seguirán lo indicado en las normas mencionadas en los diferentes párrafos del numeral anterior. Las exigencias de graduación serán comprobadas mediante ensayos granulométricos, según lo establecido en las Normas INEN 696 y 697.

El peso específico de los agregados se determinará de acuerdo al método de ensayo INEN 856 y 857, según corresponda, y el peso unitario de los agregados se determinará de acuerdo a la Norma INEN 854.

# ANEXOS

# Manual Visualizado de Laboratorio de Pavimentos

*PONTIFICIA UNIVERSIDAD CATOLICA DEL ECUADOR*

*FACULTAD DE INGENIERIA*

***INVESTIGACIÓN:*** "Utilización de disolventes comerciales como alternativa del Tricloroetileno en la Extracción de Porcentaje de Bitumen en mezclas Asfálticas con agregado mineral de alta absorción."

***REALIZADO POR:*** Sebastián Baquero M.
Nashyra Cabrera M.

***FECHA:*** Junio, 2010

***FUENTE:*** Manual Visualizado de Laboratorio de Pavimentos

***DIRIGIDO POR:*** Ing. Gustavo Yánez

## CORRECCION DE LOS VALORES DE ESTABILIDAD (TABLA Anexo1)

| VOLUMEN DE LA BRIQUETA EN CM3 | ESPESOR APROXIMADO DE LA BRIQUETA EN CM | FACTOR DE CORRECCION |
|---|---|---|
| 302 – 316 | 3.81 | 2.78 |
| 317 – 328 | 3.97 | 2.50 |
| 329 – 340 | 4.13 | 2.27 |
| 341 – 353 | 4.29 | 2.08 |
| 354 – 367 | 4.44 | 1.92 |
| 368 – 379 | 4.60 | 1.79 |
| 380 – 392 | 4.76 | 1.67 |
| 393 – 405 | 4.92 | 1.56 |
| 406 – 420 | 5.08 | 1.47 |
| 421 – 431 | 5.24 | 1.39 |
| 432 – 443 | 5.40 | 1.32 |
| 444 – 456 | 5.56 | 1.25 |
| 457 – 470 | 5.71 | 1.19 |
| 471 – 482 | 5.87 | 1.14 |
| 483 – 495 | 6.03 | 1.09 |
| 496 – 508 | 6.19 | 1.04 |
| 509 – 522 | 6.35 | 1.00 |
| 523 – 535 | 6.51 | 0.96 |
| 536 – 546 | 6.67 | 0.93 |
| 547 – 559 | 6.82 | 0.89 |
| 560 – 573 | 6.96 | 0.86 |
| 574 – 585 | 7.14 | 0.83 |
| 586 – 598 | 7.30 | 0.81 |
| 599 – 610 | 7.46 | 0.78 |
| 611 – 625 | 7.62 | 0.76 |

# ANEXOS

# NORMAS ASTM

**Designation: C 127 – 01**

# Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate[1]

This standard is issued under the fixed designation C 127; 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 covers the determination of the average density of a quantity of coarse aggregate particles (not including the volume of voids between the particles), the relative density (specific gravity), and the absorption of the coarse aggregate. Depending on the procedure used, the density ($kg/m^3$($lb/ft^3$)) is expressed as oven-dry (OD), saturated-surface-dry (SSD), or as apparent density. Likewise, relative density (specific gravity), a dimensionless quantity, is expressed as OD, SSD, or as apparent relative density (apparent specific gravity). The OD density and OD relative density are determined after drying the aggregate. The SSD density, SSD relative density, and absorption are determined after soaking the aggregate in water for a prescribed duration.

1.2 This test method is used to determine the density of the essentially solid portion of a large number of aggregate particles and provides an average value representing the sample. Distinction is made between the density of aggregate particles as determined by this test method, and the bulk density of aggregates as determined by Test Method C 29/C 29M, which includes the volume of voids between the particles of aggregates.

1.3 This test method is not intended to be used with lightweight aggregates.

1.4 The values stated in SI units are to be regarded as the standard for conducting the tests. The test results for density shall be reported in either SI units or inch-pound units, as appropriate for the use to be made of the results.

1.5 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

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:*

C 29/C 29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 128 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate[2]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]

C 566 Test Method for Total Evaporable Moisture Content of Aggregate by Drying[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 448 Classification for Sizes of Aggregate for Road and Bridge Construction[3]

E 11 Specification for Wire Cloth and Sieves for Testing Purposes[4]

2.2 *AASHTO Standard:*

AASHTO No. T 85 Specific Gravity and Absorption of Coarse Aggregate[5]

## 3. Terminology

3.1 *Definitions:*

3.1.1 *absorption, n*—the increase in mass of aggregate due to water penetration into the pores of the particles during a prescribed period of time, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass.

3.1.2 *oven-dry (OD), adj—related to aggregate particles,* the condition in which the aggregates have been dried by

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards,* Vol 04.02.

[3] *Annual Book of ASTM Standards,* Vol 04.03.

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

[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

***A Summary of Changes section appears at the end of this standard.**

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heating in an oven at 110 ± 5°C for sufficient time to reach a constant mass.

3.1.3 *saturated-surface-dry (SSD), adj—related to aggregate particles*, the condition in which the permeable pores of aggregate particle are filled with water to the extent achieved by submerging in water for the prescribed period of time, but without free water on the surface of the particles.

3.1.4 *density, n*—the mass per unit volume of a material, expressed as kilograms per cubic metre (pounds per cubic foot).

3.1.4.1 *density (OD), n*—the mass of oven dry aggregate per unit volume of aggregate particles, including the volume of permeable and impermeable pores within the particles, but not including the voids between the particles.

3.1.4.2 *density (SSD), n*—the mass of saturated-surface-dry aggregate per unit volume of the aggregate particles, including the volume of impermeable pores and water-filled voids within the particles, but not including the pores between the particles.

3.1.4.3 *apparent density, n*—the mass per unit volume of the impermeable portion of the aggregate particles.

3.1.5 *relative density (specific gravity), n*—the ratio of the density of a material to the density of distilled water at a stated temperature; the values are dimensionless.

3.1.5.1 *relative density (specific gravity) (OD), n*—the ratio of the density (OD) of the aggregate to the density of distilled water at a stated temperature.

3.1.5.2 *relative density (specific gravity) (SSD), n*—the ratio of the density (SSD) of the aggregate to the density of distilled water at a stated temperature.

3.1.5.3 *apparent relative density (apparent specific gravity), n*—the ratio of the apparent density of aggregate to the density of distilled water at a stated temperature.

3.1.6 For definitions of other terms related to aggregates, see Terminology C 125.

## 4. Summary of Test Method

4.1 A sample of aggregate is immersed in water for 24 ± 4 h to essentially fill the pores. It is then removed from the water, the water dried from the surface of the particles, and the mass determined. Subsequently, the volume of the sample is determined by the displacement of water method. Finally, the sample is oven-dried and the mass determined. Using the mass values thus obtained and formulas in this test method, it is possible to calculate density, relative density (specific gravity), and absorption.

## 5. Significance and Use

5.1 Relative density (specific gravity) is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Relative density (specific gravity) is also used in the computation of voids in aggregate in Test Method C 29/C 29M. Relative density (specific gravity) (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the relative density (specific gravity) (OD) is used for computations when the aggregate is dry or assumed to be dry.

5.2 Apparent density and apparent relative density (apparent specific gravity) pertain to the solid material making up the constituent particles not including the pore space within the particles which is accessible to water.

5.3 Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for a prescribed period of time. Aggregates mined from below the water table commonly have a moisture content greater than the absorption determined by this test method, if used without opportunity to dry prior to use. Conversely, some aggregates which have not been continuously maintained in a moist condition until used are likely to contain an amount of absorbed moisture less than the 24-h soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture is determined by deducting the absorption from the total moisture content determined by Test Method C 566.

5.4 The general procedures described in this test method are suitable for determining the absorption of aggregates that have had conditioning other than the 24-h soak, such as boiling water or vacuum saturation. The values obtained for absorption by other test methods will be different than the values obtained by the prescribed soaking, as will the relative density (specific gravity) (SSD).

5.5 The pores in lightweight aggregates are not necessarily filled with water after immersion for 24 h. In fact, the absorption potential for many such aggregates is not satisfied after several days' immersion in water. Therefore, this test method is not intended for use with lightweight aggregate.

## 6. Apparatus

6.1 *Balance*—A device for determining mass that is sensitive, readable, and accurate to 0.05 % of the sample mass at any point within the range used for this test, or 0.5 g, whichever is greater. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the center of the platform or pan of the balance.

6.2 *Sample Container*—A wire basket of 3.35 mm (No. 6) or finer mesh, or a bucket of approximately equal breadth and height, with a capacity of 4 to 7 L for 37.5-mm (1½-in.) nominal maximum size aggregate or smaller, and a larger container as needed for testing larger maximum size aggregate. The container shall be constructed so as to prevent trapping air when the container is submerged.

6.3 *Water Tank*—A watertight tank into which the sample container is placed while suspended below the balance.

6.4 *Sieves*—A 4.75-mm (No. 4) sieve or other sizes as needed (see 7.2-7.4), conforming to Specification E 11.

## 7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75.

7.2 Thoroughly mix the sample of aggregate and reduce it to the approximate quantity needed using the applicable procedures in Practice C 702. Reject all material passing a 4.75-mm

(No. 4) sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. If the coarse aggregate contains a substantial quantity of material finer than the 4.75-mm sieve (such as for Size No. 8 and 9 aggregates in Classification D 448), use the 2.36-mm (No. 8) sieve in place of the 4.75-mm sieve. Alternatively, separate the material finer than the 4.75-mm sieve and test the finer material according to Test Method C 128.

NOTE 1—If aggregates smaller than 4.75 mm (No. 4) are used in the sample, check to ensure that the size of the openings in the sample container is smaller than the minimum size aggregate.

7.3 The minimum mass of test sample to be used is given as follows. Testing the coarse aggregate in several size fractions is permited. If the sample contains more than 15 % retained on the 37.5-mm (1½-in.) sieve, test the material larger than 37.5 mm in one or more size fractions separately from the smaller size fractions. When an aggregate is tested in separate size fractions, the minimum mass of test sample for each fraction shall be the difference between the masses prescribed for the maximum and minimum sizes of the fraction.

| Nominal Maximum Size, mm (in.) | Minimum Mass of Test Sample, kg (lb) |
|---|---|
| 12.5 (½) or less | 2 (4.4) |
| 19.0 (¾) | 3 (6.6) |
| 25.0 (1) | 4 (8.8) |
| 37.5 (1½) | 5 (11) |
| 50 (2) | 8 (18) |
| 63 (2½) | 12 (26) |
| 75 (3) | 18 (40) |
| 90 (3½) | 25 (55) |
| 100 (4) | 40 (88) |
| 125 (5) | 75 (165) |

7.4 If the sample is tested in two or more size fractions, determine the grading of the sample in accordance with Test Method C 136, including the sieves used for separating the size fractions for the determinations in this method. In calculating the percentage of material in each size fraction, ignore the quantity of material finer than the 4.75-mm (No. 4) sieve (or 2.36-mm (No. 8) sieve when that sieve is used in accordance with 7.2).

NOTE 2—When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and the values obtained combined for the computations described in Section 9.

## 8. Procedure

8.1 Dry the test sample to constant mass at a temperature of 110 ± 5°C, cool in air at room temperature for 1 to 3 h for test samples of 37.5-mm (1½-in.) nominal maximum size, or longer for larger sizes until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C). Subsequently immerse the aggregate in water at room temperature for a period of 24 ± 4 h.

8.2 Where the absorption and relative density (specific gravity) values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement in 8.1 for initial drying is optional, and, if the surfaces of the particles in the sample have been kept continuously wet until tested, the requirement in 8.1 for 24 ± 4 h soaking is also optional.

NOTE 3—Values for absorption and relative density (specific gravity) (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with 8.1. This is especially true of particles larger than 75 mm since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

8.3 Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. A moving stream of air is permitted to assist in the drying operation. Take care to avoid evaporation of water from aggregate pores during the surface-drying operation. Determine the mass of the test sample in the saturated surface-dry condition. Record this and all subsequent masses to the nearest 0.5 g or 0.05 % of the sample mass, whichever is greater.

8.4 After determining the mass in air, immediately place the saturated-surface-dry test sample in the sample container and determine its apparent mass in water at 23 ± 2.0°C. Take care to remove all entrapped air before determining its mass by shaking the container while immersed.

NOTE 4—The difference between the mass in air and the mass when the sample is submerged in water equals the mass of water displaced by the sample.

NOTE 5—The container should be immersed to a depth sufficient to cover it and the test sample while determining the apparent mass in water. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

8.5 Dry the test sample to constant mass at a temperature of 110 ± 5°C, cool in air at room temperature 1 to 3 h, or until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50°C), and determine the mass.

## 9. Calculations

9.1 *Relative Density (Specific Gravity)*:

9.1.1 *Relative Density (Specific Gravity) (OD)*—Calculate the relative density (specific gravity) on the basis of oven-dry aggregate as follows:

$$\text{Relative density (specific gravity) (OD)} = A/(B - C) \quad (1)$$

where:

$A$ = mass of oven-dry test sample in air, g,
$B$ = mass of saturated-surface-dry test sample in air, g, and
$C$ = apparent mass of saturated test sample in water, g.

9.1.2 *Relative Density (Specific Gravity) (SSD)*—Calculate the relative density (specific gravity) on the basis of saturated-surface-dry aggregate as follows:

$$\text{Relative density (specific gravity) (SSD)} = B/(B - C) \quad (2)$$

9.1.3 *Apparent Relative Density (Apparent Specific Gravity)*—Calculate the apparent relative density (apparent specific gravity) as follows:

$$\text{Apparent relative density (apparent specific gravity)} = A/(A - C) \quad (3)$$

9.2 *Density*:

9.2.1 *Density (OD)*—Calculate the density on the basis of oven-dry aggregate as follows:

$$\text{Density (OD), kg/m}^3, = 997.5\, A/(B - C) \quad (4)$$

$$\text{Density (OD), lb/ft}^3, = 62.27\, A/(B - C) \quad (5)$$

NOTE 6—The constant values used in the calculations in 9.2.1-9.2.3 (997.5 kg/m$^3$ and 62.27 lb/ft$^3$) are the density of water at 23°C.

9.2.2 *Density (SSD)*—Calculate the density on the basis of saturated-surface-dry aggregate as follows:

$$\text{Density (SSD), kg/m}^3, = 997.5\ B/(B - C) \quad (6)$$

$$\text{Density (SSD), lb/ft}^3, = 62.27\ B/(B - C) \quad (7)$$

9.2.3 *Apparent Density*—Calculate the apparent density as follows:

$$\text{Apparent density, kg/m}^3 = 997.5\ A/(A - C) \quad (8)$$

$$\text{Apparent density, lb/ft}^3 = 62.27\ A/(A - C) \quad (9)$$

9.3 *Average Density and Relative Density (Specific Gravity) Values*—When the sample is tested in separate size fractions, compute the average values for density or relative density (specific gravity) of the size fraction computed in accordance with 9.1 or 9.2 using the following equation:

$$G = \frac{1}{\frac{P_1}{100\,G_1} + \frac{P_2}{100\,G_2} + \cdots \frac{P_n}{100\,G_n}} \text{ (see Appendix X1)} \quad (10)$$

where:

$G$ = average density or relative density (specific gravity). All forms of expression of density or relative density (specific gravity) can be averaged in this manner,

$G_1, G_2 \ldots G_n$ = appropriate average density or relative density (specific gravity) values for each size fraction depending on the type of density or relative density (specific gravity) being averaged, and

$P_1, P_2, \ldots P_n$ = mass percentages of each size fraction present in the original sample (not including finer material—see 7.4).

9.4 *Absorption*—Calculate the percentage of absorption, as follows:

$$\text{Absorption, \%} = [(B - A)/A] \times 100 \quad (11)$$

NOTE 7—Some authorities recommend using the density of water at 4°C (1000 kg/m$^3$ or 1.000 Mg/m$^3$ or 62.43 lb/ft $^3$) as being sufficiently accurate.

9.5 *Average Absorption Value*—When the sample is tested in separate size fractions, the average absorption value is the average of the values as computed in 9.4, weighted in proportion to the mass percentages of each size fraction present in the original sample (not including finer material—see 7.4) as follows:

$$A = (P_1A_1/100) + (P_2A_2/100) + \ldots\ (P_nA_n/100) \quad (12)$$

where:

$A$ = average absorption, %,

$A_1, A_2 \ldots A_n$ = absorption percentages for each size fraction, and

$P_1, P_2, \ldots P_n$ = mass percentages of each size fraction present in the original sample.

## 10. Report

10.1 Report density results to the nearest 10 kg/m$^3$, or 0.5 lb/ft$^3$, relative density (specific gravity) results to the nearest 0.01, and and indicate the basis for density or relative density (specific gravity), as either (OD), (SSD), or apparent.

10.2 Report the absorption result to the nearest 0.1 %.

10.3 If the density, relative density (specific gravity) and absorption values were determined without first drying the aggregate, as permitted in 8.2, note that fact in the report.

## 11. Precision and Bias

11.1 The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and AASHTO Method T 85. The significant difference between the methods is that Test Method C 127 requires a saturation period of 24 ± 4 h, while Method T 85 requires a saturation period of 15 h minimum. This difference has been found to have an insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories. The precision estimates for density were calculated from values determined for relative density (specific gravity), using the density of water at 23°C for the conversion.

11.2 *Bias*—Since there is no accepted reference material for determining the bias for the procedure in this test method, no statement on bias is being made.

## 12. Keywords

12.1 absorption; aggregate; apparent density; apparent relative density; coarse aggregate; density; relative density; specific gravity

**TABLE 1 Precision**

| | Standard Deviation (1s)[A] | Acceptable Range of Two Results (d2s)[A] |
|---|---|---|
| *Single-Operator Precision:* | | |
| Density (OD), kg/m$^3$ | 9 | 25 |
| Density (SSD), kg/m$^3$ | 7 | 20 |
| Apparent density, kg/m$^3$ | 7 | 20 |
| Relative density (specific gravity) (OD) | 0.009 | 0.025 |
| Relative density (specific gravity) (SSD) | 0.007 | 0.020 |
| Apparent relative density (apparent specific gravity) | 0.007 | 0.020 |
| *Multilaboratory Precision:* | | |
| Density (OD), kg/m$^3$ | 13 | 38 |
| Density (SSD), kg/m$^3$ | 11 | 32 |
| Apparent density, kg/m$^3$ | 11 | 32 |
| Relative density (specific gravity) (OD) | 0.013 | 0.038 |
| Relative density (specific gravity) (SSD) | 0.011 | 0.032 |
| Apparent relative density (apparent specific gravity) | 0.011 | 0.032 |

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory proficiency sample data from laboratories using 15 h minimum saturation times and other laboratories using 24 ± 4 h saturation times. Testing was performed on normal-weight aggregates, and started with aggregates in the oven-dry condition.

# APPENDIXES

**(Nonmandatory Information)**

## X1. DEVELOPMENT OF EQUATIONS

X1.1 The derivation of the equation is from the following simplified cases using two solids. Solid 1 has a mass $M_1$ in grams and a volume $V_1$ in millilitres; its relative density (specific gravity) ($G_1$) is therefore $M_1/V_1$. Solid 2 has a mass $M_2$ and volume $V_2$, and $G_2 = M_2/V_2$. If the two solids are considered together, the relative density (specific gravity) of the combination is the total mass in grams divided by the total volume in millilitres:

$$G = (M_1 + M_2) / (V_1 + V_2) \quad \text{(X1.1)}$$

Manipulation of this equation yields the following:

$$G = \frac{1}{\frac{V_1 + V_2}{M_1 + M_2}} = \frac{1}{\frac{V_1}{M_1 + M_2} + \frac{V_2}{M_1 + M_2}} \quad \text{(X1.2)}$$

$$G = \frac{1}{\frac{M_1}{M_1 + M_2}\left(\frac{V_1}{M_1}\right) + \frac{M_2}{M_1 + M_2}\left(\frac{V_2}{M_2}\right)} \quad \text{(X1.3)}$$

However, the mass fractions of the two solids are:

$$M_1/(M_1 + M_2) = P_1/100 \text{ and } M_2/(M_1 + M_2) = P_2/100 \quad \text{(X1.4)}$$

and,

$$1/G_1 = V_1/M_1 \text{ and } 1/G_2 = V_2/M_2 \quad \text{(X1.5)}$$

Therefore,

$$G = \frac{1}{\frac{P_1}{100}\frac{1}{G_1} + \frac{P_2}{100}\frac{1}{G_2}} \quad \text{(X1.6)}$$

An example of the computation is given in Table X1.1.

**TABLE X1.1 Example of Calculation of Weighted Values of Relative Density (Specific Gravity) and Absorption for a Coarse Aggregate Tested in Separate Sizes**

| Size Fraction, mm (in.) | % in Original Sample | Sample Mass Used in Test, g | Relative Density (Specific Gravity) (SSD) | Absorption, % |
|---|---|---|---|---|
| 4.75 to 12.5 (No. 4 to ½) | 44 | 2213.0 | 2.72 | 0.4 |
| 12.5 to 37.5 (½ to 1½) | 35 | 5462.5 | 2.56 | 2.5 |
| 37.5 to 63 (1½ to 2½) | 21 | 12593.0 | 2.54 | 3.0 |

Average Relative Density (Specific Gravity) (SSD)

$$G_{SSD} = \frac{1}{\frac{0.44}{2.72} + \frac{0.35}{2.56} + \frac{0.21}{2.54}} = 2.62$$

Average Absorption

$$A = (0.44)\,(0.4) + (0.35)\,(2.5) + (0.21)\,(3.0) = 1.7\ \%$$

## X2. INTERRELATIONSHIPS BETWEEN RELATIVE DENSITIES (SPECIFIC GRAVITIES) AND ABSORPTION AS DEFINED IN TEST METHODS C 127 AND C 128

X2.1 Where:

$S_d$ = relative density (specific gravity) (OD),

$S_s$ = relative density (specific gravity) (SSD),
$S_a$ = apparent relative density (apparent specific gravity), and
$A$ = absorption in %.

X2.2 Calculate the values of each as follows:

$$S_s = (1 + A/100)S_d \quad \text{(X2.1)}$$

$$S_a = \frac{1}{\frac{1}{S_d} - \frac{A}{100}} = \frac{S_d}{1 - \frac{AS_d}{100}} \quad \text{(X2.2)}$$

$$S_a = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} = \frac{S_s}{1 - \left[\frac{A}{100}(S_s - 1)\right]} \quad \text{(X2.3)}$$

$$A = \left(\frac{S_s}{S_d} - 1\right) 100 \quad \text{(X2.4)}$$

$$A = \left(\frac{S_a - S_s}{S_a(S_s - 1)}\right) 100 \quad \text{(X2.5)}$$

## SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Section 1 was revised.
(2) Section 2 was updated.
(3) Sections 3 through 11 were revised.
(4) The Appendix was revised.
(5) All tables were revised.

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Designation: C 128 – 01ε1

# Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate[1]

This standard is issued under the fixed designation C 128; 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—Table 1 was revised editorially in August 2003 to correct a typographical error in a value.

## 1. Scope*

1.1 This test method covers the determination of the average density of a quantity of fine aggregate particles (not including the volume of voids between the particles), the relative density (specific gravity), and the absorption of the fine aggregate. Depending on the procedure used, the density, in kg/m$^3$(lb/ft$^3$) is expressed as oven-dry (OD), saturated-surface-dry (SSD), or as apparent density. Likewise, relative density (specific gravity), a dimensionless quality, is expressed as OD, SSD, or as apparent relative density (apparent specific gravity). The OD density and OD relative density are determined after drying the aggregate. The SSD density, SSD relative density, and absorption are determined after soaking the aggregate in water for a prescribed duration.

1.2 This test method is used to determine the density of the essentially solid portion of a large number of aggregate particles and provides an average value representing the sample. Distinction is made between the density of aggregate particles as determined by this test method, and the bulk density of aggregates as determined by Test Method C 29/C 29M, which includes the volume of voids between the particles of aggregates.

1.3 This test method is not intended to be used for lightweight aggregates.

1.4 The values stated in SI units are to be regarded as the standard for conducting the tests. The test results for density shall be reported in either SI units or inch-pound units, as appropriate for the use to be made of the results.

1.5 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

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:*

C 29/C 29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[2]

C 70 Test Method for Surface Moisture in Fine Aggregate[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 127 Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate[2]

C 188 Test Method for Density of Hydraulic Cement[3]

C 566 Test Method for Total Evaporable Moisture Content of Aggregate by Drying[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[4]

2.2 *AASHTO Standard:*

AASHTO No. T 84 Specific Gravity and Absorption of Fine Aggregates[5]

## 3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Aug. 10, 2001. Published October 2001. Originally published as C 128–36. Last previous edition C 128–97.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 04.03.

[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

***A Summary of Changes section appears at the end of this standard.**

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3.1.1 *absorption, n*—the increase in mass of aggregate due to water penetrating into the pores of the particles, during a prescribed period of time but not including water adhering to the outside surface of the particles, expressed as percentage of the dry mass.

3.1.2 *oven-dry (OD), adj—related to aggregate particles,* the condition in which the aggregates have been dried by heating in an oven at 110 ± 5°C for sufficient time to reach a constant mass.

3.1.3 *saturated-surface-dry (SSD), adj—related to aggregate particles,* the condition in which the permeable pores of aggregate particles are filled with water to the extent achieved by submerging in water for the prescribed period of time, but without free water on the surface of the particles.

3.1.4 *density, n*—the mass per unit volume of a material, expressed as kilograms per cubic metre (pounds per cubic foot).

3.1.4.1 *density (OD), n*—the mass of oven-dry aggregate particles per unit volume of aggregate particles, including the volume of permeable and impermeable pores within particles, but not including the voids between the particles.

3.1.4.2 *density (SSD), n*—the mass of saturated-surface-dry aggregate per unit volume of the aggregate particles, including the volume of impermeable voids and water-filled pores within the particles, but not including the pores between the particles.

3.1.4.3 *apparent density, n*—the mass per unit volume of the impermeable portion of the aggregate particles.

3.1.5 *relative density (specific gravity), n*—the ratio of the density of a material to the density of water at a stated temperature; the values are dimensionless.

3.1.5.1 *relative density (specific gravity), (OD), n*—the ratio of the density (OD) of the aggregate to the density of water at a stated temperature.

3.1.5.2 *relative density (specific gravity), (SSD), n*—The ratio of the density (SSD) of the aggregate to the density of water at a stated temperature.

3.1.5.3 *apparent relative density (apparent specific gravity), n*—the ratio of the apparent density of aggregate to the density of water at a stated temperature.

3.1.6 For definitions of other terms related to aggregates see Terminology C 125.

## 4. Summary of Test Method

4.1 A sample of aggregate is immersed in water for 24 ± 4 h to essentially fill the pores. It is then removed from the water, the water is dried from the surface of the particles, and the mass determined. Subsequently, the sample (or a portion of it) is placed in a graduated container and the volume of the sample is determined by the gravimetric or volumetric method. Finally, the sample is oven-dried and the mass determined again. Using the mass values thus obtained and formulas in this test method, it is possible to calculate density, relative density (specific gravity), and absorption.

## 5. Significance and Use

5.1 Relative density (specific gravity) is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Relative density (specific gravity) is also used in the computation of voids in aggregate in Test Method C 29/C 29M. Relative density (specific gravity) (SSD) is used in the determination of surface moisture on fine aggregate by displacement of water in Test Method C 70. Relative density (specific gravity) (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the density or relative density (specific gravity) (OD) is used for computations when the aggregate is dry or assumed to be dry.

5.2 Apparent density and apparent relative density (apparent specific gravity) pertain to the solid material making up the constituent particles not including the pore space within the particles that is accessible to water. This value is not widely used in construction aggregate technology.

5.3 Absorption values are used to calculate the change in the mass of an aggregate material due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for a prescribed period of time. Aggregates mined from below the water table commonly have a moisture content greater than the absorption determined by this test method, if used without opportunity to dry prior to use. Conversely, some aggregates which have not been continuously maintained in a moist condition until used are likely to contain an amount of absorbed moisture less than the 24-h soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture is determined by deducting the absorption from the total moisture content determined by Test Method C 566 by drying.

5.4 The general procedures described in this test method are suitable for determining the absorption of aggregates that have had conditioning other than the 24-h soak, such as boiling water or vacuum saturation. The values obtained for absorption by other test methods will be different than the values obtained by the prescribed 24-h soak, as will the density (SSD) or relative density (specific gravity (SSD).

5.5 The pores in lightweight aggregates are not necessarily filled with water after immersion for 24 h. In fact, the absorption potential for many such aggregates is not satisfied after several days immersion in water. Therefore, this test method is not intended for use with lightweight aggregate.

## 6. Apparatus

6.1 *Balance*—A balance or scale having a capacity of 1 kg or more, sensitive to 0.1 g or less, and accurate within 0.1 % of the test load at any point within the range of use for this test method. Within any 100-g range of test load, a difference between readings shall be accurate within 0.1 g.

6.2 *Pycnometer (for Use with Gravimetric Procedure)*—A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced within ± 0.1 $cm^3$. The volume of the container filled to mark shall be at least 50 % greater than

the space required to accommodate the test sample. A volumetric flask of 500-$cm^3$ capacity or a fruit jar fitted with a pycnometer top is satisfactory for a 500-g test sample of most fine aggregates.

6.3 *Flask (for Use with Volumetric Procedure)*—A Le Chatelier flask as described in Test Method C 188 is satisfactory for an approximately 55-g test sample.

6.4 *Mold and Tamper for Surface Moisture Test*—The metal mold shall be in the form of a frustum of a cone with dimensions as follows: 40 ± 3-mm inside diameter at the top, 90± 3-mm inside diameter at the bottom, and 75 ± 3 mm in height, with the metal having a minimum thickness of 0.8 mm. The metal tamper shall have a mass of 340 ± 15 g and a flat circular tamping face 25 ± 3 mm in diameter.

## 7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75. Thoroughly mix the sample and reduce it to obtain a test specimen of approximately 1 kg using the applicable procedures described in Practice C 702.

## 8. Preparation of Test Specimen

8.1 Dry the test specimen in a suitable pan or vessel to constant mass at a temperature of 110 ± 5°C. Allow it to cool to comfortable handling temperature, cover with water, either by immersion or by the addition of at least 6 % moisture to the fine aggregate, and permit to stand for 24 ± 4 h.

8.1.1 Where the absorption and relative density (specific gravity) values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement in 8.1 for initial drying is optional, and, if the surfaces of the particles in the sample have been kept continuously wet until tested, the requirement in 8.1 for 24 ± 4 h soaking is also optional.

NOTE 1—Values for absorption and for relative density (specific gravity) (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with 8.1.

8.2 Decant excess water with care to avoid loss of fines, spread the sample on a flat nonabsorbent surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying. Employ mechanical aids such as tumbling or stirring to assist in achieving the saturated surface-dry condition, if desired. Continue this operation until the test specimen approaches a free-flowing condition. Follow the procedure in 8.3 to determine if surface moisture is still present on the constituent fine aggregate particles. Make the first trial for surface moisture when there is still some surface water in the test specimen. Continue drying with constant stirring and test at frequent intervals until the test indicates that the specimen has reached a surface-dry condition. If the first trial of the surface moisture test indicates that moisture is not present on the surface, it has been dried past the saturated surface-dry condition. In this case, thoroughly mix a few millilitres of water with the fine aggregate and permit the specimen to stand in a covered container for 30 min. Then resume the process of drying and testing at frequent intervals for the onset of the surface-dry condition.

8.3 *Test for Surface Moisture*—Hold the mold firmly on a smooth nonabsorbent surface with the large diameter down. Place a portion of the partially dried fine aggregate loosely in the mold by filling it to overflowing and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Start each drop approximately 5 mm above the top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops over the surface. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. Slight slumping of the molded fine aggregate indicates that it has reached a surface-dry condition.

8.3.1 Some fine aggregate with predominately angular-shaped particles or with a high proportion of fines does not slump in the cone test upon reaching the surface-dry condition. Test by dropping a handful of the fine aggregate from the cone test onto a surface from a height of 100 to 150 mm, and observe for fines becoming airborne; presence of airborne fines indicates this problem. For these materials, consider the saturated surface-dry condition as the point that one side of the fine aggregate slumps slightly upon removing the mold.

NOTE 2—The following criteria have also been used on materials that do not readily slump:

*(1) Provisional Cone Test*—Fill the cone mold as described in 8.3 except only use 10 drops of the tamper. Add more fine aggregate and use 10 drops of the tamper again. Then add material two more times using 3 and 2 drops of the tamper, respectively. Level off the material even with the top of the mold, remove loose material from the base; and lift the mold vertically.

*(2) Provisional Surface Test*—If airborne fines are noted when the fine aggregate is such that it will not slump when it is at a moisture condition, add more moisture to the sand, and at the onset of the surface-dry condition, with the hand lightly pat approximately 100 g of the material on a flat, dry, clean, dark or dull nonabsorbent surface such as a sheet of rubber, a worn oxidized, galvanized, or steel surface, or a black-painted metal surface. After 1 to 3 s, remove the fine aggregate. If noticeable moisture shows on the test surface for more than 1 to 2 s then surface moisture is considered to be present on the fine aggregate.

*(3)* Colorimetric procedures described by Kandhal and Lee, Highway Research Record No. 307, p. 44.

*(4)* For reaching the saturated surface-dry condition on a single size material that slumps when wet, hard-finish paper towels can be used to surface dry the material until the point is just reached where the paper towel does not appear to be picking up moisture from the surfaces of the fine aggregate particles.

## 9. Procedure

9.1 Test by either the gravimetric procedure in 9.2 or the volumetric procedure in 9.3. Make all determinations of mass to 0.1 g.

9.2 *Gravimetric (Pycnometer) Procedure*:

9.2.1 Partially fill the pycnometer with water. Introduce into the pycnometer 500 ± 10 g of saturated surface-dry fine aggregate prepared as described in Section 8, and fill with additional water to approximately 90 % of capacity. Agitate the pycnometer as described in 9.2.1.1 (manually) or 9.2.1.2 (mechanically).

9.2.1.1 Manually roll, invert, and agitate the pycnometer to eliminate all air bubbles.

NOTE 3—About 15 to 20 min are normally required to eliminate the air bubbles by manual methods. Dipping the tip of a paper towel into the pycnometer has been found to be useful in dispersing the foam that sometimes builds up when eliminating the air bubbles. Optionally, a small amount of isopropyl alcohol may be used to disperse the foam.

9.2.1.2 Mechanically agitate the pycnometer by external vibration in a manner that will not degrade the sample. A level of agitation adjusted to just set individual particles in motion is sufficient to promote de-airing without degradation. A mechanical agitator shall be considered acceptable for use if comparison tests for each six-month period of use show variations less that the acceptable range of two results (d2s) indicated in Table 1 from the results of manual agitation on the same material.

9.2.2 After eliminating all air bubbles, adjust the temperature of the pycnometer and its contents to 23.0 ± 2.0°C if necessary by partial immersion in circulating water, and bring the water level in the pycnometer to its calibrated capacity. Determine the total mass of the pycnometer, specimen, and water.

9.2.3 Remove the fine aggregate from the pycnometer, dry to constant mass at a temperature of 110 ± 5°C, cool in air at room temperature for 1 ± ½ h, and determine the mass.

**TABLE 1 Precision**

| | Standard Deviation (1s)[A] | Acceptable Range of Two Results (d2s)[A] |
|---|---|---|
| *Single-Operator Precision:* | | |
| Density (OD), kg/m$^3$ | 11 | 13 |
| Density (SSD), kg/m$^3$ [B†] | 9.5 | 27 |
| Apparent density, kg/m$^3$ | 9.5 | 27 |
| Relative density (specific gravity) (OD) | 0.011 | 0.032 |
| Relative density (specific gravity) (SSD) | 0.0095 | 0.027 |
| Apparent relative density (apparent specific gravity) | 0.0095 | 0.027 |
| Absorption[C], % | 0.11 | 0.31 |
| *Multilaboratory Precision:* | | |
| Density (OD), kg/m$^3$ | 23 | 64 |
| Density (SSD), kg/m$^3$ | 20 | 56 |
| Apparent density, kg/m$^3$ | 20 | 56 |
| Relative density (specific gravity) (OD) | 0.023 | 0.066 |
| Relative density (specific gravity) (SSD) | 0.020 | 0.056 |
| Apparent relative density (apparent specific gravity) | 0.020 | 0.056 |
| Absorption[C], % | 0.23 | 0.66 |

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory proficiency sample data from laboratories using 15 to 19-h saturation times and other laboratories using 24 ± 4-h saturation time. Testing was performed on normal weight aggregates, and started with aggregates in the oven-dry condition.

[B†] Revised editorially to correct a typographical error in August 2003.

[C] Precision estimates are based on aggregates with absorptions of less than 1 % and may differ for manufactured fine aggregates and the aggregates having absorption values greater than 1 %.

9.2.4 Determine the mass of the pycnometer filled to its calibrated capacity with water at 23.0 ± 2.0°C.

9.3 *Volumetric (Le Chatelier Flask) Procedure*:

9.3.1 Fill the flask initially with water to a point on the stem between the 0 and the 1-mL mark. Record this initial reading with flask and contents within the temperature range of 23.0 ± 2.0°C. Add 55 ± 5 g of fine aggregate in the saturated surface-dry condition (or other measured quantity as necessary). After all fine aggregate has been introduced, place the stopper in the flask and roll the flask in an inclined position, or gently whirl it in a horizontal circle so as to dislodge all entrapped air, continuing until no further bubbles rise to the surface (Note 4). Take a final reading with the flask and contents within 1°C of the original temperature.

NOTE 4—A small measured amount (not to exceed 1 mL) of isopropyl alcohol may be used to eliminate foam appearing on the water surface. The volume of alcohol used must be subtracted from the final reading ($R_2$).

9.3.2 For determination of the absorption, use a separate 500 ± 10-g portion of the saturated surface-dry fine aggregate, dry to constant mass, and determine the dry mass.

## 10. Calculations

10.1 *Symbols*:

$A$ = mass of oven dry specimen, g

$B$ = mass of pycnometer filled with water, to calibration mark, g

$C$ = mass of pycnometer filled with specimen and water to calibration mark, g

$R_1$= initial reading of water level in Le Chatelier flask, mL

$R_2$= final reading of water in Le Chatelier flask, mL

$S$ = mass of saturated surface-dry specimen (used in the gravimetric procedure for density and relative density (specific gravity), or for absorption with both procedures), g

$S_1$= mass of saturated surface-dry specimen (used in the volumetric procedure for density and relative density (specific gravity)), g

10.2 *Relative Density (Specific Gravity)*:

10.2.1 *Relative Density (Specific Gravity ) (Oven dry)*—Calculate the relative density (specific gravity) on the basis of oven-dry aggregate as follows:

10.2.1.1 *Gravimetric Procedure*:

$$\text{Relative density (specific gravity) (OD)} = A/(B + S - C) \quad (1)$$

10.2.1.2 *Volumetric Procedure*:

$$\text{Relative density (specific gravity) (OD)} = [S_1\,(A/S)]/[0.9975\,(R_2 - R_1)] \quad (2)$$

10.2.2 *Relative Density (Specific Gravity) Saturated Surface-dry)*—Calculate the relative density (specific gravity) on the basis of saturated surface-dry aggregate as follows:

10.2.2.1 *Gravimetric Procedure*:

$$\text{Relative density (specific gravity) (SSD)} = S/(B + S - C) \quad (3)$$

10.2.2.2 *Volumetric Procedure*:

$$\text{Relative density (specific gravity) (SSD)} = S_1/[0.9975\,(R_2 - R_1)] \quad (4)$$

10.2.3 *Apparent Relative Density (Apparent Specific Gravity)*—Calculate the apparent relative density (apparent specific gravity) as follows:

10.2.3.1 *Gravimetric Procedure*:

$$\text{Apparent relative density (apparent specific gravity)} = A/(B + A - C) \quad (5)$$

10.2.3.2 *Volumetric Procedure*:

$$\text{Apparent relative density (apparent specific gravity)} = \frac{S_1\,(A/S)}{0.9975\,(R_2 - R_1) - [(S_1/S)(S - A)]} \quad (6)$$

10.3 *Density*:

10.3.1 *Density (Oven-dry)*—Calculate the density on the basis of oven-dry aggregates as follows:

10.3.1.1 *Gravimetric Procedure*:

$$\text{Density (OD), kg/m}^3 = 997.5\,A/(B + S - C) \quad (7)$$

$$\text{Density (OD), lb/ft}^3 = 62.27\,A/(B + S - C) \quad (8)$$

10.3.1.2 *Volumetric Procedure*:

$$\text{Density (OD), kg/m}^3 = 997.5\,S_1\,(A/S)/[0.9975\,(R_2 - R_1)] \quad (9)$$

$$\text{Density (OD), lb/ft}^3 = 62.27\,S_1\,(A/S)/[0.9975\,(R_2 - R_1)] \quad (10)$$

NOTE 5—The constant values used in the calculations in 10.3.1-10.3.3 (997.5 kg/m$^3$ and 62.27 lb/ft$^3$) are the density of water at 23°C. Some authorities recommend using the density of water at 4°C (1000 kg/m$^3$ or 1000 Mg/m$^3$ or 62.43 lb/ft$^3$) as being sufficiently accurate.

10.3.2 *Density (Saturated surface-dry)*—Calculate the density on the basis of saturated surface-dry aggregate as follows:

10.3.2.1 *Gravimetric Procedure*:

$$\text{Density (SSD), kg/m}^3 = 997.5\,S/(B + S - C) \quad (11)$$

$$\text{Density (SSD), lb/ft}^3 = 62.27\,S/(B + S - C) \quad (12)$$

10.3.2.2 *Volumetric Procedure*:

$$\text{Density (SSD), kg/m}^3 = 997.5\,S_1/[0.9975\,(R_2 - R_1)] \quad (13)$$

$$\text{Density (SSD), lb/ft}^3 = 62.27\,S_1/[0.9975\,(R_2 - R_1)] \quad (14)$$

10.3.3 *Apparent Density*—Calculate the apparent density as follows:

10.3.3.1 *Gravimetric Procedure*:

$$\text{Apparent density (SSD), kg/m}^3 = 997.5\,A/(B + A - C) \quad (15)$$

$$\text{Apparent density (SSD), lb/ft}^3 = 62.27\,A/(B + A - C) \quad (16)$$

10.3.3.2 *Volumetric Procedure*:

$$\text{Apparent density (SSD), kg/m}^3, = \frac{997.5\,S_1\,(A/S)}{0.9975\,(R_2 - R_1) - [(S_1/S)(S - A)]} \quad (17)$$

$$\text{Apparent density (SSD), lb/ft}^3, = \frac{62.27\,S_1\,(A/S)}{0.9975\,(R_2 - R_1) - [(S_1/S)(S - A)]} \quad (18)$$

10.4 *Absorption*—Calculate the percentage of absorption as follows:

$$\text{Absorption, \%} = 100\,[(S - A)/A] \quad (19)$$

## 11. Report

11.1 Report density results to the nearest 10 kg/m$^3$, or 0.5 lb/ft$^3$, relative density (specific gravity) results to the nearest 0.01, and indicate the basis for density or relative density (specific gravity), as either oven-dry (OD), saturated-surface-dry (SSD), or apparent.

11.2 Report the absorption result to the nearest 0.1 %.

11.3 If the density and relative density (specific gravity) values were determined without first drying the aggregate, as permitted in 8.2, note that fact in the report.

## 12. Precision and Bias

12.1 *Precision*—The estimates of precision of this test method (listed in Table 1) are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and AASHTO Method T 84. The significant difference between the methods is that Test Method C 128 requires a saturation period of 24 ± 4 h, and AASHTO Test Method T 84 requires a saturation period of 15 to 19 h. This difference has been found to have an insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories. The precision estimates for density were calculated from values determined for relative density (specific gravity), using the density of water at 23°C for the conversion.

12.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for this test method, no statement on bias is being made.

## 13. Keywords

13.1 absorption; aggregate; aparent density; apparent relative density; density; fine aggregate; relative density; specific gravity

## APPENDIX

**(Nonmandatory Information)**

### X1. INTERRELATIONSHIPS BETWEEN RELATIVE DENSITIES (SPECIFIC GRAVITIES) AND ABSORPTION AS DEFINED IN TEST METHODS C 127 AND C 128

X1.1 This appendix gives mathematical interrelationships among the three types of relative densities (specific gravities) and absorption. These may be useful in checking the consistency of reported data or calculating a value that was not reported by using other reported data.

X1.2 Where:

$S_d$ = relative density (specific gravity) (OD),
$S_s$ = relative density (specific gravity) (SSD),
$S_a$ = apparent relative density (apparent specific gravity), and
$A$ = absorption, in %.

Calculate the values of each as follows:

$$S_s = (1 + A/100)S_d \quad \text{(X1.1)}$$

$$S_s = \frac{1}{\frac{1}{S_d} - \frac{A}{100}} = \frac{S_d}{1 - \frac{AS_d}{100}} \quad \text{(X1.2)}$$

$$\text{or } S_a = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} \quad \text{(X1.3)}$$

$$= \frac{S_s}{1 = \frac{A}{100}(S_s - 1)}$$

$$A = \left(\frac{S_s}{S_d} - 1\right) 100 \quad \text{(X1.4)}$$

$$A = \left(\frac{S_a - S_s}{S_a (S_s - 1)}\right) 100 \quad \text{(X1.5)}$$

## SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Entire standard was rewritten.

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Designation: C 131 – 03

# Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[1]

This standard is issued under the fixed designation C 131; 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 covers a procedure for testing sizes of coarse aggregate smaller than 37.5 mm (1½ in.) for resistance to degradation using the Los Angeles testing machine (Note 1).

NOTE 1—A procedure for testing coarse aggregate larger than 19.0 mm (¾ in.) is covered in Test Method C 535.

1.2 The values stated in SI units are to be regarded as the standard. The inch-pound 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:*

A 6/A 6M Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[3]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[3]

C 535 Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[3]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[3]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[3]

D 75 Practice for Sampling Aggregates[4]

E 11 Specification for Wire Cloth and Sieves for Testing Purposes[5]

## 3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology C 125.

## 4. Summary of Test Method

4.1 This test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres, the number depending upon the grading of the test sample. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate picks up the sample and the steel spheres, and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss.

## 5. Significance and Use

5.1 This test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions. The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Assign specification limits with extreme care in consideration of available aggregate types and their performance history in specific end uses.

## 6. Apparatus

6.1 *Los Angeles Machine*—A Los Angeles machine, conforming in all essential characteristics to the design shown in Fig. 1, shall be used. The machine shall consist of a hollow steel cylinder, with a wall thickness of not less than 12.4 mm

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards,* Vol 01.04.

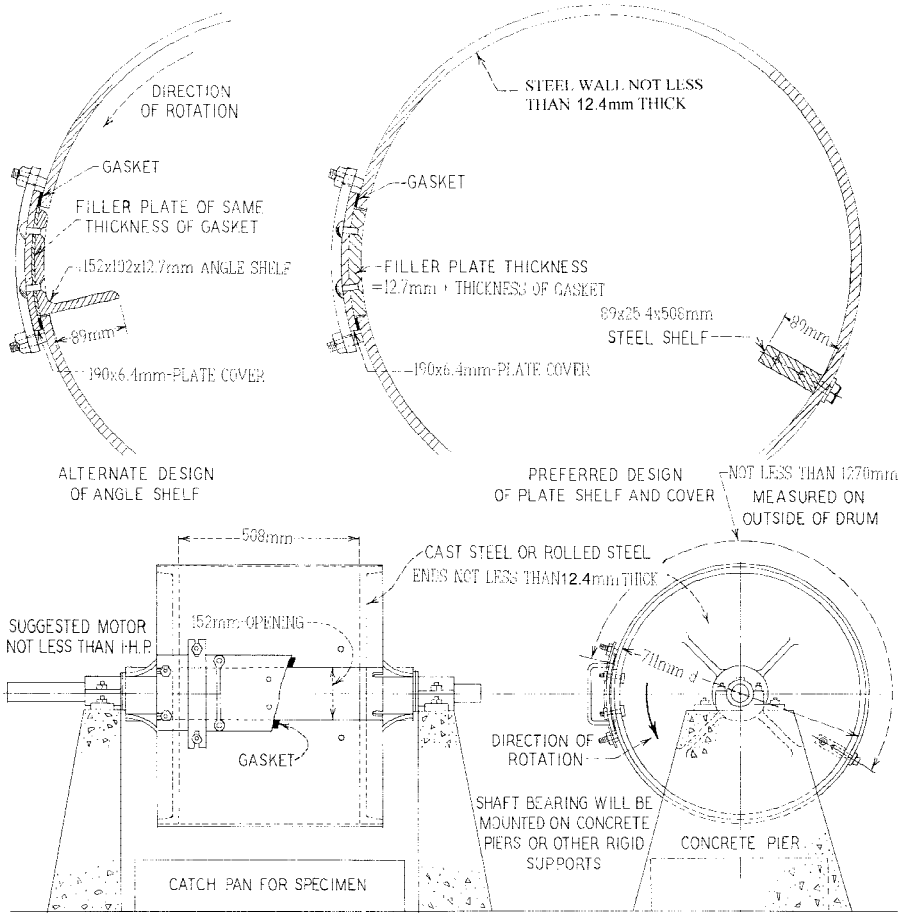
[3] *Annual Book of ASTM Standards,* Vol 04.02.

[4] *Annual Book of ASTM Standards,* Vol 04.03.

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

***A Summary of Changes section appears at the end of this standard.**

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**Inch Equivalents**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| mm | 6.4 | 12.7 | 25.4 | 89 | 102 | 152 | 190 | 508 | 711 | 1270 |
| in. | ¼ | ½ | 1 | 3½ | 4 | 6 | 7½ | 20 | 28 | 50 |

**FIG. 1 Los Angeles Testing Machine**

(Note 2) closed at both ends, conforming to the dimensions shown in Fig. 1, having an inside diameter of 711 ± 5 mm (28 ± 0.2 in.), and an inside length of 508 ± 5 mm (20 ± 0.2 in.). The cylinder shall be mounted on stub shafts attached to the ends of the cylinder but not entering it, and shall be mounted in such a manner that it rotates with the axis in a horizontal position within a tolerance in slope of 1 in 100. An opening in the cylinder shall be provided for the introduction of the test sample. A suitable, dust-tight cover shall be provided for the opening with means for bolting the cover in place. The cover shall be so designed as to maintain the cylindrical contour of the interior surface unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test. A removable steel shelf extending the full length of the cylinder and projecting inward 89 ± 2 mm (3.5 ± 0.1 in.) shall be mounted on the interior cylindrical surface of the cylinder, in such a way that a plane centered between the large faces coincides with an axial plane. The shelf shall be of such thickness and so mounted, by bolts or other suitable means, as to be firm and rigid. The position of the shelf (Note 3) shall be such that the sample and the steel spheres shall not impact on or near the opening and its cover, and that the distance from the shelf to the opening, measured along the outside circumference of the cylinder in the direction of rotation, shall be not less than 1270 mm (50 in.). Inspect the shelf periodically to determine that it is not bent either lengthwise or from its normal radial position with respect to the cylinder. If either condition is found, repair or replace the shelf before further tests are conducted.

NOTE 2—This is the minimum tolerance permitted on 12.7 mm (½ in.) rolled steel plate as described in Specification A 6/A 6M.

NOTE 3—The use of a shelf of wear-resistant steel, rectangular in cross section and mounted independently of the cover, is preferred. However, a shelf consisting of a section of rolled angle, properly mounted on the inside of the cover plate, may be used provided the direction of rotation is such that the charge will be caught on the outside face of the angle.

6.1.1 The machine shall be so driven and so counterbalanced as to maintain a substantially uniform peripheral speed (Note 4). If an angle is used as the shelf, the direction of rotation shall be such that the charge is caught on the outside surface of the angle.

NOTE 4—Back-lash or slip in the driving mechanism is very likely to furnish test results which are not duplicated by other Los Angeles machines producing constant peripheral speed.

6.2 *Sieves*, conforming to Specification E 11.

6.3 *Balance*—A balance or scale accurate within 0.1 % of test load over the range required for this test.

6.4 *Charge*—The charge shall consist of steel spheres averaging approximately 46.8 mm (1 27/32 in.) in diameter and each having a mass of between 390 and 445 g.

6.4.1 The charge, (Note 5) depending upon the grading of the test sample as described in Section 8, shall be as follows:

| Grading | Number of Spheres | Mass of Charge, g |
|---|---|---|
| A | 12 | 5000 ± 25 |
| B | 11 | 4584 ± 25 |
| C | 8 | 3330 ± 20 |
| D | 6 | 2500 ± 15 |

NOTE 5—Steel ball bearings 46.0 mm (1 13/16 in.) and 47.6 mm (1 7/8 in.) in diameter, having a mass of approximately 400 and 440 g each, respectively, are readily available. Steel spheres 46.8 mm (1 27/32 in.) in diameter having a mass of approximately 420 g may also be obtainable. The charge may consist of a mixture of these sizes conforming to the mass tolerances of 6.4 and 6.4.1.

## 7. Sampling

7.1 Obtain the field sample in accordance with Practice D 75, and reduce the field sample to adequate sample size in accordance with Practice C 702.

## 8. Test Sample Preparation

8.1 Wash the reduced sample and oven dry at 110 ± 5°C (230 ± 9°F) to substantially constant mass (see 9.1.1), separate into individual size fractions, and recombine to the grading of Table 1 most nearly corresponding to the range of sizes in the aggregate as furnished for the work. Record the mass of the sample prior to test to the nearest 1 g.

## 9. Procedure

9.1 Place the test sample and the charge in the Los Angeles testing machine and rotate the machine at a speed of 30 to 33 r/min for 500 revolutions (Note 6). After the prescribed number of revolutions, discharge the material from the machine and make a preliminary separation of the sample on a sieve coarser than the 1.70-mm (No. 12) sieve. Sieve the finer portion on a 1.70-mm sieve in a manner conforming to Test Method C 136. Wash the material coarser than the 1.70-mm (No. 12) sieve and oven-dry at 110 ± 5°C (230 ± 9°F) to substantially constant mass (see 9.1.1), and determine the mass to the nearest 1 g (Note 7).

9.1.1 If the aggregate is essentially free of adherent coatings and dust, the requirement for washing after the test is optional. However, in the case of referee testing, the washing procedure shall be performed.

NOTE 6—Valuable information concerning the uniformity of the sample under test may be obtained by determining the loss after 100 revolutions. The loss should be determined by dry sieving the material on the 1.70-mm sieve without washing. The ratio of the loss after 100 revolutions to the loss after 500 revolutions should not greatly exceed 0.20 for material of uniform hardness. When this determination is made, take care to avoid losing any part of the sample; return the entire sample, including the dust of fracture, to the testing machine for the final 400 revolutions required to complete the test.

NOTE 7—Elimination of washing after test will seldom reduce the measured loss by more than about 0.2 % of the original sample mass.

## 10. Calculation

10.1 Calculate the loss (difference between the original mass and the final mass of the test sample) as a percentage of the original mass of the test sample. Report this value as the percent loss (Note 8).

NOTE 8—The percent loss determined by this test method has no known consistent relationship to the percent loss for the same material when tested by Test Method C 535.

## 11. Report

11.1 Report the following information:

11.1.1 Identification of the aggregate as to source, type, and nominal maximum size;

11.1.2 Grading designation from Table 1 used for the test; and

11.1.3 Loss by abrasion and impact of the sample expressed to the nearest 1 % by mass.

## 12. Precision and Bias

12.1 For nominal 19.0-mm (¾-in.) maximum size coarse aggregate with percent losses in the range of 10 to 45 %, the multilaboratory coefficient of variation has been found to be 4.5 %.[6] Therefore, results of two properly conducted tests from two different laboratories on samples of the same coarse aggregates are not expected to differ from each other by more

[6] These numbers represent, respectively, the (1s%) and (d2s%) limits as described in Practice C 670.

**TABLE 1 Gradings of Test Samples**

| Sieve Size (Square Openings) | | Mass of Indicated Sizes, g | | | |
|---|---|---|---|---|---|
| Passing | Retained on | Grading | | | |
| | | A | B | C | D |
| 37.5 mm (1½ in.) | 25.0 mm (1 in.) | 1 250 ± 25 | ... | ... | ... |
| 25.0 mm (1 in.) | 19.0 mm (¾ in.) | 1 250 ± 25 | ... | ... | ... |
| 19.0 mm (¾ in.) | 12.5 mm (½ in.) | 1 250 ± 10 | 2 500 ± 10 | ... | ... |
| 12.5 mm (½ in.) | 9.5 mm (⅜ in.) | 1 250 ± 10 | 2 500 ± 10 | ... | ... |
| 9.5 mm (⅜ in.) | 6.3 mm (¼ in.) | ... | ... | 2 500 ± 10 | ... |
| 6.3 mm (¼ in.) | 4.75-mm (No. 4) | ... | ... | 2 500 ± 10 | ... |
| 4.75-mm (No. 4) | 2.36-mm (No. 8) | ... | ... | ... | 5 000 ± 10 |
| Total | | 5 000 ± 10 | 5 000 ± 10 | 5 000 ± 10 | 5 000 ± 10 |

than 12.7 %[6] (95 % probability) of their average. The single-operator coefficient of variation has been found to be 2.0 %.[6] Therefore, results of two properly conducted tests by the same operator on the same coarse aggregate are not expected to differ from each other by more than 5.7 % (95 % probability) of their average.[6]

12.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for this procedure, no statement on bias is being made.

## 13. Keywords

13.1 abrasion; aggregate (coarse; small size); degradation; impact; Los Angeles machine

## APPENDIX

**(Nonmandatory Information)**

### X1. MAINTENANCE OF SHELF

X1.1 The shelf of the Los Angeles machine is subject to severe surface wear and impact. With use, the working surface of the shelf is peened by the balls and tends to develop a ridge of metal parallel to and about 32 mm (1¼ in.) from the junction of the shelf and the inner surface of the cylinder. If the shelf is made from a section of rolled angle, not only may this ridge develop but the shelf itself may be bent longitudinally or transversely from its proper position.

X1.2 The shelf should be inspected periodically to determine that it is not bent either lengthwise or from its normal radial position with respect to the cylinder. If either condition is found, the shelf should be repaired or replaced before further tests are made. The influence on the test result of the ridge developed by peening of the working face of the shelf is not known. However, for uniform test conditions, it is recommended that the ridge be ground off if its height exceeds 2 mm (0.1 in.).

## SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue (C 131-01).

(1) 1.2 was revised.
(2) Specification A 6/A 6M was added to Section 2.
(3) 6.1 was revised, and Note 2 was added.
(4) Remaining notes were renumbered.
(5) 8.1 was revised.
(6) 9.1 was revised.
(7) 9.1.1 was revised.
(8) 12.1 was revised.
(9) Note 6 was revised.
(10) Fig. 1 was revised.

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Designation: C 136 – 01

# Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates[1]

This standard is issued under the fixed designation C 136; 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 covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2 Some specifications for aggregates which reference this method contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information purposes only. Specification E 11 designates the size of sieve frames with inch units as standard, but in this test method the frame size is designated in SI units exactly equivalent to the inch units.

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:*

C 117 Test Method for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

E 11 Specification for Wire-Cloth and Sieves for Testing Purposes[4]

2.2 *AASHTO Standard:*

AASHTO No. T 27 Sieve Analysis of Fine and Coarse Aggregates[5]

## 3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, refer to Terminology C 125.

## 4. Summary of Test Method

4.1 A sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

## 5. Significance and Use

5.1 This test method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

5.2 Accurate determination of material finer than the 75-µm (No. 200) sieve cannot be achieved by use of this method alone. Test Method C 117 for material finer than 75-µm sieve by washing should be employed.

## 6. Apparatus

6.1 *Balances*—Balances or scales used in testing fine and coarse aggregate shall have readability and accuracy as follows:

6.1.1 For fine aggregate, readable to 0.1 g and accurate to 0.1 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

6.1.2 For coarse aggregate, or mixtures of fine and coarse aggregate, readable and accurate to 0.5 g or 0.1 % of the test load, whichever is greater, at any point within the range of use.

6.2 *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

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

[5] Available from American Association of State Highway and Transportation Officials, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001.

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frames shall conform to the requirements of Specification E 11. Nonstandard sieve frames shall conform to the requirements of Specification E 11 as applicable.

NOTE 1—It is recommended that sieves mounted in frames larger than standard 203.2-mm (8 in.) diameter be used for testing coarse aggregate to reduce the possibility of overloading the sieves. See 8.3.

6.3 *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in 8.4 is met in a reasonable time period.

NOTE 2—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 min) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a small sample of coarse aggregate or fine aggregate.

6.4 *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

## 7. Sampling

7.1 Sample the aggregate in accordance with Practice D 75. The size of the field sample shall be the quantity shown in Practice D 75 or four times the quantity required in 7.4 and 7.5 (except as modified in 7.6), whichever is greater.

7.2 Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in Practice C 702. The sample for test shall be approximately the quantity desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined quantity shall not be permitted.

NOTE 3—Where sieve analysis, including determination of material finer than the 75-µm sieve, is the only testing proposed, the size of the sample may be reduced in the field to avoid shipping excessive quantities of extra material to the laboratory.

7.3 *Fine Aggregate*—The size of the test sample, after drying, shall be 300 g minimum.

7.4 *Coarse Aggregate*—The size of the test sample of coarse aggregate shall conform with the following:

| Nominal Maximum Size, Square Openings, mm (in.) | Test Sample Size, min, kg (lb) |
|---|---|
| 9.5 (⅜) | 1 (2) |
| 12.5 (½) | 2 (4) |
| 19.0 (¾) | 5 (11) |
| 25.0 (1) | 10 (22) |
| 37.5 (1½) | 15 (33) |
| 50 (2) | 20 (44) |
| 63 (2½) | 35 (77) |
| 75 (3) | 60 (130) |
| 90 (3½) | 100 (220) |
| 100 (4) | 150 (330) |
| 125 (5) | 300 (660) |

7.5 *Coarse and Fine Aggregate Mixtures*—The size of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate in 7.4.

7.6 *Samples of Large Size Coarse Aggregate*—The size of sample required for aggregate with 50-mm nominal maximum size or larger is such as to preclude convenient sample reduction and testing as a unit except with large mechanical splitters and sieve shakers. As an option when such equipment is not available, instead of combining and mixing sample increments and then reducing the field sample to testing size, conduct the sieve analysis on a number of approximately equal sample increments such that the total mass tested conforms to the requirement of 7.4.

7.7 In the event that the amount of material finer than the 75-µm (No. 200) sieve is to be determined by Test Method C 117, proceed as follows:

7.7.1 For aggregates with a nominal maximum size of 12.5 mm (1/2 in.) or less, use the same test sample for testing by Test Method C 117 and this method. First test the sample in accordance with Test Method C 117 through the final drying operation, then dry sieve the sample as stipulated in 8.2-8.7 of this method.

7.7.2 For aggregates with a nominal maximum size greater than 12.5 mm (½ in.), a single test sample may be used as described in 7.7.1, or separate test samples may be used for Test Method C 117 and this method.

7.7.3 Where the specifications require determination of the total amount of material finer than the 75-µm sieve by washing and dry sieving, use the procedure described in 7.7.1.

## 8. Procedure

8.1 Dry the sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F).

NOTE 4—For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless: (*1*) the nominal maximum size is smaller than about 12.5 mm (½ in.); (*2*) the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4); or (*3*) the coarse aggregate is highly absorptive (a lightweight aggregate, for example). Also, samples may be dried at the higher temperatures associated with the use of hot plates without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles, and temperatures are not so great as to cause chemical breakdown of the aggregate.

8.2 Select sieves with suitable openings to furnish the information required by the specifications covering the material to be tested. Use additional sieves as desired or necessary to provide other information, such as fineness modulus, or to regulate the amount of material on a sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy or sieving described in 8.4.

8.3 Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75-mm (No. 4), the quantity retained on any sieve at the completion of the sieving operation shall not exceed 7 kg/m$^2$ of sieving surface area (Note 5). For sieves with openings 4.75 mm (No. 4) and larger, the quantity retained in kg shall not exceed the product of 2.5 × (sieve opening, mm × (effective sieving area, m$^2$)). This quantity is shown in Table 1 for five sieve-frame dimensions in common

**TABLE 1 Maximum Allowable Quantity of Material Retained on a Sieve, kg**

| Sieve Opening Size, mm | Nominal Dimensions of Sieve[A] | | | | |
|---|---|---|---|---|---|
| | 203.2-mm dia[B] | 254-mm dia[B] | 304.8-mm dia[B] | 350 by 350 mm | 372 by 580 mm |
| | Sieving Area, $m^2$ | | | | |
| | 0.0285 | 0.0457 | 0.0670 | 0.1225 | 0.2158 |
| 125 | [C] | [C] | [C] | [C] | 67.4 |
| 100 | [C] | [C] | [C] | 30.6 | 53.9 |
| 90 | [C] | [C] | 15.1 | 27.6 | 48.5 |
| 75 | [C] | 8.6 | 12.6 | 23.0 | 40.5 |
| 63 | [C] | 7.2 | 10.6 | 19.3 | 34.0 |
| 50 | 3.6 | 5.7 | 8.4 | 15.3 | 27.0 |
| 37.5 | 2.7 | 4.3 | 6.3 | 11.5 | 20.2 |
| 25.0 | 1.8 | 2.9 | 4.2 | 7.7 | 13.5 |
| 19.0 | 1.4 | 2.2 | 3.2 | 5.8 | 10.2 |
| 12.5 | 0.89 | 1.4 | 2.1 | 3.8 | 6.7 |
| 9.5 | 0.67 | 1.1 | 1.6 | 2.9 | 5.1 |
| 4.75 | 0.33 | 0.54 | 0.80 | 1.5 | 2.6 |

[A] Sieve frame dimensions in inch units: 8.0-in. diameter; 10.0-in. diameter, 12.0-in. diameter; 13.8 by 13.8 in. (14 by 14 in. nominal); 14.6 by 22.8 in. (16 by 24 in. nominal).

[B] The sieve area for round sieve frames is based on an effective diameter 12.7 mm (½ in.) less than the nominal frame diameter, because Specification E 11 permits the sealer between the sieve cloth and the frame to extend 6.35 mm (¼ in.) over the sieve cloth. Thus the effective sieving diameter for a 203.2-mm (8.0-in.) diameter sieve frame is 190.5 mm (7.5 in.). Some manufacturers of sieves may not infringe on the sieve cloth by the full 6.35 mm (¼ in.).

[C] Sieves indicated have less than five full openings and should not be used for sieve testing except as provided in 8.6.

use. In no case shall the quantity retained be so great as to cause permanent deformation of the sieve cloth.

8.3.1 Prevent an overload of material on an individual sieve by one of the following methods:

8.3.1.1 Insert an additional sieve with opening size intermediate between the sieve that may be overloaded and the sieve immediately above that sieve in the original set of sieves.

8.3.1.2 Split the sample into two or more portions, sieving each portion individually. Combine the masses of the several portions retained on a specific sieve before calculating the percentage of the sample on the sieve.

8.3.1.3 Use sieves having a larger frame size and providing greater sieving area.

NOTE 5—The 7 $kg/m^2$ amounts to 200 g for the usual 203.2-mm (8-in.) diameter sieve (with effective sieving surface diameter of 190.5 mm (7.5 in.)).

8.4 Continue sieving for a sufficient period and in such manner that, after completion, not more than 1 % by mass of the material retained on any individual sieve will pass that sieve during 1 min of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203-mm (8 in.) diameter sieves to verify the sufficiency of sieving.

8.5 In the case of coarse and fine aggregate mixtures, the portion of the sample finer than the 4.75-mm (No. 4) sieve may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

8.5.1 Alternatively, the portion finer than the 4.75-mm (No. 4) sieve may be reduced in size using a mechanical splitter according to Practice C 702. If this procedure is followed, compute the mass of each size increment of the original sample as follows:

$$A = \frac{W_1}{W_2} \times B \quad (1)$$

where:

$A$ = mass of size increment on total sample basis,
$W_1$ = mass of fraction finer than 4.75-mm (No. 4) sieve in total sample,
$W_2$ = mass of reduced portion of material finer than 4.75-mm (No. 4) sieve actually sieved, and
$B$ = mass of size increment in reduced portion sieved.

8.6 Unless a mechanical sieve shaker is used, hand sieve particles larger than 75 mm (3 in.) by determining the smallest sieve opening through which each particle will pass. Start the test on the smallest sieve to be used. Rotate the particles, if necessary, in order to determine whether they will pass through a particular opening; however, do not force particles to pass through an opening.

8.7 Determine the mass of each size increment on a scale or balance conforming to the requirements specified in 5.1 to the nearest 0.1 % of the total original dry sample mass. The total mass of the material after sieving should check closely with original mass of sample placed on the sieves. If the amounts differ by more than 0.3 %, based on the original dry sample mass, the results should not be used for acceptance purposes.

8.8 If the sample has previously been tested by Test Method C 117, add the mass finer than the 75-µm (No. 200) sieve determined by that method to the mass passing the 75-µm (No. 200) sieve by dry sieving of the same sample in this method.

## 9. Calculation

9.1 Calculate percentages passing, total percentages retained, or percentages in various size fractions to the nearest 0.1 % on the basis of the total mass of the initial dry sample. If the same test sample was first tested by Test Method C 117, include the mass of material finer than the 75-µm (No. 200) size by washing in the sieve analysis calculation; and use the total dry sample mass prior to washing in Test Method C 117 as the basis for calculating all the percentages.

9.1.1 When sample increments are tested as provided in 7.6, total the masses of the portion of the increments retained on each sieve, and use these masses to calculate the percentages as in 9.1.

9.2 Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: 150-µm (No. 100), 300-µm (No. 50), 600-µm (No. 30), 1.18-mm (No. 16), 2.36-mm (No. 8), 4.75-mm (No. 4), 9.5-mm (⅜-in.), 19.0-mm (¾-in.), 37.5-mm (1½-in.), and larger, increasing in the ratio of 2 to 1.

## 10. Report

10.1 Depending upon the form of the specifications for use of the material under test, the report shall include the following:

10.1.1 Total percentage of material passing each sieve, or

10.1.2 Total percentage of material retained on each sieve, or

10.1.3 Percentage of material retained between consecutive sieves.

10.2 Report percentages to the nearest whole number, except if the percentage passing the 75-µm (No. 200) sieve is less than 10 %, it shall be reported to the nearest 0.1 %.

10.3 Report the fineness modulus, when required, to the nearest 0.01.

## 11. Precision and Bias

11.1 *Precision*—The estimates of precision for this test method are listed in Table 2. The estimates are based on the results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by Test Method C 136 and AASHTO Test Method T 27. The data are based on the analyses of the test results from 65 to 233 laboratories that tested 18 pairs of coarse aggregate proficiency test samples and test results from 74 to 222 laboratories that tested 17 pairs of fine aggregate proficiency test samples (Samples No. 21 through 90). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

11.1.1 The precision values for fine aggregate in Table 2 are based on nominal 500-g test samples. Revision of this test method in 1994 permits the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 3, which indicate only minor differences due to test sample size.

NOTE 6—The values for fine aggregate in Table 2 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

**TABLE 2 Precision**

| | Total Percentage of Material Passing | | Standard Deviation (1s), %[A] | Acceptable Range of Two Results (d2s), %[A] |
|---|---|---|---|---|
| *Coarse Aggregate:*[B] | | | | |
| Single-operator precision | <100 | ≥95 | 0.32 | 0.9 |
| | <95 | ≥85 | 0.81 | 2.3 |
| | <85 | ≥80 | 1.34 | 3.8 |
| | <80 | ≥60 | 2.25 | 6.4 |
| | <60 | ≥20 | 1.32 | 3.7 |
| | <20 | ≥15 | 0.96 | 2.7 |
| | <15 | ≥10 | 1.00 | 2.8 |
| | <10 | ≥5 | 0.75 | 2.1 |
| | <5 | ≥2 | 0.53 | 1.5 |
| | <2 | >0 | 0.27 | 0.8 |
| Multilaboratory precision | <100 | ≥95 | 0.35 | 1.0 |
| | <95 | ≥85 | 1.37 | 3.9 |
| | <85 | ≥80 | 1.92 | 5.4 |
| | <80 | ≥60 | 2.82 | 8.0 |
| | <60 | ≥20 | 1.97 | 5.6 |
| | <20 | ≥15 | 1.60 | 4.5 |
| | <15 | ≥10 | 1.48 | 4.2 |
| | <10 | ≥5 | 1.22 | 3.4 |
| | <5 | ≥2 | 1.04 | 3.0 |
| | <2 | >0 | 0.45 | 1.3 |
| *Fine Aggregate:* | | | | |
| Single-operator precision | <100 | ≥95 | 0.26 | 0.7 |
| | <95 | ≥60 | 0.55 | 1.6 |
| | <60 | ≥20 | 0.83 | 2.4 |
| | <20 | ≥15 | 0.54 | 1.5 |
| | <15 | ≥10 | 0.36 | 1.0 |
| | <10 | ≥2 | 0.37 | 1.1 |
| | <2 | >0 | 0.14 | 0.4 |
| Multilaboratory precision | <100 | ≥95 | 0.23 | 0.6 |
| | <95 | ≥60 | 0.77 | 2.2 |
| | <60 | ≥20 | 1.41 | 4.0 |
| | <20 | ≥15 | 1.10 | 3.1 |
| | <15 | ≥10 | 0.73 | 2.1 |
| | <10 | ≥2 | 0.65 | 1.8 |
| | <2 | >0 | 0.31 | 0.9 |

[A] These numbers represent, respectively, the (1s) and (d2s) limits described in Practice C 670.

[B] The precision estimates are based on aggregates with nominal maximum size of 19.0 mm (¾ in.).

11.2 *Bias*—Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

## 12. Keywords

12.1 aggregate; coarse aggregate; fine aggregate; gradation; grading; sieve analysis; size analysis

**TABLE 3 Precision Data for 300-g and 500-g Test Samples**

| Fine Aggregate Proficiency Sample | | | | Within Laboratory | | Between Laboratory | |
|---|---|---|---|---|---|---|---|
| Test Result | Sample Size | Number Labs | Average | 1s | d2s | 1s | d2s |
| ASTM C136/AASHTO T27 | | | | | | | |
| Total material passing the No. 4 sieve (%) | 500 g | 285 | 99.992 | 0.027 | 0.066 | 0.037 | 0.104 |
| | 300 g | 276 | 99.990 | 0.021 | 0.060 | 0.042 | 0.117 |
| Total material passing the No. 8 sieve (%) | 500 g | 281 | 84.10 | 0.43 | 1.21 | 0.63 | 1.76 |
| | 300 g | 274 | 84.32 | 0.39 | 1.09 | 0.69 | 1.92 |
| Total material passing the No. 16 sieve (%) | 500 g | 286 | 70.11 | 0.53 | 1.49 | 0.75 | 2.10 |
| | 300 g | 272 | 70.00 | 0.62 | 1.74 | 0.76 | 2.12 |
| Total material passing the No. 30 sieve (%) | 500 g | 287 | 48.54 | 0.75 | 2.10 | 1.33 | 3.73 |
| | 300 g | 276 | 48.44 | 0.87 | 2.44 | 1.36 | 3.79 |
| Total material passing the No. 50 sieve (%) | 500 g | 286 | 13.52 | 0.42 | 1.17 | 0.98 | 2.73 |
| | 300 g | 275 | 13.51 | 0.45 | 1.25 | 0.99 | 2.76 |
| Total material passing the No. 100 sieve (%) | 500 g | 287 | 2.55 | 0.15 | 0.42 | 0.37 | 1.03 |
| | 300 g | 270 | 2.52 | 0.18 | 0.52 | 0.32 | 0.89 |
| Total Material passing the No. 200 sieve (%) | 500 g | 278 | 1.32 | 0.11 | 0.32 | 0.31 | 0.85 |
| | 300 g | 266 | 1.30 | 0.14 | 0.39 | 0.31 | 0.85 |

## SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporatedsince the last issue.

(1) Paragraph 8.4 was revised.

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Designation: C 142 – 97

American Association of State
Highway and Transportation Officials Standard
AASHTO No. T112

# Standard Test Method for Clay Lumps and Friable Particles in Aggregates[1]

This standard is issued under the fixed designation C 142; 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 approximate determination of clay lumps and friable particles in aggregates.

1.2 The values given in SI units are to be regarded as the standard. The values given in parentheses are provided for information purposes 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:*

C 33 Specification for Concrete Aggregates[2]

C 117 Test Method for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 1005 Specification for Reference Masses and Devices for Determining Mass for Use in the Physical Testing of Hydraulic Cements[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

## 3. Significance and Use

3.1 This test method is of primary significance in determining the acceptability of aggregate with respect to the requirements of Specification C 33.

## 4. Apparatus

4.1 *Balance*—A balance or scale accurate to within 0.1 % of the mass of the test sample at any point within the range of use. Balances shall conform to the accuracy of the applicable sections of Specification C 1005.

4.2 *Containers*—Rust-resistant containers of a size and shape that will permit the spreading of the sample on the bottom in a thin layer.

4.3 *Sieves*—Sieves conforming to Specification E 11.

4.4 *Drying Oven*—An oven providing free circulation of air and capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F).

## 5. Samples

5.1 Aggregate for this test method shall consist of the material remaining after completion of testing in accordance with Test Method C 117. To provide the quantities designated in 5.3 and 5.4 it may be necessary to combine material from more than one test by Test Method C 117.

5.2 Dry the aggregate to substantially constant mass at a temperature of 110 ± 5°C (230 ± 9°F).

5.3 Test samples of fine aggregate shall consist of the particles coarser than a 1.18-mm (No. 16) sieve and shall have a mass not less than 25 g.

5.4 Separate the test samples of coarse aggregate into different sizes, using the following sieves: 4.75-mm (No. 4), 9.5-mm (⅜-in.), 19.0-mm (¾-in.), and 37.5-mm (1½-in.). The test sample shall have a mass not less than indicated in the following table:

| Size of Particles Making Up Test Sample | Mass of Test Sample, min, g |
|---|---|
| 4.75 to 9.5-mm (No. 4 to ⅜-in.) | 1000 |
| 9.5 to 19.0-mm (⅜ to ¾-in.) | 2000 |
| 19.0 to 37.5-mm (¾ to 1½-in.) | 3000 |
| Over 37.5-mm (1½-in.) | 5000 |

5.5 In the case of mixtures of fine and coarse aggregates, separate the material on the 4.75-mm (No. 4) sieve, and prepare the samples of fine and coarse aggregates in accordance with 5.3 and 5.4.

## 6. Procedure

6.1 Determine the mass of the test sample to the accuracy specified in 4.1 and spread it in a thin layer on the bottom of the container, cover it with distilled water, and soak it for a period of 24 ± 4 h. Roll and squeeze particles individually between the thumb and forefinger to attempt to break the particle into smaller sizes. Do not use the fingernails to break up particles, or press particles against a hard surface or each other. Classify any particles that can be broken with the fingers into fines removable by wet sieving as clay lumps or friable particles. After all discernible clay lumps and friable particles have been broken, separate the detritus from the remainder of the sample by wet sieving over the sieve prescribed in the following table:

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[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

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

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| Size of Particles Making Up Sample | Size of Sieve for Removing Residue of Clay Lumps and Friable Particles |
|---|---|
| Fine aggregate (retained on 1.18-mm (No. 16) sieve) | 850-µm (No. 20) |
| 4.75 to 9.5-mm (No. 4 to ⅜-in.) | 2.36-mm (No. 8) |
| 9.5 to 19.0-mm (⅜ to ¾-in.) | 4.75-mm (No. 4) |
| 19.0 to 37.5-mm (¾ to 1½-in.) | 4.75-mm (No. 4) |
| Over 37.5-mm (1½-in.) | 4.75-mm (No. 4) |

Perform the wet sieving by passing water over the sample through the sieve while manually agitating the sieve, until all undersize material has been removed.

6.2 Remove the retained particles carefully from the sieve, dry to substantially constant mass at a temperature of 110 ± 5°C (230 ± 9°F), allow to cool, and determine the mass to the nearest 0.1 % of the mass of the test sample as defined in 5.3 or 5.4.

## 7. Calculation

7.1 Calculate the percent of clay lumps and friable particles in fine aggregate or individual sizes of coarse aggregate as follows:

$$P = [(M - R)/M] \times 100 \quad (1)$$

where:

$P$ = percent of clay lumps and friable particles,
$M$ = mass of test sample (for fine aggregate the mass of the portion coarser than the 1.18-mm (No. 16) sieve as described in 5.3), and
$R$ = mass of particles retained on designated sieve as determined in accordance with 6.2.

7.2 For coarse aggregates, the percent of clay lumps and friable particles shall be an average based on the percent of clay lumps and friable particles in each sieve size fraction weighted in accordance with the grading of the original sample before separation or, preferably, the average grading of the supply represented by the sample. Should the aggregate contain less than 5 % of any of the sizes specified in 6.1, that size shall not be tested but, for the purpose of calculating the weighted average, shall be considered to contain the same percent of clay lumps and friable particles as the next larger or next smaller size, whichever is present.

## 8. Precision and Bias

8.1 *Precision*[5]—The estimate of the precision of this test method is provisional and is based on samples of one fine aggregate which was tested by ten different operators at nine different laboratories. For that sample, the average "percent of clay lumps and friable particles" in the aggregate was 1.2 %, and the standard deviation was 0.6 %. Based on this standard deviation, the acceptable range of two test results on samples from the same aggregate sent to different laboratories is 1.7 %.

8.2 *Bias*—Since there is no acceptable reference material for determining the bias for the procedure in this test method, no statement is being made.

## 9. Keywords

9.1 aggregates; clay lumps; friable particles

[5] A research report is on file at ASTM Headeuarters. Request RR:C09-1016.

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**Designation: C 88 – 99a**

# Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate[1]

This standard is issued under the fixed designation C 88; 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 covers the testing of aggregates to estimate their soundness when subjected to weathering action in concrete or other applications. This is accomplished by repeated immersion in saturated solutions of sodium or magnesium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing. This test method furnishes information helpful in judging the soundness of aggregates when adequate information is not available from service records of the material exposed to actual weathering conditions.

1.2 The values given in parentheses are provided for information purposes only.

1.3 *This standard does not purport to address the safety problems 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:*

C 33 Specification for Concrete Aggregates[2]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 3665 Practice for Random Sampling of Construction Materials[3]

E 11 Specification for Wire Cloth Sieves for Testing Purposes[4]

E 100 Specification for ASTM Hydrometers[5]

E 323 Specification for Perforated-Plate Sieves for Testing Purposes[4]

## 3. Significance and Use

3.1 This test method provides a procedure for making a preliminary estimate of the soundness of aggregates for use in concrete and other purposes. The values obtained may be compared with specifications, for example Specification C 33, that are designed to indicate the suitability of aggregate proposed for use. Since the precision of this test method is poor (Section 12), it may not be suitable for outright rejection of aggregates without confirmation from other tests more closely related to the specific service intended.

3.2 Values for the permitted-loss percentage by this test method are usually different for fine and coarse aggregates, and attention is called to the fact that test results by use of the two salts differ considerably and care must be exercised in fixing proper limits in any specifications that include requirements for these tests. The test is usually more severe when magnesium sulfate is used; accordingly, limits for percent loss allowed when magnesium sulfate is used are normally higher than limits when sodium sulfate is used.

NOTE 1—Refer to the appropriate sections in Specification C 33 establishing conditions for acceptance of coarse and fine aggregates which fail to meet requirements based on this test.

## 4. Apparatus

4.1 *Sieves*—With square openings of the following sizes

[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregatesand is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ATSM Standards*, Vol 04.03.

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

[5] *Annual Book of ASTM Standards*, Vol 14.03.

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conforming to Specifications E 11 or E 323, for sieving the samples in accordance with Sections 6, 7, and 9:

| | |
|---|---|
| 150 µm (No. 100) | 8.0 mm (5/16 in.) |
| | 9.5 mm (3/8 in.) |
| 300 µm (No. 50) | 12.5 mm (1/2 in.) |
| | 16.0 mm (5/8 in.) |
| 600 µm (No. 30) | 19.0 mm (3/4 in.) |
| | 25.0 mm (1 in.) |
| 1.18 mm (No. 16) | 31.5 mm (1 1/4 in.) |
| 2.36 mm (No. 8) | 37.5 mm (1 1/2 in.) |
| | 50 mm (2 in.) |
| 4.00 mm (No. 5) | 63 mm (2 1/2 in.) |
| | larger sizes by |
| 4.75 mm (No. 4) | 12.5-mm (1/2-in.) |
| | spread |

4.2 *Containers*—Containers for immersing the samples of aggregate in the solution, in accordance with the procedure described in this test method, shall be perforated in such a manner as to permit free access of the solution to the sample and drainage of the solution from the sample without loss of aggregate.

NOTE 2—Baskets made of suitable wire mesh or sieves with suitable openings are satisfactory containers for the samples.

4.3 *Temperature Regulation*—Suitable means for regulating the temperature of the samples during immersion in the sodium sulfate or magnesium sulfate solution shall be provided.

4.4 *Balances*—For fine aggregate, a balance or scale accurate within 0.1 g over the range required for this test; for coarse aggregate, a balance or scale accurate within 0.1 % or 1 g, whichever is greater, over the range required for this test.

4.5 *Drying Oven*—The oven shall be capable of being heated continuously at 230 ± 9°F (110 ± 5°C) and the rate of evaporation, at this range of temperature, shall be at least 25 g/h for 4 h, during which period the doors of the oven shall be kept closed. This rate shall be determined by the loss of water from 1-L Griffin low-form beakers, each initially containing 500 g of water at a temperature of 70 ± 3°F (21 ± 2°C), placed at each corner and the center of each shelf of the oven. The evaporation requirement is to apply to all test locations when the oven is empty except for the beakers of water.

4.6 *Specific Gravity Measurement*—Hydrometers conforming to the requirements of Specification E 100, or a suitable combination of graduated glassware and balance, capable of measuring the solution specific gravity within ±0.001.

## 5. Special Solutions Required

5.1 Prepare the solution for immersion of test samples from either sodium or magnesium sulfate in accordance with 5.1.1 or 5.1.2 (Note 3). The volume of the solution shall be at least five times the solid volume of all samples immersed at any one time.

NOTE 3—Some aggregates containing carbonates of calcium or magnesium are attacked chemically by fresh sulfate solution, resulting in erroneously high measured losses. If this condition is encountered or is suspected, repeat the test using a filtered solution that has been used previously to test the same type of carbonate rock, provided that the solution meets the requirements of 5.1.1 and 5.1.2 for specific gravity.

5.1.1 *Sodium Sulfate Solution*—Prepare a saturated solution of sodium sulfate by dissolving a USP or equal grade of the salt in water at a temperature of 77 to 86°F (25 to 30°C). Add sufficient salt (Note 4), of either the anhydrous ($Na_2SO_4$) or the crystalline ($Na_2SO_4 \cdot 10H_2O$) form,[6] to ensure not only saturation but also the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool to 70 ± 2°F (21 ± 1°C). Again stir, and allow the solution to remain at the designated temperature for at least 48 h before use. Prior to each use, break up the salt cake, if any, in the container, stir the solution thoroughly, and determine the specific gravity of the solution. When used, the solution shall have a specific gravity not less than 1.151 nor more than 1.174. Discard a discolored solution, or filter it and check for specific gravity.

NOTE 4—For the solution, 215 g of anhydrous salt or 700 g of the decahydrate per litre of water are sufficient for saturation at 71.6°F (22°C). However, since these salts are not completely stable and since it is desirable that an excess of crystals be present, the use of not less than 350 g of the anhydrous salt or 750 g of the decahydrate salt per litre of water is recommended.

5.1.2 *Magnesium Sulfate Solution*—Prepare a saturated solution of magnesium sulfate by dissolving a USP or equal grade of the salt in water at a temperature of 77 to 86°F (25 to 30°C). Add sufficient salt (Note 5), of either the anhydrous ($MgSO_4$) or the crystalline ($MgSO_4 \cdot 7H_2O$) (Epsom salt) form, to ensure saturation and the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool to 70 ± 2°F (21 ± 1°C). Again stir, and allow the solution to remain at the designated temperature for at least 48 h before use. Prior to each use, break up the salt cake, if any, in the container, stir the solution thoroughly, and determine the specific gravity of the solution. When used, the solution shall have a specific gravity not less than 1.295 nor more than 1.308. Discard a discolored solution, or filter it and check for specific gravity.

NOTE 5—For the solution, 350 g of anhydrous salt or 1230 g of the heptahydrate per litre of water are sufficient for saturation at 73.4°F (23°C). However, since these salts are not completely stable, with the hydrous salt being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate salt be used and in an amount of not less than 1400 g/litre of water.

5.1.3 *Barium Chloride Solution*—Prepare 100 mL of 5 % barium chloride solution by dissolving 5 g of $BaCl_2$ in 100 mL of distilled water.

## 6. Samples

6.1 The sample shall be obtained in general accordance with Practice D 75 and reduced to test portion size in accordance with Practice C 702.

6.2 *Fine Aggregate*—Fine aggregate for the test shall be

[6] Experience with the test method indicates that a grade of sodium sulfate designated by the trade as dried powder, which may be considered as approximately anhydrous, is the most practical for use. That grade is more economically available than the anhydrous form. The decahydrate sodium sulfate presents difficulties in compounding the required solution on account of its cooling effect on the solution.

passed through a 9.5-mm (⅜-in.) sieve. The sample shall be of such size that it will yield not less than 100 g of each of the following sizes, which shall be available in amounts of 5 % or more, expressed in terms of the following sieves:

| Passing Sieve | Retained on Sieve |
|---|---|
| 600 µm (No. 30) | 300 µm (No. 50) |
| 1.18 mm (No. 16) | 600 µm (No. 30) |
| 2.36 mm (No. 8) | 1.18 mm (No. 16) |
| 4.75 mm (No. 4) | 2.36 mm (No. 8) |
| 9.5 mm (⅜ in.) | 4.75 mm (No. 4) |

6.3 *Coarse Aggregate*—Coarse aggregate for the test shall consist of material from which the sizes finer than the No. 4 sieve have been removed. The sample shall be of such a size that it will yield the following amounts of the indicated sizes that are available in amounts of 5 % or more:

| Size (Square-Opening Sieves) | Mass, g |
|---|---|
| 9.5 mm (⅜ in.) to 4.75 mm (No. 4) | 300 ± 5 |
| 19.0 mm (¾ in.) to 9.5 mm (⅜ in.) | 1000 ± 10 |
| Consisting of: | |
| 12.5-mm (½-in.) to 9.5-mm (⅜-in.) material | 330 ± 5 |
| 19.0-mm (¾-in.) to 12.5-mm (½-in.) material | 670 ± 10 |
| 37.5-mm (1½-in.) to 19.0-mm (¾ in.) | 1500 ± 50 |
| Consisting of: | |
| 25.0-mm (1-in.) to 19.0-mm (¾-in.) material | 500 ± 30 |
| 37.5-mm (1½-in.) to 25.0-mm (1-in.) material | 1000 ± 50 |
| 63-mm (2½ in.) to 37.5-mm (1½ in.) | 5000 ± 300 |
| Consisting of: | |
| 50-mm (2 in.) to 37.5-mm (1½-in.) material | 2000 ± 200 |
| 63-mm (2½-in.) to 50-mm (2-in.) material | 3000 ± 300 |
| Larger sizes by 25-mm (1-in.) spread in sieve size, each fraction | 7000 ± 1000 |

6.4 When an aggregate to be tested contains appreciable amounts of both fine and coarse material, having a grading with more than 10 weight % coarser than the 9.5-mm (⅜-in.) sieve and, also, more than 10 weight % finer than the 4.75-mm (No. 4) sieve, test separate samples of the minus No. 4 fraction and the plus No. 4 fraction in accordance with the procedures for fine aggregate and coarse aggregate, respectively. Report the results separately for the fine-aggregate fraction and the coarse-aggregate fraction, giving the percentages of the coarse- and fine-size fractions in the initial grading.

## 7. Preparation of Test Sample

7.1 *Fine Aggregate*—Thoroughly wash the sample of fine aggregate on a 300-µm (No. 50) sieve, dry to constant weight at 230 ± 9°F (110 ± 5°C), and separate into the different sizes by sieving, as follows: Make a rough separation of the graded sample by means of a nest of the standard sieves specified in 6.2. From the fractions obtained in this manner, select samples of sufficient size to yield 100 g after sieving to refusal. (In general, a 110-g sample will be sufficient.) Do not use fine aggregate sticking in the meshes of the sieves in preparing the samples. Weigh samples consisting of 100 ± 0.1 g out of each of the separated fractions after final sieving and place in separate containers for the test.

7.2 *Coarse Aggregate*—Thoroughly wash and dry the sample of coarse aggregate to constant weight at 230 ± 9°F (110 ± 5°C) and separate it into the different sizes shown in 6.3 by sieving to refusal. Weigh out quantities of the different sizes within the tolerances of 6.3 and, where the test portion consists of two sizes, combine them to the designated total weight. Record the weights of the test samples and their fractional components. In the case of sizes larger than 19.0 mm (¾in.), record the number of particles in the test samples.

## 8. Procedure

8.1 *Storage of Samples in Solution*—Immerse the samples in the prepared solution of sodium sulfate or magnesium sulfate for not less than 16 h nor more than 18 h in such a manner that the solution covers them to a depth of at least ½ in. (Note 6). Cover the containers to reduce evaporation and prevent the accidental addition of extraneous substances. Maintain the samples immersed in the solution at a temperature of 70 ± 2°F (21 ± 1°C) for the immersion period.

NOTE 6—Suitably weighted wire grids placed over the sample in the containers will permit this coverage to be achieved with very lightweight aggregates.

8.2 *Drying Samples After Immersion*—After the immersion period, remove the aggregate sample from the solution, permit it to drain for 15 ± 5 min, and place in the drying oven. The temperature of the oven shall have been brought previously to 230 ± 9°F (110± 5°C). Dry the samples at the specified temperature until constant weight has been achieved. Establish the time required to attain constant weight as follows: with the oven containing the maximum sample load expected, check the weight losses of test samples by removing and weighing them, without cooling, at intervals of 2 to 4 h; make enough checks to establish required drying time for the least favorable oven location (see 4.5) and sample condition (Note 7). Constant weight will be considered to have been achieved when weight loss is less than 0.1 % of sample weight in 4 h of drying. After constant weight has been achieved, allow the samples to cool to room temperature, when they shall again be immersed in the prepared solution as described in 8.1.

NOTE 7—Drying time required to reach constant weight may vary considerably for several reasons. Efficiency of drying will be reduced as cycles accumulate because of salt adhering to particles and, in some cases, because of increase in surface area due to breakdown. The different size fractions of aggregate will have differing drying rates. The smaller sizes will tend to dry more slowly because of their larger surface area and restricted interparticle voids, but this tendency may be altered by the effects of container size and shape.

8.3 *Number of Cycles*—Repeat the process of alternate immersion and drying until the required number of cycles is obtained.

8.4 After the completion of the final cycle and after the sample has cooled, wash the sample free from the sodium sulfate or magnesium sulfate as determined by the reaction of the wash water with barium chloride ($BaCl_2$). Wash by circulating water at 110 ± 10°F (43± 6°C) through the samples in their containers. This may be done by placing them in a tank into which the hot water can be introduced near the bottom and allowed to overflow. In the washing operation, the samples shall not be subjected to impact or abrasion that may tend to break up particles.

NOTE 8—Tap water containing sulfates when used for the wash water will cloud when tested with the barium chloride solution. The cloudiness of a solution of tap water and the barium chloride solution should be judged so that tested wash water with the same degree of cloudiness can be assumed to be free of sulfates from the test.

## 9. Quantitative Examination

9.1 Make the quantitative examination as follows:

9.1.1 After the sodium sulfate or magnesium sulfate has been removed, dry each fraction of the sample to constant weight at 230 ± 9°F (110 ± 5°C). Sieve the fine aggregate over the same sieve on which it was retained before the test, and sieve the coarse aggregate over the sieve shown below for the appropriate size of particle. For fine aggregate, the method and duration of sieving shall be the same as were used in preparing the test samples. For coarse aggregate, sieving shall be by hand, with agitation sufficient only to assure that all undersize material passes the designated sieve. No extra manipulation shall be employed to break up particles or cause them to pass the sieves. Weigh the material retained on each sieve and record each amount. The difference between each of these amounts and the initial weight of the fraction of the sample tested is the loss in the test and is to be expressed as a percentage of the initial weight for use in Table 1.

| Size of Aggregate | Sieve Used to Determine Loss |
|---|---|
| 63 mm (2½ in.) to 37.5 mm (1½ in.) | 31.5 mm (1¼ in.) |
| 37.5 mm (1½ in.) to 19.0 mm (¾ in.) | 16.0 mm (⅝ in.) |
| 19 mm (¾ in.) to 9.5 mm (⅜ in.) | 8.0 mm (5⁄16 in.) |
| 9.5 mm (⅜ in.) to 4.75 mm (No. 4) | 4.0 mm (No. 5) |

## 10. Qualitative Examination

10.1 Make a qualitative examination of test samples coarser than 19.0 mm (¾ in.) as follows (Note 9):

10.1.1 Separate the particles of each test sample into groups according to the action produced by the test (Note 9).

10.1.2 Record the number of particles showing each type of distress.

NOTE 9—Many types of action may be expected. In general, they may be classified as disintegration, splitting, crumbling, cracking, flaking, etc. While only particles larger than ¾ in. in size are required to be examined qualitatively, it is recommended that examination of the smaller sizes be made in order to determine whether there is any evidence of excessive splitting.

## 11. Report

11.1 Report the following data (Note 10):

11.1.1 Weight of each fraction of each sample before test,

11.1.2 Material from each fraction of the sample finer than the sieve designated in 9.1.1 for sieving after test, expressed as a percentage of the original weight of the fraction,

11.1.3 Weighted average calculated in accordance with Test Method C 136 from the percentage of loss for each fraction, based on the grading of the sample as received for examination or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative except that:

11.1.3.1 For fine aggregates (with less than 10 % coarser than the 9.5-mm (⅜-in.) sieve), assume sizes finer than the 300-µm (No. 50) sieve to have 0 % loss and sizes coarser than the 9.5-mm (⅜-in.) sieve to have the same loss as the next smaller size for which test data are available.

11.1.3.2 For coarse aggregate (with less than 10 % finer than the 4.75-mm (No. 4) sieve), assume sizes finer than the 4.75-mm (No. 4) sieve to have the same loss as the next larger size for which test data are available.

11.1.3.3 For an aggregate containing appreciable amounts of both fine and coarse material tested as two separate samples as required in 6.4, compute the weighted average losses separately for the minus No. 4 and plus No. 4 fractions based on recomputed gradings considering the fine fraction as 100 % and the coarse fraction as 100 %. Report the results separately giving the percentage of the minus No. 4 and plus No. 4 material in the initial grading.

11.1.3.4 For the purpose of calculating the weighted average, consider any sizes in 6.2 or 6.3 that contain less than 5 % of the sample to have the same loss as the average of the next smaller and the next larger size, or if one of these sizes is

**TABLE 1 Suggested Form for Recording Test Data (with Illustrative Test Values)**

| Sieve Size | | | Grading of Original Sample, % | Weight of Test Fractions Before Test, g | Percentage Passing Designated Sieve After Test | Weighted Percentage Loss |
|---|---|---|---|---|---|---|
| **Soundness Test of Fine Aggregate** | | | | | | |
| Minus 150 µm (No. 100) | | | 6 | ... | ... | ... |
| 300 µm (No. 50) to No. 100 | | | 11 | ... | ... | ... |
| 600 µm (No. 30) to No. 50 | | | 26 | 100 | 4.2 | 1.1 |
| 1.18 mm (No. 16) to No. 30 | | | 25 | 100 | 4.8 | 1.2 |
| 2.36 mm (No. 8) to No. 16 | | | 17 | 100 | 8.0 | 1.4 |
| 4.75 mm (No. 4) to No. 8 | | | 11 | 100 | 11.2 | 1.2 |
| 9.5 mm (⅜ in.) to No. 4 | | | 4 | ... | 11.2[A] | 0.4 |
| Totals | | | 100.0 | ... | ... | 5 |
| **Soundness Test of Coarse Aggregate** | | | | | | |
| 63 mm (2½ in.) to 50 mm (2 in.) | 2825 g | | | | | |
| 50 mm (2 in.) to 37.5 mm (1½ in.) | 1958 g | 2½ to 1½ in. | 20 | 4783 | 4.8 | 1.0 |
| 37.5 mm (1½ in.) to 25.0 mm (1 in.) | 1012 g | | | | | |
| 25 mm (1 in.) to 19.0 mm (¾ in.) | 513 g | 1½ to ¾ in. | 45 | 1525 | 8.0 | 3.6 |
| 19.0 mm (¾ in.) to 12.5 mm (½ in.) | 675 g | | | | | |
| 12.5 mm (in.) to 9.5 mm (in.) | 333 g | ¾ to ⅜ in. | 23 | 1008 | 9.6 | 2.2 |
| 9.5 mm (⅜ in.) to 4.75 mm (No. 4) | 298 g | | 12 | 298 | 11.2 | 1.3 |
| Totals | | | 100 | ... | ... | 8 |

[A] The percentage loss (11.2 %) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5 % of the original sample as received. See 11.1.3.4.

**TABLE 2 Suggested Form for Qualitative Examination (with Illustrative Test Values)**

| Sieve Size | Qualitative Examination of Coarse Sizes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Particles Exhibiting Distress | | | | | | | | |
| | Splitting | | Crumbling | | Cracking | | Flaking | | Total No. of Particles Before Test |
| | No. | % | No. | % | No. | % | No. | % | |
| 63 mm (2½ in.) to 37.5 mm (1½ in.) | 2 | 7 | ... | ... | 2 | 7 | ... | ... | 29 |
| 37.5 mm (1½ in.) to 19.0 mm (¾ in.) | 5 | 10 | 1 | 2 | 4 | 8 | ... | ... | 50 |

absent, to have the same loss as the next larger or next smaller size, whichever is present.

11.1.4 Report the weighted percentage loss to the nearest whole number,

11.1.5 In the case of particles coarser than 19.0 mm (¾ in.) before test: (*1*) The number of particles in each fraction before test, and (*2*) the number of particles affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc., as shown in Table 2, and

11.1.6 Kind of solution (sodium or magnesium sulfate) and whether the solution was freshly prepared or previously used.

NOTE 10—Table 1, shown with test values inserted for purpose of illustration, is a suggested form for recording test data. The test values shown might be appropriate for either salt, depending on the quality of the aggregate.

## 12. Precision

12.1 *Precision*—For coarse aggregate with weighted average sulfate soundness losses in the ranges of 6 to 16 % for sodium and 9 to 20 % for magnesium, the precision indexes are as follows:

| | Coefficient of Variation (1S %), %[A] | Difference Between Two Tests (D2S %), % of Average[A] |
|---|---|---|
| *Multilaboratory:* | | |
| Sodium sulfate | 41 | 116 |
| Magnesium sulfate | 25 | 71 |
| *Single-Operator:* | | |
| Sodium sulfate | 24 | 68 |
| Magnesium sulfate | 11 | 31 |

[A] These numbers represent, respectively, the (1S %) and (D2S %) limits as described in Practice C 670.

12.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for this procedure, no statement on bias is being made.

## 13. Keywords

13.1 aggregates; magnesium sulfate; sodium sulfate; soundness; weathering

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Designation: D 2419 – 02

# Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate[1]

This standard is issued under the fixed designation D 2419; 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 is intended to serve as a rapid field-correlation test. The purpose of this test method is to indicate, under standard conditions, the relative proportions of clay-like or plastic fines and dust in granular soils and fine aggregates that pass the 4.75-mm (No. 4) sieve. The term "sand equivalent" expresses the concept that most granular soils and fine aggregates are mixtures of desirable coarse particles, sand, and generally undesirable clay or plastic fines and dust.

NOTE 1—Some agencies perform the test on material with a top size smaller than the 4.75-mm (No. 4) sieve. This is done to avoid trapping the clay-like or plastic fines and dust below flaky shaped 4.75 to 2.36 mm (No. 4 to 8) sized particles. Testing smaller top sized material may lower the numerical results of the test.

1.2 *Units of Measurement*:

1.2.1 The values stated in SI units are to be regarded as the standard, with the exception of the dimensions of the special sand equivalent test apparatus described in Fig. 1, in which the the inch dimensions are standard. Values 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:*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 8 Terminology Relating to Materials for Roads and Pavements[3]

D 75 Practice for Sampling Aggregates[3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

E 11 Specification for Wire-Cloth and Sieves for Testing Purposes[5]

2.2 *AASHTO Standard:*

T 176 Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of Sand Equivalent Test[6]

## 3. Terminology

3.1 *Definitions:*

3.1.1 *fine aggregate*—aggregate passing the 9.5-mm (⅜-in.) sieve and almost entirely passing the 4.75-mm (No. 4) sieve and predominantly retained on the 75-μm (No. 200) sieve (see Terminology D 8).

3.1.2 *sand equivalent*—a measure of the amount of silt or clay contamination in the fine aggregate (or soil) as determined by test (see Terminology D 653). (For further explanation, see Summary of Test Method and Significance and Use.)

3.1.3 *soil*—sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks which may or may not contain organic matter (see Terminology D 653).

## 4. Summary of Test Method

4.1 A measured volume of soil or fine aggregate and a small quantity of flocculating solution are poured into a graduated plastic cylinder and are agitated to loosen the claylike coatings from the sand particles in the test specimen. The specimen is then "irrigated" using additional flocculating solution forcing the claylike material into suspension above the sand. After a prescribed sedimentation period, the height of flocculated clay is read and the height of sand in the cylinder is determined. The sand equivalent is the ratio of the height of sand to the height of clay times 100.

## 5. Significance and Use

5.1 This test method assigns an empirical value to the relative amount, fineness, and character of claylike material present in the test specimen.

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[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.51 on Aggregate Tests.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

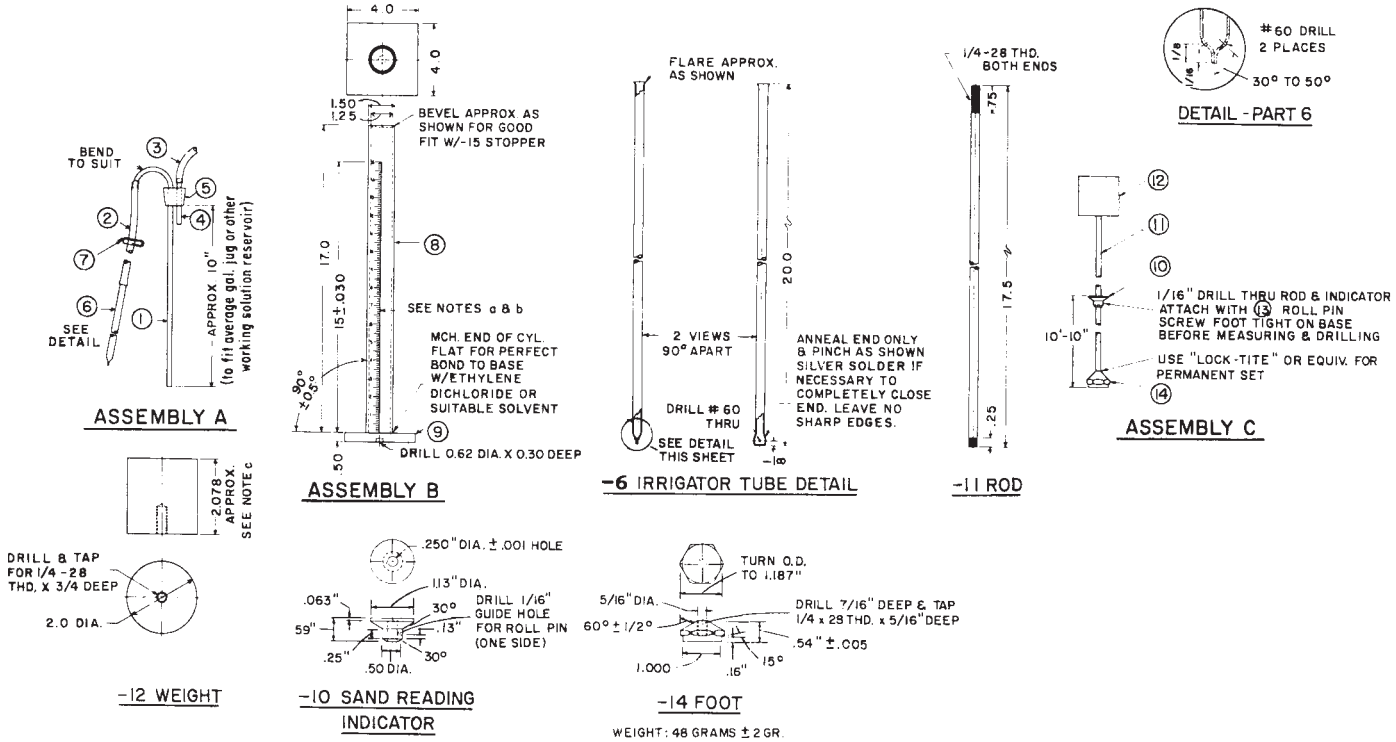
[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

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

[6] Available from American Association of State Highway and Transportation Officials, 444 N. Capitol St. NW, Suite 225, Washington, DC 20001.

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List of Material

| Assembly | Part No. | Description | Stock Size, In. | Material |
|---|---|---|---|---|
| *A* | | *Siphon Assembly:* | | |
| | 1 | siphon tube | ¼diameter by 16 | copper tube (may be plated) |
| | 2 | siphon hose | 3⁄16ID by 48 | rubber tube, pure gum or equivalent |
| | 3 | blow hose | 3⁄16 ID by 2 | rubber tube, pure gum or equivalent |
| | 4 | blow tube | ¼ diameter by 2 | copper tube (may be plated) |
| | 5 | 2-hole stopper | No. 6 | rubber |
| | 6 | irrigator tube | ¼OD 0.035 wall by 20 SS tube, Type 316 | |
| | 7 | clamp | Pinchcock, Day, BKH No. 21730 or equivalent | |
| *B* [A,B] | | *Graduate Assembly:* | | |
| | 8 | tube | 1.50 OD by 17 | transparent acrylic plastic |
| | 9 | base | ¼ by 4 by 4 | transparent acrylic plastic |
| *C* [C] | | *Weighted Foot Assembly:* | | |
| | 10 | sand reading indicator | 1¼diameter by 0.59 | nylon 101 type 66 annealed |
| | 11 | rod | ¼ diameter by 17½ | brass (may be plated) |
| | 12 | weight | 2 diameter by 2.078 | C. R. steel (may be plated) |
| | 13 | roll pin | 1⁄16 diameter by½ | corrosion-resistant metal |
| | 14 | foot | 11⁄16 hex by 0.54 | brass (may be plated) |
| | 15 | solid stopper | No. 7 | rubber |

[A] *Assembly B*—Accuracy of scale should be± 0.010 in. per tenth of an inch. Error at any point on scale should be± 0.030 in. of true distance to zero.
[B] *Assembly B*—Graduations on graduate should be in tenths of an inch. Inch marks should be numerically designated as shown. The inch and half-inch division lines should be approximately ¼ in. long. All division lines should be 0.015 in. deep with width across top 0.030 in.
[C] *Assembly C*—Weighted foot assembly should weigh 1000 ± 5 g.

*Metric Equivalents*

| in. | mm | in. | mm | in. | mm | in. | mm |
|---|---|---|---|---|---|---|---|
| 0.001 | 0.025 | 0.13 | 3.30 | 0.62 | 15.75 | 2 | 50.80 |
| 0.005 | 0.127 | 3⁄16 | 4.76 | 0.63 | 16.00 | 2.078 | 52.78 |
| 0.010 | 0.254 | 0.25 | 6.35 | 0.75 | 19.05 | 4 | 101.60 |
| 0.015 | 0.381 | ¼ | 6.35 | ¾ | 19.05 | 10.10 | 256.54 |
| 0.020 | 0.508 | 0.30 | 7.62 | 1 | 25.4 | 15 | 381.00 |
| 0.030 | 0.762 | 5⁄16 | 7.94 | 1 1⁄16 | 26.99 | 16 | 406.40 |
| 0.035 | 0.889 | ⅜ | 9.51 | 1.24 | 31.50 | 17 | 431.80 |
| 1⁄16 | 1.59 | 0.50 | 12.70 | 1¼ | 31.75 | 17.5 | 444.50 |
| 0.100 | 2.54 | 0.54 | 13.72 | 1.50 | 38.10 | 20 | 508.00 |
| ⅛ | 3.17 | 0.59 | 14.99 | 1½ | 38.10 | 48 | 1219.2 |

NOTE 1—The sand reading indicator and foot specified by ASTM Method D 2419 – 69. Fig. 1, may be used where this equipment is previously available.

**FIG. 1 Sand Equivalent Test Apparatus**

5.2 A minimum sand equivalent value may be specified to limit the permissible quantity of claylike fines in an aggregate.

5.3 This test method provides a rapid field method for determining changes in the quality of aggregates during production or placement.

## 6. Interferences

6.1 Maintain the temperature of the working solution at 22 ± 3°C (72 ± 5°F) during the performance of this test.

NOTE 2—If field conditions preclude the maintenance of the temperature range, frequent referee samples should be submitted to a laboratory where proper temperature control is possible. It is also possible to establish temperature correction curves for each material being tested where proper temperature control is not possible. However, no general correction should be utilized for several materials even within a narrow range of sand equivalent values. Samples that meet the minimum sand equivalent requirement at a working solution temperature below the recommended range need not be subject to referee testing.

6.2 Perform the test at a location free from vibration. Excessive vibration may cause the suspended material to settle at a greater rate than normal.

6.3 Do not expose the plastic cylinders to direct sunlight any more than is necessary.

6.4 Occasionally it may be necessary to remove a fungus growth from the working calcium chloride solution container and from the inside of the flexible tubing and irrigator tube. This fungus can easily be seen as a slimy substance in the solution, or as a mold growing on the inside of the container.

6.4.1 To remove this growth, prepare a cleaning solvent by diluting sodium hypochlorite solution (household chlorine bleach) with an equal quantity of water.

6.4.2 After discarding the contaminated solution, fill the solution container with the prepared cleaning solvent: allow about 1 L of the cleaning solvent to flow through the siphon assembly and irrigator tube, then place the pinch clamp on the end of the tubing to cut off the flow of solvent and to hold the solvent in the tube. Refill the container and allow to stand overnight.

6.4.3 After soaking, allow the cleaning solvent to flow out through the siphon assembly and irrigator tube.

6.4.4 Remove the siphon assembly from the solution container and rinse both with clear water. The irrigator tube and siphon assembly can be rinsed easily by attaching a hose between the tip of the irrigator tube and water faucet and backwashing fresh water through the tube.

6.5 Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out using extreme care not to enlarge the size of the opening.

6.6 Working solution which is more than two weeks old shall be discarded.

6.7 Mixing and storage container(s) for solutions shall be thoroughly rinsed prior to mixing a fresh batch of solution.

6.8 Fresh solution shall not be added to old solution regardless of age.

## 7. Apparatus

7.1 A graduated transparent acrylic plastic cylinder, rubber stopper, irrigator tube, weighted foot assembly and siphon assembly all conforming to the respective specifications and dimensions shown in Fig. 1. See Annex A1 for alternative apparatus.

7.2 *Measuring Tin*— A cylindrical tin approximately 57 mm (2¼ in.) in diameter having a capacity of 85 ± 5 mL.

7.3 *4.75-mm (No. 4) Sieve*, conforming to the requirements of Specification E 11.

7.4 *Funnel*, wide-mouth, for transferring test specimens into the graduated cylinder.

7.5 *Bottles*, two 3.8-L (1.0-gal) to store stock solution and working solution.

7.6 *Flat Pan*, for mixing.

7.7 *Clock or Watch*, reading in minutes and seconds.

7.8 *Mechanical Sand Equivalent Shaker*, designed to hold the required graduated plastic cylinder in a horizontal position while subjecting it to a reciprocating motion parallel to its length and having a throw of 203.2 ± 1.0 mm (8 ± 0.04 in.) and operating at 175 ± 2 cpm. A typical apparatus is shown in Fig. 2. The shaker shall be securely fastened to a firm and level mount.

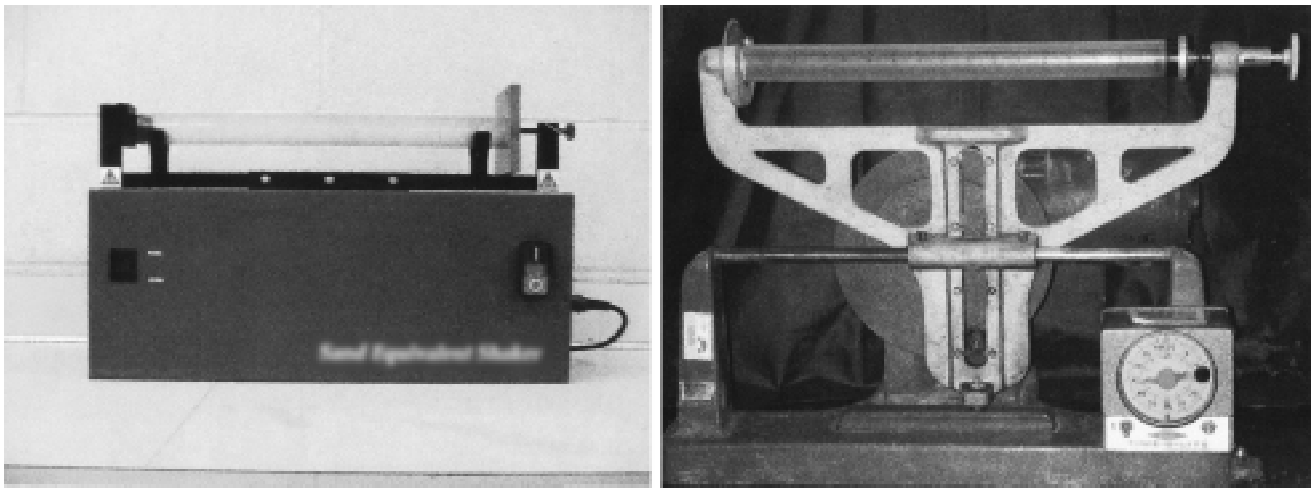


**FIG. 2 Mechanized Shakers**

NOTE 3—Moving parts of the mechanical shaker should be provided with a safety guard for protection of the operator.

7.9 *Manually Operated Sand Equivalent Shaker*— (optional), as shown in Fig. 3, or equivalent, capable of producing an oscillating motion at a rate of 100 complete cycles in 45 ± 5 s, with a hand-assisted half stroke length of 12.7 ± 0.5 cm (5 ± 0.2 in.). The device shall be designed to hold the required graduated cylinder in a horizontal position while subjecting it to a reciprocating motion parallel to its length. The shaker shall be fastened securely to a firm and level mount. If only a few tests are to be run the shaker may be held by hand on a firm level mount.

7.10 *Oven*, of sufficient size, and capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F).

7.11 *Filter Paper*, Watman No. 2V or equivalent.

## 8. Reagents and Materials

8.1 *Stock Solution*— The materials listed in 8.1.1, 8.1.2 or 8.1.3 may be used to prepare the stock solution. If the use of formaldehyde as the biocide is of concern, the materials in 8.1.2 or 8.1.3 should be used. A fourth alternative is not to use any biocide provided the time of storage of stock solution is not sufficient to promote the growth of fungi.

8.1.1 Stock solution with formaldehyde.

8.1.1.1 *Anhydrous Calcium Chloride*, 454 g (1.0 lb) of technical grade.

8.1.1.2 *USP Glycerin*, 2050 g (1640 mL).

8.1.1.3 *Formaldehyde*, (40 volume % solution) 47 g (45 mL).

8.1.1.4 Dissolve the 454 g (1.0 lb) of calcium chloride in 1.89 L (½ gal) of distilled water. Cool and filter through ready pleated rapid filtering paper. Add the 2050 g of glycerin and the 47 g of formaldehyde to the filtered solution, mix well, and dilute to 3.78 L (1 gal).

8.1.2 Stock solution with glutaraldehyde.

8.1.2.1 *Calcium Chloride Dihydrate*, 577 g (1.27 lb) of A. C. S. grade.

NOTE 4—ACS grade calcium chloride dihydrate is specified for the stock solution prepared with glutaraldehyde because tests indicate that impurities in the technical grade anhydrous calcium chloride may react with the glutaraldehyde resulting in an unknown precipitate.

8.1.2.2 *USP Glycerin*, 2050 g (1640 mL).

8.1.2.3 *1,5-Pentanedial (Glutaraldehyde)*, 50 % solution in water 59 g (53 mL).

8.1.2.4 Dissolve the 577 g (1.27 lb) of calcium chloride dihydrate in 1.89 L (½ gal) of distilled water. Cool and add the 2050 g of glycerin and the 59 g of glutaraldehyde to the solution, mix well, and dilute to 3.78 L (1 gal).

NOTE 5—1,5-pentanedial, also known as glutaraldehyde, glutaric dialdehyde, and trade name UCARCIDE 250, may be obtained as "Glutaraldehyde Solution 50 %."[7]

8.1.3 Stock solution with Kathon CG/ICP.

8.1.3.1 *Calcium Chloride Dihydrate*, 577 g (1.27 lb) of A. C. S. grade.

8.1.3.2 *USP Glycerin*, 2050 g (1640 mL).

8.1.3.3 *Kathon CG/ICP*[8], 63 g (53 mL).

8.1.3.4 Dissolve the 577 g (1.27 lb) of calcium chloride dihydrate in 1.89 L (½ gal) of distilled water. Cool and add the 2050 g of glycerin and the 63 g of Kathon CG/ICP to the solution, mix well, and dilute to 3.78 L (1 gal).

8.2 *Working Calcium Chloride Solution*—Prepare the working calcium chloride solution by diluting one measuring tin (85 ± 5 mL) full of the stock calcium chloride solution to 3.8 L (1.0 gal) with water. Use distilled or demineralized water for the normal preparation of the working solution. However, if it is determined that the local tap water is of such purity that it does not affect the test results, it is permissible to use it instead of distilled or demineralized water except in the event of dispute.

[7] Available from Aldrich Chemical Company, P. O. Box 2060, Milwaukee, WI 53201 or Fisher Scientific, 711 Forbes Ave., Pittsburg, PA 15219.

[8] Kathon CG/ICP may be obtained from Rohm and Hass Chemical Company, Independence Mall West, Philadelphia, PA 19105.

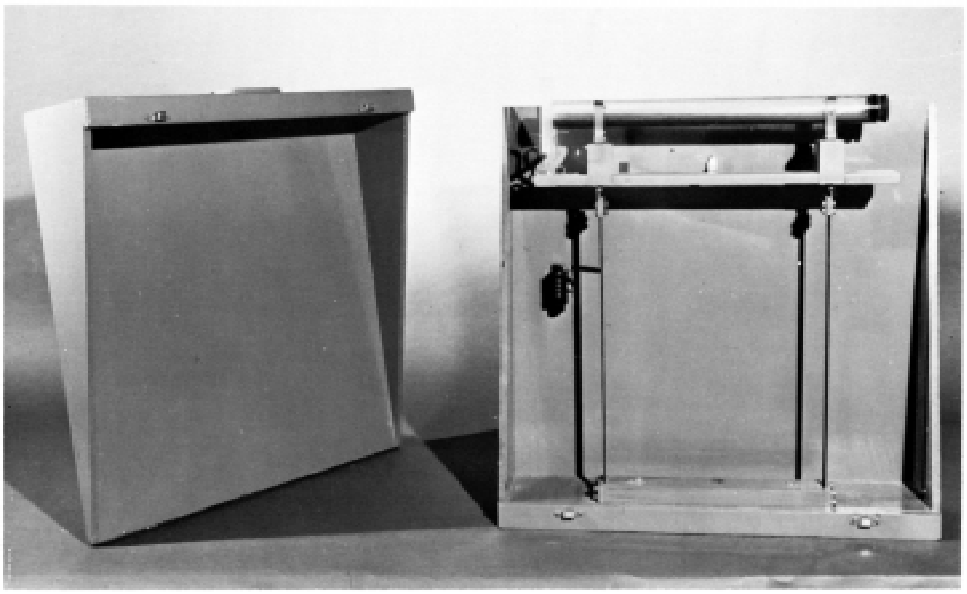


**FIG. 3 Manually Operated Shaker**

NOTE 6—The effect of local tap water on sand equivalent test results may be determined by comparing the results of three sand equivalent tests using distilled water with the results of three sand equivalent tests using the local tap water. The six test specimens required for this comparison shall be prepared from the sample of material and oven-dried as prescribed in this test method.

## 9. Sample Preparation

9.1 Sample the material to be tested in accordance with Practice D 75.

9.2 Thoroughly mix the sample and reduce it as necessary using the applicable procedures in Practice C 702.

9.3 Obtain at least 1500 g of material passing the 4.75-mm (No. 4) sieve in the following manner:

9.3.1 Separate the sample on the 4.75-mm (No. 4) sieve by means of a lateral and vertical motion of the sieve, accompanied by a jarring action so as to keep the sample moving continuously over the surface of the sieve. Continue the sieving until not more than 1 weight % of the residue passes the sieve during 1 min. Perform the sieving operation either by hand or by a mechanical apparatus. When thoroughness of mechanical sieving is being determined, test by the hand method described above using a single layer of material on the sieve.

9.3.2 Break down any lumps of material in the coarse fraction to pass the 4.75-mm (No. 4) sieve. Use a mortar and rubber-covered pestle or any other means that will not cause appreciable degradation of the aggregate.

9.3.3 Remove any coatings of fines adhering to the coarse aggregate. These fines may be removed by surface-drying the coarse aggregate, then rubbing between the hands over a flat pan.

9.3.4 Add the material passing the sieve obtained in 9.3.2 and 9.3.3 to the separated fine portion of the sample.

9.4 Prepare test specimens from the material passing the 4.75-mm (No. 4) sieve portion of the sample by either the procedure described in 9.4.1 or 9.4.2.

NOTE 7—Experiments show that as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is decreased. For this reason, it is imperative that extreme care be exercised when preparing the test specimens.

9.4.1 *Test Specimen Preparation, Procedure A*:

9.4.1.1 If it appears necessary, dampen the material to avoid segregation or loss of fines during the splitting or quartering operations. Use care in adding moisture to the sample to retain a free-flowing condition of the material.

9.4.1.2 Using the measuring tin, dip out four of these measures from the sample. Each time a measure full of the material is dipped from the sample, tap the bottom edge of the measure on a work table or other hard surface at least four times and jog it slightly to produce a measure of consolidated material level-full or slightly rounded above the brim.

9.4.1.3 Determine and record the amount of material contained in these four measures either by weight or by volume in a dry plastic cylinder.

9.4.1.4 Return this material back to the sample and proceed to split or quarter the sample, using the applicable procedures in Practice C 702 and making the necessary adjustments to obtain the predetermined weight or volume. When this weight or volume is obtained, two successive splitting or quartering operations without adjustment should provide the proper amount of material to fill the measure, and therefore provide one test specimen.

9.4.1.5 Dry the test specimen to constant weight at 110 ± 5°C (230 ± 9°F) and cool to room temperature before testing.

NOTE 8—Sand equivalent results on test specimens that have not been dried will generally be lower than the results obtained on identical test specimens that have been dried. As a time-saving expedient, it is permissible to test most materials without drying when the sand equivalent value is used to determine compliance with a specification giving a minimum acceptable test value. If the resulting test value is lower than that specified, however, it will be necessary to rerun the test on a dried test specimen. If the sand equivalent determined from a test on one dried test specimen, is below the minimum specification limit, it will be necessary to perform two additional tests on dried test specimens from the same sample. The sand equivalent for a sample shall be determined in accordance with the calculation section.

9.4.2 *Test Specimen Preparation, Procedure B*:

9.4.2.1 Maintaining a free-flowing condition, dampen the material sufficiently to prevent segregation or loss of fines.

9.4.2.2 Split or quarter out 1000 to 1500 g of the material. Mix thoroughly with a hand trowel in a circular pan by scooping toward the middle of the pan while rotating it horizontally. Mixing or remixing should be continued for at least 1 min to achieve uniformity. Check the material for the necessary moisture condition by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If a cast is formed that permits careful handling without breaking, the correct moisture range has been obtained. If the material is too dry, the cast will crumble and it will be necessary to add water and remix and retest until the material forms a cast. If the material shows any free water it is too wet to test and must be drained and air-dried, mixing it frequently to ensure uniformity. This overly wet material will form a good cast when checked initially, so the drying process should continue until a squeeze check on the drying material gives a cast which is more fragile and delicate to handle than the original. If the “as received” moisture content is within the limits described above, the sample may be run immediately. If the moisture content is altered to meet these limits, the sample should be put in the pan, covered with a lid or with a damp towel that does not touch the material, and allowed to stand for a minimum of 15 min.

9.4.2.3 After the minimum curing time, remix for 1 min without water. When thoroughly mixed, form the material into a cone with a trowel.

9.4.2.4 Take the tin measure in one hand and push it directly through the base of the pile while holding the free hand firmly against the pile opposite the measure.

9.4.2.5 As the can travels through the pile and emerges, hold enough hand pressure to cause the material to fill the can to overflowing. Press firmly with the palm of the hand, compacting the material until it consolidates in the can. The excess material should be struck off level with the top of the can, moving the edge of the trowel in a sawing motion across the brim.

9.4.2.6 To obtain additional test specimens, repeat the procedures in 9.4.2.3 through 9.4.2.5.

## 10. Preparation of Apparatus

10.1 Fit the siphon assembly to a 3.8-L (1.0-gal) bottle of working calcium chloride solution. Place the bottle on a shelf 90 ± 5 cm (36 ± 2 in.) above the working surface, (see Fig. 4).

NOTE 9—Instead of the 3.8-L (1.0-gal) bottle, a glass or plastic vat having a larger capacity may be used provided the liquid level of the working solution is maintained between 90 and 120 cm (36 and 48 in.) above the work surface.

10.2 Start the siphon by blowing into the top of the solution bottle through a short piece of tubing while the pinch clamp is open.

## 11. Procedure

11.1 Siphon 4 ± 0.1 in. (102 ± 3 mm) (indicated on the graduated cylinder) of working calcium chloride solution into the plastic cylinder.

11.2 Pour one of the test specimens into the plastic cylinder using the funnel to avoid spillage (see Fig. 5).

11.3 Tap the bottom of the cylinder sharply on the heel of the hand several times to release air bubbles and to promote thorough wetting of the specimen.

11.4 Allow the wetted specimen and cylinder to stand undisturbed for 10 ± 1 min.

11.5 At the end of the 10-min soaking period, stopper the cylinder, then loosen the material from the bottom by partially inverting the cylinder and shaking it simultaneously.

11.6 After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any of the following three methods:

11.6.1 *Mechanical Shaker Method*—Place the stoppered cylinder in the mechanical sand equivalent shaker, set the time, and allow the machine to shake the cylinder and the contents for 45 ± 1 s.

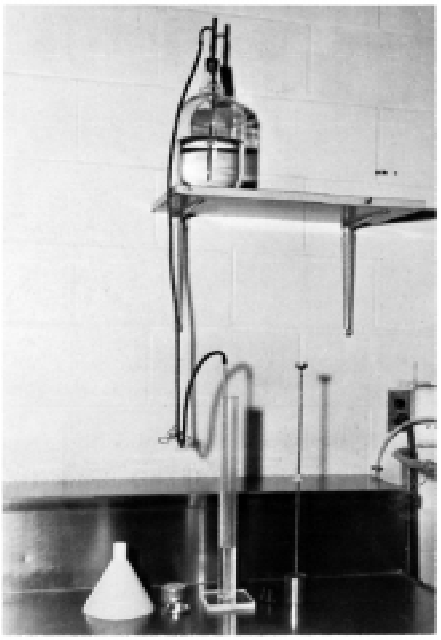


**FIG. 4 Graduated Cylinder, Irrigator Tube, Weighted Foot Assembly, and Siphon**



**FIG. 5 Transfer of Samples from Measuring Tin to Cylinder**

11.6.2 *Manual Shaker Method*:

11.6.2.1 Secure the stoppered cylinder in the three spring clamps of the carriage of the hand-operated sand equivalent shaker and reset the stroke counter to zero.

NOTE 10—To prevent spillage, be sure the stopper is firmly seated in the cylinder before placing in the manual shaker.

11.6.2.2 Stand directly in front of the shaker and force the pointer to the stroke limit marker painted on the backboard by applying an abrupt horizontal thrust to the upper portion of the right-hand spring steel strap. Then remove the hand from the strap and allow the spring action of the straps to move the carriage and cylinder in the opposite direction without assistance or hindrance.

11.6.2.3 Apply enough force to the right-hand spring steel strap during the thrust portion of each stroke to move the pointer to the stroke limit marker by pushing against the strap with the ends of the fingers to maintain a smooth oscillating motion (see Fig. 6). The center of the stroke limit marker is positioned to provide the proper stroke length and its width provides the maximum allowable limits of variation. The proper shaking action is accomplished only when the tip of the pointer reverses direction within the marker limits. Proper shaking action can best be maintained by using only the forearm and wrist action to propel the shaker.

11.6.2.4 Continue the shaking action for 100 strokes.

11.6.3 *Hand Method*:

11.6.3.1 Hold the cylinder in a horizontal position as illustrated in Fig. 7 and shake it vigorously in a horizontal linear motion from end to end.

11.6.3.2 Shake the cylinder 90 cycles in approximately 30 s using a throw of 23 ± 3 cm (9 ± 1 in.). A cycle is defined as a complete back and forth motion. To shake the cylinder at this speed properly, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.

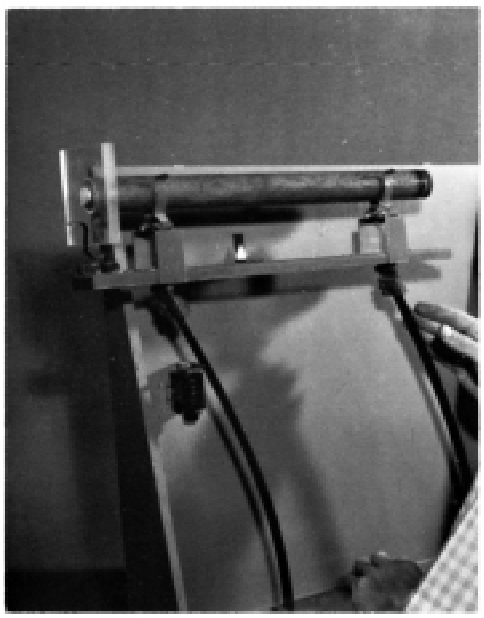


FIG. 6 Use of Manual Shaker



FIG. 7 Using Hand Method of Shaking

11.7 Following the shaking operation, set the cylinder upright on the work table and remove the stopper.

11.8 *Irrigation Procedure*:

11.8.1 During the irrigation procedure, keep the cylinder vertical and the base in contact with the work surface. Insert the irrigator tube in the top of the cylinder, remove the spring clamp from the hose, and rinse the material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action while the working solution flows from the irrigator tip. This flushes the fine material into suspension above the coarser sand particles (see Fig. 8).

11.8.2 Continue to apply a stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 15-in. (38.0 cm) graduation. Then raise the irrigator tube slowly without shutting off the flow so that the liquid level is maintained at about the 15-in. (38.0-cm) graduation while the irrigator tube is being withdrawn. Regulate the flow just before the irrigator tube is entirely withdrawn and adjust the final level to the 15-in. (38.0-cm) graduation.

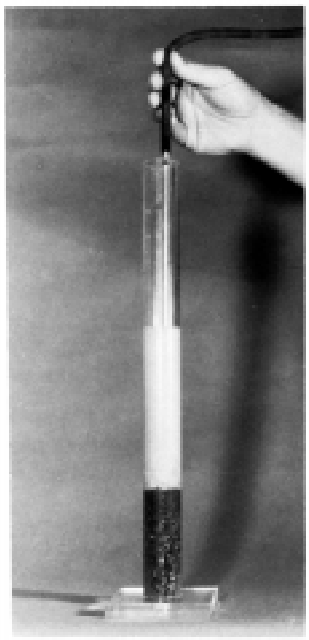


FIG. 8 Irrigation

11.9 Allow the cylinder and contents to stand undisturbed for 20 min ± 15 s. Start the timing immediately after withdrawing the irrigator tube.

11.10 At the end of the 20-min sedimentation period, read and record the level of the top of the clay suspension as prescribed in 11.12. This is referred to as the "clay reading." If no clear line of demarcation has formed at the end of the specified 20-min sedimentation period, allow the sample to stand undisturbed until a clay reading can be obtained; then immediately read and record the level of the top of the clay suspension and the total sedimentation time. If the total sedimentation time exceeds 30 min, rerun the test using three individual specimens of the same material. Record the clay column height for the sample requiring the shortest sedimentation period as the clay reading.

11.11 *Sand Reading Determination*:

11.11.1 After the clay reading has been taken, place the weighted foot assembly over the cylinder and gently lower the assembly until it comes to rest on the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered.

11.11.2 As the weighted foot comes to rest on the sand, tip the assembly toward the graduations on the cylinder until the indicator touches the inside of the cylinder. Subtract 10-in. (25.4 cm) from the level indicated by the extreme top edge of the indicator and record this value as the "sand reading" (see Fig. 9).

NOTE 11—See Annex A1 for the use of alternative foot apparatus and measurement procedure.

11.11.3 When taking the sand reading, use care not to press down on the weighted foot assembly since this could give an erroneous reading.

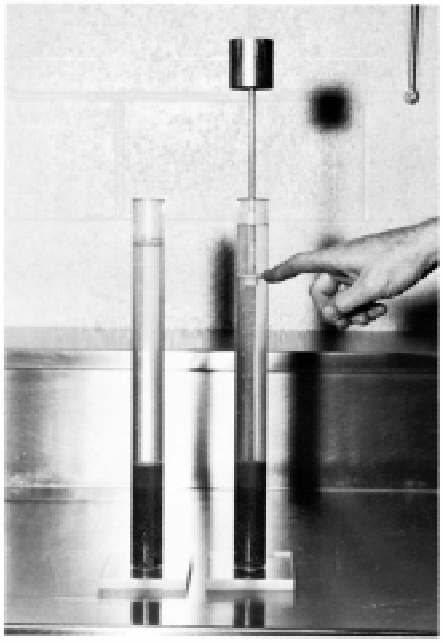


**FIG. 9 Sand Reading**

11.12 If clay or sand readings fall between 0.1-in. (2.5-mm) graduations, record the level of the higher graduation as the reading.

## 12. Calculation and Report

12.1 Calculate the sand equivalent to the nearest 0.1 % as follows:

$$SE = (\text{sand reading/clay reading}) \times 100 \quad (1)$$

where:
SE = sand equivalent.

12.2 If the calculated sand equivalent is not a whole number, report it as the next higher whole number. For example, if the clay level were 8.0 and the sand level were 3.3, the calculated sand equivalent would be:

$$(3.3/8.0) \times 100 = 41.2 \quad (2)$$

Since this calculated sand equivalent is not a whole number it would be reported as the next higher whole number which is 42.

12.3 If it is desired to average a series of sand equivalent values, average the whole number values determined as described in 12.2. If the average of these values is not a whole number, raise it to the next higher whole number as shown in the following example:

12.3.1 Calculate SE values: 41.2, 43.8, 40.9.

12.3.2 After raising each to the next higher whole number they become 42, 44, 41.

12.3.3 Determine the average of these values as follows:

$$(42 + 44 + 41)/3 = 42.3 \quad (3)$$

12.3.4 Since the average value is not a whole number, it is raised to the next higher whole number, and the sand equivalent value is reported as 43.

## 13. Precision and Bias

13.1 *Precision*—The following estimates of precision for this test method are based on results from the AASHTO Materials Reference Laboratory (AMRL) Reference Sample program, with testing conducted using this test method and AASHTO Method T 176. There are no significant differences between the two methods. The data are based on the analyses of eight paired test results from 50 to 80 laboratories, with the range of average sand equivalent values for the samples varying from approximately 60 to 90.

13.1.1 *Single Operator Precision*—The single operator standard deviation has been found to be 1.5 for sand equivalent values greater than 80 and 2.9 for values less than 80 (1s).[9] Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 4.2 and 8.2, respectively (d2s).

13.1.2 *Multi-laboratory Precision*—The multi-laboratory standard deviation has been found to be 4.4 for sand equivalent values greater than 80 and 8.0 for values less than 80 (1s).[9]Therefore, results of two properly conducted tests from different laboratories on similar material should not differ by more than 12.5 and 22.6,[9] respectively (d2s).

13.1.3 Additional precision data is available from a study done by one state agency involving the circulation of pairs of samples to over 20 laboratories on three separate occasions. The range of average sand equivalent values for these samples varied from approximately 30 to 50; these were materials containing much more fines than the AMRL samples reported on in 13.1.1 and 13.1.2.

13.1.3.1 The Multi-laboratory standard deviation from these single agency tests was found to be 3.2 (1s). Therefore, within the laboratories of this agency, results of two properly conducted tests from different laboratories on similar material should not differ by more than 9.1 (d2s).

13.2 *Bias*—The procedure in this test method has no bias because the value of sand equivalent is defined only in terms of the test method.

[9] These numbers represent, respectively, the (ls) and (d2s) limits as described in Practice C 670.

## ANNEX

**(Mandatory Information)**

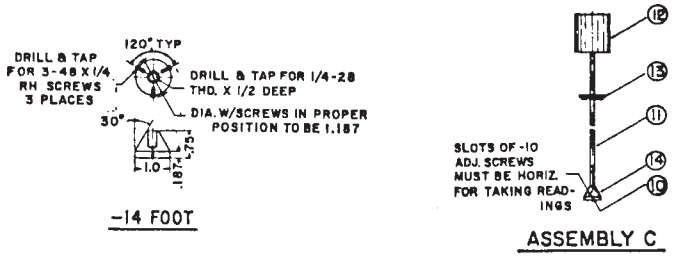
### A1. READING PROCEDURE FOR THE SAND READING WHEN THE 1969 SAND READING INDICATOR AND FOOT CONFORMING TO FIG. OF ASTM D2419 – 69 IS BEING USED

A1.1 *Differences in 1969 Equipment:*

A1.1.1 See Fig. A1.1 for the 1969 weighted foot (Assembly C) and the details of the 1969 Foot (Item 14).

A1.2 *Sand Reading Procedure* when 1969 foot assembly is used:

A1.2.1 After the clay reading has been taken, place the weighted foot assembly over the cylinder with the guide cap in position on the mouth of the cylinder and gently lower theassembly until it comes to rest on the sand. While the weighted foot is being lowered, keep one of the adj. screws (see Item 10 on Fig. A1.1) in contact with the cylinder wall near the graduations so that it can be seen at all times. When the weighted foot has come to rest on the sand, read and record the level of the horizontal slot of the adj. screw as the "Sand Reading" value.




| PART NO. | DESCRIPTION | STOCK SIZE | MATERIAL |
|---|---|---|---|
| 14 | Foot | 1 dia by ¾ | Bronze |
| 13 | Guide | 1.50 dia by ¼ | Brass |
| 12 | Weight | 2 dia by 2.078 | C.R.SH. |
| 11 | Rod | ¼ dia by 17½ | Brass |
| 10 | Adj. Screws | 3-48 by ¼ RH | Brass |

**FIG. A1.1 1969 Weighted Foot Assembly from Test Method D 2419 – 69**

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**Designation: D 5 – 97**

# Standard Test Method for Penetration of Bituminous Materials[1]

This standard is issued under the fixed designation D 5; 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 covers determination of the penetration of semi-solid and solid bituminous materials.

1.2 The needles, containers and other conditions described in this test method provide for the determinations of penetrations up to 500.

1.3 The values stated in SI units are to be considered standard.

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:*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

D 36 Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)[3]

E 1 Specification for ASTM Thermometers[4]

E 77 Test Method for Inspection and Verification of Liquid-in-Glass Thermometers[4]

2.2 *ANSI Standard:*

B46.1 Surface Texture[5]

2.3 *ISO Standard:*

ISO Standard 468 Surface Roughness—Parameters, Their Values and General Rules for Specifying Requirements[5]

## 3. Terminology

3.1 *Definitions:*

3.1.1 *penetration, n*—consistency of a bituminous material expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature.

**TABLE 1 Precision Criteria**

| Material | Standard Deviation or Coefficient of Variation (Is) or (Is %) | Acceptable Range of Two Test Results (d2s) or (d2s %) |
|---|---|---|
| Single-operator precision: | | |
| Asphalts at 77°F (25°C) below 50 penetration, units | 0.35 | 1 |
| Asphalts at 77°F (25°C) 60 penetration and above, percent of their mean | 1.4 | 4 |
| Tar pitches at 77°F (25°C)[A] percent of their mean | 5.2 | 15 |
| Multilaboratory precision: | | |
| Asphalts at 77°F (25°C) below 50 penetration, units | 1.4 | 4 |
| Asphalts at 77°F (25°C) 60 penetration and above, percent of their mean | 3.8 | 11 |
| Tar pitches at 77°F (25°C),[A] units | 1.4 | 4 |

[A] Estimates of precision for tar pitches are based on results from 2 pitches with penetration of 7 and 24. Estimates may not be applicable to appreciably harder or softer materials.

## 4. Summary of Test Method

4.1 The sample is melted and cooled under controlled conditions. The penetration is measured with a penetrometer by means of which a standard needle is applied to the sample under specific conditions.

## 5. Significance and Use

5.1 The penetration test is used as a measure of consistency. Higher values of penetration indicate softer consistency.

## 6. Apparatus

6.1 *Penetration Apparatus*—Any apparatus that permits the needle holder (spindle) to move vertically without measurable friction and is capable of indicating the depth of penetration to the nearest 0.1 mm, will be acceptable. The weight of the spindle shall be 47.5 ± 0.05 g. The total weight of the needle and spindle assembly shall be 50.0 ± 0.05 g. Weights of 50 ± 0.05 g and 100 ± 0.05 g shall also be provided for total loads of 100 g and 200 g, as required for some conditions of the test. The surface on which the sample container rests shall be flat and the axis of the plunger shall be at approximately 90° to this surface. The spindle shall be easily detached for checking its weight.

6.2 *Penetration Needle*:

6.2.1 The needle (see Fig. 1) shall be made from fully hardened and tempered stainless steel, Grade 440-C or equal,

[1] This test method is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.44 on Rheological Tests.

Current edition approved Nov. 10, 1997. Published February 1998. Originally published as D 5 – 59 T. Last previous edition D 5 – 95.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.04.

[4] *Annual Book of ASTM Standards*, Vol 14.03.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

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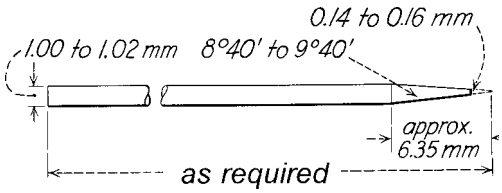



**FIG. 1 Needle for Penetration Test**

HRC 54 to 60. The standard needle shall be approximately 50 mm (2 in.) in length, the long needle approximately 60 mm (24 in.).[6] The diameter of all needles shall be 1.00 to 1.02 mm (0.0394 to 0.0402 in.). It shall be symmetrically tapered at one end by grinding to a cone having an angle between 8.7 and 9.7° over the entire cone length. The cone should be coaxial with the straight body of the needle. The total axial variation of the intersection between the conical and straight surfaces shall not be in excess of 0.2 mm (0.008 in.). The truncated tip of the cone shall be within the diameter limits of 0.14 and 0.16 mm (0.0055 and 0.0063 in.) and square to the needle axis within 2°. The entire edge of the truncated surface at the tip shall be sharp and free of burrs. When the surface texture is measured in accordance with American National Standard B 46.1 or ISO 468 the surface roughness height, Ra, of the tapered cone shall be 0.2 to 0.3 µm (8 to 12 µin.) arithmetic average. The surface roughness height, Ra, of the needle shank shall be 0.025 to 0.125 µm (1 to 5 µin.). The needle shall be mounted in a non-corroding metal ferrule. The ferrule shall be 3.2 ± 0.05 mm (0.126 ± 0.002 in.) in diameter and 38 ± 1 mm (1.50 ± 0.04 in.) in length. The exposed length of the standard needle shall be within the limits of 40 to 45 mm (1.57 to 1.77 in.), and the exposed length of the long needle shall be 50 to 55 mm (1.97 to 2.19 in.). The needle shall be rigidly mounted in the ferrule. The run-out (total-indicator reading) of the needle tip and any portion of the needle relative to the ferrule axis shall not exceed 1 mm (0.04 in.). The weight of the ferrule needle assembly shall be 2.50 ± 0.05 g. (A drill hole at the end of the ferrule or a flat on the side is permissible to control the weight.) Individual identification markings shall be placed on the ferrule of each needle; the same markings shall not be repeated by a manufacturer within a 3-year period.

6.2.2 Needles used in testing materials for conformance to specifications shall be shown to have met the requirements of 6.2.1 when tested by a qualified agency.

6.3 *Sample Container*[7]—A metal or glass cylindrical, flat-bottom container of essentially the following dimensions shall be used:

| | |
|---|---|
| For penetrations below 200: | |
| Diameter, mm | 55 |
| Internal depth, mm | 35 |
| For penetrations between 200 and 350: | |
| Diameter, mm | 55 |
| Internal depth, mm | 70 |

6.4 *Water Bath*—A bath having a capacity of at least 10 L and capable of maintaining a temperature of 25 ± 0.1°C or any other temperature of test within 0.1°C. The bath shall have a perforated shelf supported in a position not less than 50 mm from the bottom and not less than 100 mm below the liquid level in the bath. If penetration tests are to be made in the bath itself, an additional shelf strong enough to support the penetrometer shall be provided. Brine may be used in the bath for determinations at low temperatures.

NOTE 1—The use of distilled water is recommended for the bath. Take care to avoid contamination of the bath water by surface active agents, release agents, or other chemicals; as their presence may affect the penetration values obtained.

6.5 *Transfer Dish*—When used, the transfer dish shall have a capacity of at least 350 mL and of sufficient depth of water to cover the large sample container. It shall be provided with some means for obtaining a firm bearing and preventing rocking of the container. A three-legged stand with three-point contact for the sample container is a convenient way of ensuring this.

6.6 *Timing Device*—For hand-operated-penetrometers any convenient timing device such as an electric timer, a stop watch, or other spring activated device may be used provided it is graduated in 0.1 s or less and is accurate to within ±0.1 s for a 60-s interval. An audible seconds counter adjusted to provide 1 beat each 0.5 s may also be used. The time for a 11-count interval must be 5 ± 0.1 s. Any automatic timing device attached to a penetrometer must be accurately calibrated to provide the desired test interval within ±0.1 s.

6.7 *Thermometers*—Calibrated liquid–in–glass thermometers of suitable range with subdivisions and maximum scale error of 0.1°C (0.2°F) or any other thermometric device of equal accuracy, precision and sensitivity shall be used. Thermometers shall conform to the requirements of Specification E 1.

6.7.1 Suitable thermometers commonly used are:

| ASTM Number | Range |
|---|---|
| 17C or 17F | 19 to 27°C (66 to 80°F) |
| 63C or 63F | −8 to + 32°C (18 to 89°F) |
| 64C or 64F | 25 to 55°C (77 to 131°F) |

6.7.2 The thermometer used for the water bath shall periodically be calibrated in accordance with Test Method E 77.

## 7. Preparation of Test Specimen

7.1 Heat the sample with care, stirring when possible to prevent local overheating, until it has become sufficiently fluid to pour. In no case should the temperature be raised to more than 60°C above the expected softening point for tar pitch in accordance with Test Method D 36, or to more than 90°C above it for petroleum asphalt (bitumen). Do not heat samples for more than 30 min. Avoid incorporating bubbles into the sample.

7.2 Pour the sample into the sample container to a depth such that, when cooled to the temperature of test, the depth of the sample is at least 10 mm greater than the depth to which the needle is expected to penetrate. Pour two separate portions for each variation in test conditions.

7.3 Loosely cover each container as a protection against dust (a convenient way of doing this is by covering with a lipped beaker) and allow to cool in air at a temperature between 15 and 30°C for 1 to 1.5 h for the small container and 1.5 to 2

[6] Long needles are available from Stanhope-Seta, Park Close, Englefield Green, Egham, Surrey, U.K. TW20 OXD.

[7] Sample Containers are available from Ellisco Inc., 6301 Eastern Ave., Baltimore MD, 21224 and Freund Can Co., 155 West 84th St., Chicago IL, 60620–1298.

h for the taller. Then place the two samples together with the transfer dish, if used, in the water bath maintained at the prescribed temperature of test. Allow the smaller container to remain for 1 to 1.5 h and the taller (6 oz) container to remain for 1.5 to 2 h.

## 8. Test Conditions

8.1 Where the conditions of test are not specifically mentioned, the temperature, load, and time are understood to be 25°C (77°F), 100 g, and 5 s, respectively. Other conditions may be used for special testing, such as the following:

| Temperature, °C (°F) | Load, g | Time, s |
|---|---|---|
| 0 (32) | 200 | 60 |
| 4 (39.2) | 200 | 60 |
| 45 (113) | 50 | 5 |
| 46.1 (115) | 50 | 5 |

In such cases the specific conditions of test shall be reported.

## 9. Procedure

9.1 Examine the needle holder and guide to establish the absence of water and other extraneous materials. If the penetration is expected to exceed 350 use a long needle, otherwise use a short needle. Clean a penetration needle with toluene or other suitable solvent, dry with a clean cloth, and insert the needle into the penetrometer. Unless otherwise specified place the 50-g weight above the needle, making the total weight 100 ± 0.1 g.

9.2 If tests are to be made with the penetrometer in the bath, place the sample container directly on the submerged stand of the penetrometer (Note 2). Keep the sample container completely covered with water in the bath. If the tests are to be made with the penetrometer outside the bath, place the sample container in the transfer dish, cover the container completely with water from the constant temperature bath and place the transfer dish on the stand of the penetrometer.

NOTE 2—For referee tests, penetrations at temperatures other than 25°C (77°F) should be made without removing the sample from the bath.

9.3 Position the needle by slowly lowering it until its tip just makes contact with the surface of the sample. This is accomplished by bringing the actual needle tip into contact with its image reflected on the surface of the sample from a properly placed source of light (Note 3). Either note the reading of the penetrometer dial or bring the pointer to zero. Quickly release the needle holder for the specified period of time and adjust the instrument to measure the distance penetrated in tenths of a millimetre. If the container moves, ignore the result.

NOTE 3—The positioning of the needle can be materially aided by using an illuminated poly-methyl methacrylate tube.

9.4 Make at least three determinations at points on the surface of the sample not less than 10 mm from the side of the container and not less than 10 mm apart. If the transfer dish is used, return the sample and transfer dish to the constant temperature bath between determinations. Use a clean needle for each determination. If the penetration is greater than 200, use at least three needles leaving them in the sample until the three determinations have been completed.

## 10. Report

10.1 Report to nearest whole unit the average of three penetrations whose values do not differ by more than the following:

| | 0 to 49 | 50 to 149 | 150 to 249 | 250 to 500 |
|---|---|---|---|---|
| Penetration | | | | |
| Maximum difference between highest and lowest penetration | 2 | 4 | 12 | 20 |

## 11. Precision and Bias

11.1 Use the following criteria for judging the acceptability of penetration results for asphalt at 25°C. The precision at other temperatures is being determined.

11.1.1 *Single Operator Precision*—The single operator coefficient of variation has been found to be 1.4 % for penetrations above 60, and the single operator standard deviation has been found to be 0.35 % for penetrations below 50. Therefore, the results of two properly conducted tests by the same operator on the same material of any penetration, using the same equipment, should not differ from each other by more than 4 % of their mean, or 1 unit, whichever is larger.

11.1.2 *Multilaboratory Precision*—The multilaboratory coefficient of variation has been found to be 3.8 % for penetrations above 60, and the multilaboratory standard deviation has been found to be 1.4 for penetrations below 50. Therefore, the results of two properly conducted tests on the same material of any penetration, in two different laboratories, should not differ from each other by more than 11 % of their mean, or 4 units, whichever is larger.

NOTE 4—These values represent, respectively, the d1s (or d1s %) and d2s (or d2s %) limits as described in Practice C 670.

11.1.3 *Bias*—This test method has no bias because the values determined are defined only in terms of the test method.

## 12. Keywords

12.1 asphalt; bitumen; penetration

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Designation: D 113 – 99

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T51

# Standard Test Method for Ductility of Bituminous Materials[1]

This standard is issued under the fixed designation D 113; 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 The ductility of a bituminous material is measured by the distance to which it will elongate before breaking when two ends of a briquet specimen of the material, of the form described in Section 4, are pulled apart at a specified speed and at a specified temperature. Unless otherwise specified, the test shall be made at a temperature of 25 ± 0.5°C and with a speed of 5 cm/min ± 5.0 %. At other temperatures the speed should be specified.

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.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

D 5 Test Method for Penetration of Bituminous Materials[3]

D 1754 Test Method for Effects of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)[3]

D 2872 Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)[3]

E 1 Specification for ASTM Thermometers[4]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[5]

## 3. Significance and Use

3.1 This test method provides one measure of tensile properties of bituminous materials and may be used to measure ductility for specification requirements.

## 4. Apparatus

4.1 *Mold*—The mold shall be similar in design to that shown in Fig. 1. The mold shall be made of brass, the ends *b* and *b′* being known as clips, and the parts *a* and *a′* as sides of the mold. The dimensions of the assembled mold shall be as shown in Fig. 1 with the permissible variations indicated.

4.2 *Water Bath*—The water bath shall be maintained at the specified test temperature, varying not more than 0.18°F (0.1°C) from this temperature. The volume of water shall be not less than 10 L, and the specimen shall be immersed to a depth of not less than 10 cm and shall be supported on a perforated shelf not less than 5 cm from the bottom of the bath.

4.3 *Testing Machine*— For pulling the briquet of bituminous material apart, any apparatus may be used which is so constructed that the specimen will be continuously immersed in water as specified in 5.3, while the two clips are pulled apart at a uniform speed, as specified, without undue vibration.

4.4 *Thermometer*— A thermometer having a range as shown below and conforming to the requirements prescribed in Specification E 1 (Note 1).

| Temperature Range | ASTM Thermometer No. |
|---|---|
| −8 to 32°C | 63C |

NOTE 1—In those cases where the ductility specimens are aged in the standard penetration bath at 25°C, the thermometer as prescribed for Test Method D 5 may be substituted in place of the above.

## 5. Procedure

5.1 Assemble the mold on a brass plate. Thoroughly coat the surface of the plate and interior surfaces of the sides *a* and *a′*, Fig. 1, of the mold with a thin layer of a mixture of glycerin and dextrin, talc, or kaolin (china clay) to prevent the material under test from sticking. The plate upon which the mold is placed shall be perfectly flat and level so that the bottom surface of the mold will be in contact throughout. Carefully heat the sample to prevent local overheating until it has become sufficiently fluid to pour. Strain the melted sample through a 300-μm sieve conforming to Specification E 11. After a thorough stirring, pour it into the mold. In filling the mold, take care not to disarrange the parts and thus distort the briquet. In filling, pour the material in a thin stream back and forth from end to end of the mold until the mold is more than level full. Let the mold containing the material cool to room temperature

[1] This test method is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.44 on Rheological Tests.

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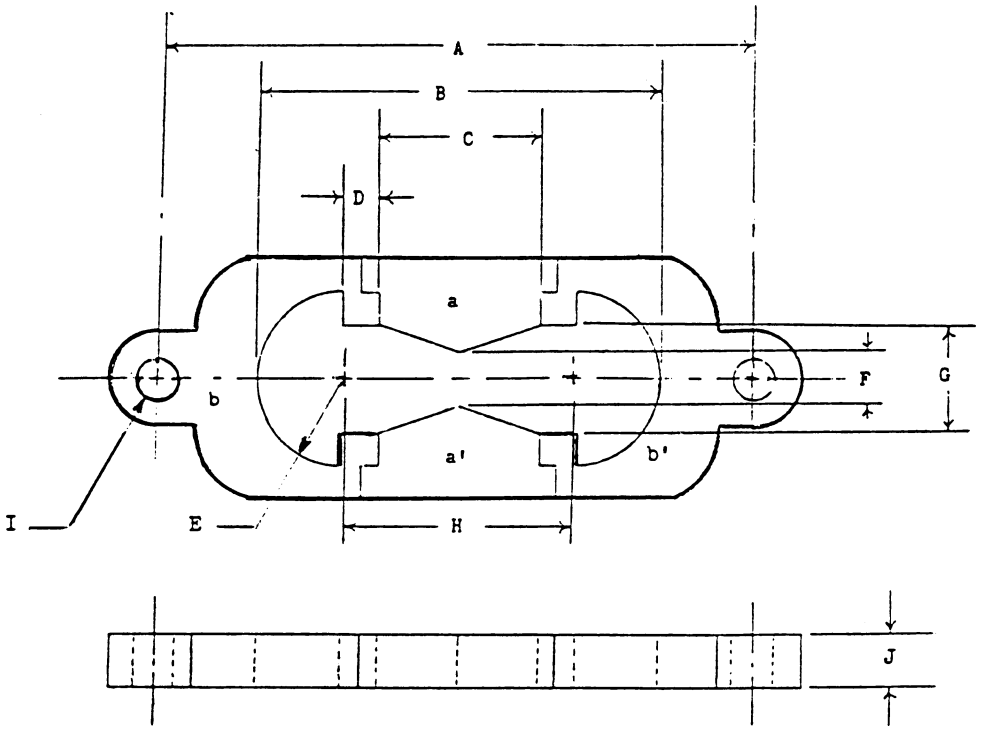
[2] *Annual Book of ASTM Standards,* Vol 04.02.

[3] *Annual Book of ASTM Standards,* Vol 04.03.

[4] *Annual Book of ASTM Standards,* Vol 14.03.

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

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A—Distance between centers, 111.5 to 113.5 mm.
B—Total length of briquet, 74.5 to 75.5 mm.
C—Distance between clips, 29.7 to 30.3 mm.
D—Shoulder, 6.8 to 7.2 mm.
E—Radius, 15.75 to 16.25 mm.
F—Width at minimum cross section, 9.9 to 10.1 mm.
G—Width at mouth of clip, 19.8 to 20.2 mm.
H—Distance between centers of radii, 42.9 to 43.1 mm.
I—Hole diameter, 6.5 to 6.7 mm.
J—Thickness, 9.9 to 10.1 mm.

**FIG. 1 Mold for Ductility Test Specimen**

for a period of from 30 to 40 min and then place it in the water bath maintained at the specified temperature of test for 30 min; then cut off the excess bitumen with a hot straightedged putty knife or spatula to make the mold just level full.

5.2 *Keeping Specimen at Standard Temperature*—Place the brass plate and mold, with briquet specimen, in the water bath and keep at the specified temperature for a period of from 85 to 95 min. Then remove the briquet from the plate, detach the side pieces, and immediately test the briquet.

5.3 *Testing*—Attach the rings at each end of the clips to the pins or hooks in the testing machine and pull the two clips apart at a uniform speed as specified until the briquet ruptures. A variation of ±5 % from the speed specified will be permissible. Measure the distance in centimetres through which the clips have been pulled to produce rupture. While the test is being made, the water in the tank of the testing machine shall cover the specimen both above and below it by at least 2.5 cm and shall be kept continuously at the temperature specified within 0.5°C.

## 6. Report

6.1 A normal test is one in which the material between the two clips pulls out to a point or thread until rupture occurs at the point where the thread has practically no cross-sectional area. Report the average of three normal tests as the ductility of the sample.

6.2 If the bituminous material comes in contact with the surface of the water or the bottom of the bath, the test shall not be considered normal. Adjust the specific gravity of the bath by the addition of either methyl alcohol or sodium chloride so that the bituminous material neither comes to the surface of the water, nor touches the bottom of the bath at any time during the test.

6.3 If a normal test is not obtainable on three tests, report the ductility as being unobtainable under the conditions of the test.

## 7. Precision

7.1 Criteria for judging the acceptability of ductility test results at 25°C obtained by this test method are shown in Fig. 2.

NOTE 2—The precision statement for ductility, as presented in Fig. 2, is based on tests performed on asphalt cements. The precision of tests on residues, such as those obtained by Test Methods D 1754 and D 2872, have not been established.

NOTE 3—The numbers plotted in Fig. 2 represent the (1S) and (D2S) limits for single operator precision and multilaboratory precision as

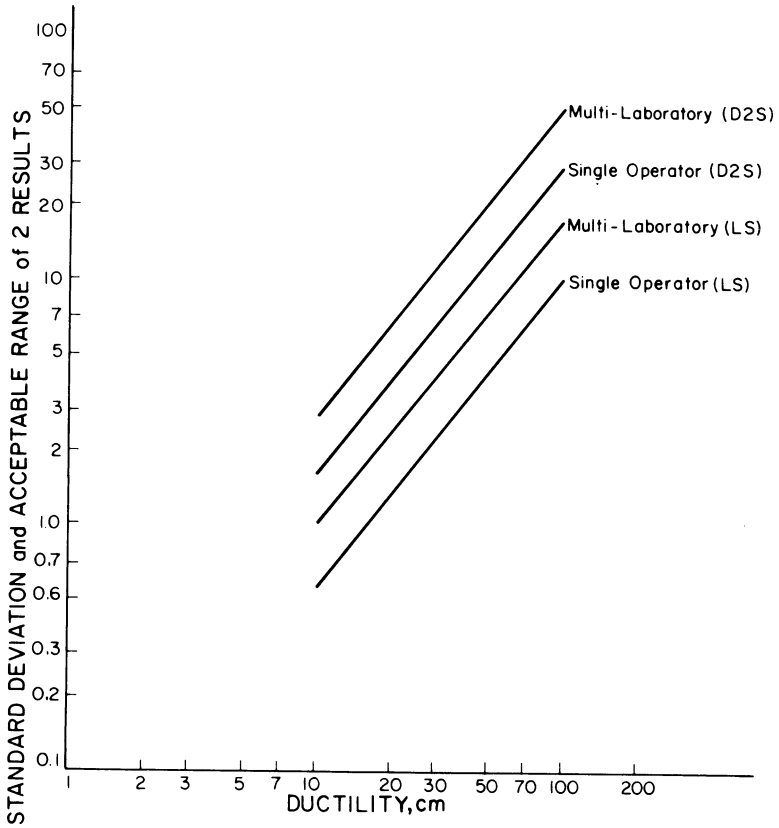



**FIG. 2 Precision Data**

described in Practice C 670.

NOTE 4—Insufficient data are available to properly define precision at 15.6°C. However, analysis of data resulting from tests by 13 laboratories on one asphalt for which the average ductility test result was 45 cm shows a multi-laboratory precision (D2S) of 23 cm.

## 8. Keywords

8.1 ductility; ductility mold; ductilometer

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Designation: D 3142 – 97

# Standard Test Method for Density of Liquid Asphalts (Hydrometer Method)[1]

This standard is issued under the fixed designation D 3142; 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 density of cutback asphalts using a glass hydrometer. It is applicable to cutback asphalts which are liquid at room temperature (see Note 1). It provides more explicit testing procedures than those in Test Method D 1298.

NOTE 1—For materials that are solid or semi-solid at room temperature, use Test Method D 70 or Test Method D 3289.

1.2 The values in SI units are to be regarded as the standard.

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.* Specific precautionary statements are given in Section 7.

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

D 70 Test Method for Density of Semi-Solid and Solid Bituminous Materials (Pycnometer Method)[3]

D 140 Practice for Sampling Bituminous Materials[3]

D 1250 Petroleum Measurement Tables[4]

D 1298 Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method[4]

D 2026 Specification for Cutback Asphalt (Slow-Curing Type)[3]

D 2027 Specification for Cutback Asphalt (Medium-Curing Type)[3]

D 2028 Specification for Cutback Asphalt (Rapid-Curing Type)[3]

D 3289 Test Method for Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method)[3]

D 4311 Practice for Determining Asphalt Volume Correction to a Base Temperature[3]

E 1 Specification for ASTM Thermometers[5]

E 100 Specification for ASTM Hydrometers[5]

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *API gravity*—a function of specific gravity 15.6/15.6°F, represented by the equation:

$$°\text{API} = (141.5/\text{SG } 15.6/15.6°\text{C}) - 131.5 \quad (1)$$

3.1.2 *density*—the mass per unit volume of a material.

3.1.3 *observed values*—values observed at temperatures other than the standard reference temperature. Values observed at other temperatures are only hydrometer readings, and not density, relative density (specific gravity), or API gravity.

3.1.4 *relative density*—the ratio of the mass of a given volume of a material to the mass of the same volume of water at the same temperature.

3.1.4.1 *Discussion*—Relative density is also called specific gravity.

3.1.5 *specific gravity*—relative density.

## 4. Summary of Test Method

4.1 The sample is brought to the testing temperature and transferred to a cylinder at approximately the same temperature. The cylinder and its contents are placed in a constant-temperature bath to avoid excessive temperature variation during the test. The appropriate hydrometer is lowered into the sample and allowed to settle. After temperature equilibrium, the hydrometer is read and the temperature of the sample is noted. The hydrometer reading is converted to the density at 15°C using standard tables.

4.2 The hydrometer reading is corrected to density at 15°C by referring to standard tables.

## 5. Significance and Use

5.1 Values of density are used for converting volumes to units of mass, and for correcting measured volumes from the temperature of measurement to a standard temperature using Practice D 4311.

## 6. Apparatus

6.1 *Hydrometers*, glass, graduated in units of specific gravity, or API gravity as required, conforming to Specification E 100 as listed in Table 1.

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[1] This test method is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.47 on Miscellaneous Asphalt Tests.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 05.01.

[5] *Annual Book of ASTM Standards*, Vol 14.03.

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**TABLE 1 Recommended Hydrometers**

| Hydrometer Designation | Measurement | Range | Total Length, mm | Body Diameter, mm |
|---|---|---|---|---|
| 1H to 4H | API Gravity | –1 to 41°API | 325-335 | 23-27 |
| 21H to 28H | API Gravity | 0 to 41°API | 158-168 | 12-15 |
| 85H to 90H | Relative Density (SG) 15.6/15.6°C | 0.8 to 1.1 | 325-335 | 23-27 |
| 105H to 108H | Relative Density (SG) 15.6/15.6°C | 0.8 to 1.0 | 250-270 | 20-24 |
| 315H to 320H | Density at 15°C | 800-1100 kg/m$^3$ | 325-335 | 21-27 |

6.2 Other hydrometers conforming to the performance and accuracy requirements of Specification E 100 may be used.

6.3 *Thermometers*—Calibrated liquid in glass total immersion thermometers with a maximum scale error of 0.1°C. Thermometer 12C as defined in Specification E 1 is suitable. Any other thermometric device of equal accuracy may be used.

6.4 *Hydrometer Cylinder*, clear glass, plastic (Note 2), or metal. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least 20 mm greater than the outside diameter of the hydrometer used in it. The height of the cylinder shall be such that the hydrometer floats in the sample with at least 25 mm clearance between the bottom of the hydrometer and the bottom of the cylinder.

NOTE 2—Hydrometer cylinders constructed of plastic materials shall be resistant to discoloration or attack by oil samples and must not become opaque by prolonged exposure to sunlight and oil samples.

6.5 *Constant-Temperature Bath*, capable of maintaining the testing temperature to ±0.5°C and of such dimensions that the level of the liquid is approximately the same as that of the sample in the hydrometer cylinder.

6.6 *Oven*, for preheating the sample, and capable of maintaining the selected testing temperature to within ±3°C.

## 7. Hazards

7.1 Materials tested using this procedure may contain volatile and flammable hydrocarbons. Heat the sample in a covered container to minimize loss of volatile components. Carry out the test in a well ventilated area, and avoid breathing any vapours which may be generated. Keep sources of ignition away from materials being tested.

## 8. Sampling

8.1 Take samples in accordance with Practice D 140. The sample shall be free of foreign substances.

8.2 Thoroughly mix the sample before removing a representative portion for testing.

## 9. Temperature of Test

9.1 Because of differences in viscosity between various grades of liquid asphalts, the temperature of the test must be adjusted so that it will provide sufficient fluidity to conduct the test over a reasonable period of time. The recommended testing temperatures for the various grades shown in Table 2 are based on a viscosity of approximately 200 to 500 cst.

**TABLE 2 Recommended Testing Temperatures for Various Grades of Liquid Asphalts**

| Grade | Testing Temperature, °C |
|---|---|
| MC-30 | Room |
| SC-70, MC-70, RC-70 | 40 |
| SC-250, MC-250, RC-250 | 60 |
| SC-800, MC-800, RC-800 | 80 |
| SC-3000, MC-3000, RC-3000 | 100 |

9.2 When the hydrometer value is to be used to select multipliers for correcting volumes to standard temperatures, the hydrometer reading should be made preferably at a temperature within ±3°C of the temperature at which the bulk volume of the oil was measured (Note 3). However, in cases when appreciable amounts of light fractions may be lost during determination at the bulk asphalt temperature, the temperatures given in Table 2 should not be exceeded.

NOTE 3—Volume and density correction tables are based on an average coefficient of expansion for a number of typical materials. Since the same coefficients were used in computing both sets of tables, corrections made over the same temperature interval minimize errors arising from possible differences between the coefficients of the material under test and the standard coefficients. This effect becomes more important as temperatures diverge significantly from 15°C.

## 10. Procedure

10.1 Select the test temperature in accordance with the indications given in Section 9. Heat the sample in an oven to within 3°C of the test temperature but without exceeding it. The container shall be covered with a loose-fitting cover to prevent solvent evaporation. Bring the hydrometer cylinder and thermometer to approximately the same temperature as the sample to be tested.

10.2 Transfer the sample to a clean hydrometer cylinder (Note 4) without splashing, to avoid the formation of air bubbles, and to reduce to a minimum the evaporation of the lower boiling constituents of the more volatile samples. Remove any air bubbles formed, after they have collected on the surface of the sample, by touching them with a piece of clean filter paper before inserting the hydrometer.

NOTE 4—When metal cylinders are used, accurate reading of the hydrometer can only be ensured if the level of the sample is within 5 mm of the top of the cylinder.

10.3 Place the cylinder containing the sample in the constant-temperature bath previously brought up to the test temperature ±0.5°C. Allow sufficient time for the sample to reach the bath temperature and verify its temperature with the thermometer, taking care that the mercury thread is kept fully immersed. If a thermohydrometer is used, it may be lowered into the sample at this point instead of the thermometer. As soon as a steady thermometer reading is obtained, record the temperature of the sample to the nearest 0.2°C.

10.4 Lower the hydrometer gently into the sample. Take care to avoid wetting the stem above the level to which it will be immersed in the liquid. Allow sufficient time for the hydrometer to become completely stationary and for all air bubbles to come to the surface. This is particularly necessary in the case of the more viscous samples.

10.5 When the hydrometer has come to rest, floating freely

away from the walls of the cylinder, read the hydrometer to the nearest scale division. Take the reading by observing with the eye slightly above the plane of the surface of the liquid, the point on the hydrometer scale to which the sample rises. This reading, at the top of the meniscus, requires correction since hydrometers are calibrated to be read at the principal surface of the liquid. The corrections for the particular hydrometer in use may be determined by observing the maximum height above the principal surface of the liquid to which oil rises on the hydrometer scale when the hydrometer in question is immersed in a transparent oil having a surface tension similar to that of the sample under test. For routine work, determine the height of the meniscus by sighting across the principal surface of the liquid and estimating the rise of the meniscus on the hydrometer scale.

10.6 Immediately after observing the hydrometer scale value, cautiously stir the sample with the thermometer, keeping the mercury thread fully immersed. Record the temperature of the sample to the nearest 0.2°C (Note 5). Should this temperature differ from the previous reading by more than 0.5°C repeat the hydrometer and the thermometer observations until the temperature becomes stable within 0.5°C.

NOTE 5—After use at a temperature higher than 100°F (37.7°C), allow all hydrometers of the lead shot in wax type to drain and cool in a vertical position.

## 11. Calculation

11.1 Apply any relevant corrections to the observed thermometer reading (for scale and bulb) and to the hydrometer reading (scale). Make the appropriate correction to the observed hydrometer reading. Record to the nearest 0.1°API, 0.001 relative density (specific gravity), or 1 kg/m$^3$ the corrected hydrometer reading. After application of any relevant corrections, record to the nearest 0.5°C the mean of the temperature values observed immediately before and after the final hydrometer reading.

11.2 To convert the observed hydrometer reading to density at 15°C, use the following tables from Tables D 1250:

11.2.1 When an API gravity hydrometer has been used, use Table 5A to convert the hydrometer reading to the API gravity. Then use Table 3 to obtain the density at 15°C.

11.2.2 When a relative density (specific gravity) hydrometer has been used, use Table 23A to convert the hydrometer reading to the relative density 15.6/15.6°C. Then use Table 21 to obtain the density at 15°C.

11.2.3 When a density scaled hydrometer has been used, use Table 53A to obtain the density at 15°C.

## 12. Report

12.1 Report the density at 15°C to the nearest 1 kg/m$^3$.

## 13. Precision and Bias

13.1 *Single Operator Precision*—The single-operator standard deviation for the relative density of cutback asphalts has been found to be 0.00195. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 5.5 kg/m$^3$ (0.0055 kg/L).

13.2 *Multilaboratory Precision*—The multilaboratory standard deviation for the relative density of cutback asphalts has been found to be 0.00276. Therefore, results of two properly conducted tests by two laboratories on samples of the same material should not differ by more than 7.8 kg/m$^3$.

NOTE 6—These numbers represent the 1S and D2S limits as described in Practice C 670.

13.3 *Bias*—The bias of this test method has not been determined.

## 14. Keywords

14.1 cutback asphalt; density; liquid asphalt

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Designation: D 2172 – 01ε1

# Standard Test Methods for Quantitative Extraction of Bitumen From Bituminous Paving Mixtures[1]

This standard is issued under the fixed designation D 2172; 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—The word '1, 1, 1–trichloroethane' was editorially changed to 'normal Propyl Bromide' throughout. The address in paragraph 7.1 was editorially corrected. All corrections applied March 2002.

## 1. Scope

1.1 These test methods cover the quantitative determination of bitumen in hot-mixed paving mixtures and pavement samples. Aggregate obtained by these test methods may be used for sieve analysis using Test Method C 117 and Test Method C 136.

1.2 The values stated in inch-pound 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.* Specific hazards are given in Section 7.

NOTE 1—The results obtained by these test methods may be affected by the age of the material tested, with older samples tending to yield slightly lower bitumen content. Best quantitative results are obtained when the test is made on mixtures and pavements shortly after their preparation. It is difficult to remove all the asphalt when some aggregates are used and some chlorides may remain within the mineral matter affecting the measured asphalt content.

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 117 Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[2]

C 128 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate[2]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

D 70 Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method)[3]

D 604 Specification for Diatomaceous Silica Pigment[4]

D 979 Practice for Sampling Bituminous Paving Mixtures[3]

D 1461 Test Method for Moisture or Volatile Distillates in Bituminous Paving Mixtures[3]

D 1856 Test Method for Recovery of Asphalt from Solution by Abson Method[3]

D 2111 Test Methods for Specific Gravity of Halogenated Organic Solvents and Their Admixtures[5]

D 6368 Specification for Vapor-Degreasing Grade and General Grade *normal*–Propyl Bromide[5]

2.2 *Federal Specifications:*

O-T-634 (latest) normal Propyl Bromide, Technical[6]

## 3. Summary of Test Methods

3.1 The paving mixture is extracted with trichloroethylene, normal Propyl Bromide, or methylene chloride using the extraction equipment applicable to the particular method. The bitumen content is calculated by difference from the mass of the extracted aggregate, moisture content, and mineral matter in the extract. The bitumen content is expressed as mass percent of moisture-free mixtures.

## 4. Significance and Use

4.1 All of these test methods can be used for quantitative determinations of bitumen in hot-mixed paving mixtures and pavement samples for specification acceptance, service evaluation, control, and research. Each method prescribes the solvent or solvents and any other reagents that can be used in the test method. Test Method D 1856 requires that Method A be used when asphalt is recovered from solution.

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[1] These test methods are under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and are the direct responsibilities of Subcommittee D04.25 on Analysis of Bituminous Mixtures.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 06.03.

[5] *Annual Book of ASTM Standards*, Vol 15.05.

[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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## 5. Apparatus

5.1 *Oven*, capable of maintaining the temperature at 230 ± 9°F (110 ± 5°C).

5.2 *Pan*, flat, 12 in. (305 mm) long, 8 in. (203 mm) wide, and 1 in. (25 mm) deep.

5.3 *Balance*, or balances having an accuracy of at least 0.01 % of the sample mass.

5.4 *Hot Plate*, electric, 700-W continuous or low, medium, and high settings.

5.5 *Small-Mouth Graduate*, 1000 or 2000-mL capacity. Optional small-mouth graduate, 100-mL capacity.

5.6 *Ignition Dish*, 125-mL capacity.

5.7 *Desiccator*.

5.8 *Analytical Balance*.

## 6. Reagents

6.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society,[7] where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6.2 *Ammonium Carbonate* Solution—Saturated solution of reagent grade ammonium carbonate [$(NH_4)_2CO_3$].

6.3 *Methylene Chloride*, technical grade. **Caution**—see Section 7.

6.4 *normal-Propyl Bromide (nPB)*, conforming to Specification D 6368. **Caution**—see Section 7.

6.5 *Trichloroethylene*, technical grade, Type 1, Federal Specification O-T-634, latest revision. **Caution**—see Section 7.

## 7. Hazards

7.1 **Caution**—The solvents listed in Section 6 should be used only under a hood or with an effective surface exhaust system in a well-ventilated area, since they are toxic to various degrees. Consult the current Threshold Limit Concentration Committee of the American Conference of Governmental Industrial Hygienists[8] for the current threshold limit values.

## 8. Sampling

8.1 Obtain samples in accordance with Practice D 979.

8.2 *Preparation of Test Specimens*:

8.2.1 If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan and warm to 230 ± 9°F (110 ± 5°C) only until it can be handled or mixed. Split or quarter the material until the mass of material required for test is obtained.

8.2.2 The size of the test sample shall be governed by the nominal maximum aggregate size of the mixture and shall conform to the mass requirement shown in Table 1 (Note 2):

NOTE 2—When the mass of the test specimen exceeds the capacity of the equipment used (for a particular method), the test specimen may be divided into suitable increments, tested, and the results appropriately combined for calculation of bitumen content (Section 12).

8.2.3 In addition, a test specimen is required for the determination of moisture (Section 9) in the mixtures. Take this test specimen from the remaining sample of the mixture immediately after obtaining the extraction test specimen.

NOTE 3—If recovery of bitumen from the solution obtained from the extraction test is not required, the entire test specimen may be dried to constant mass in an oven at a temperature of 230 ± 9°F (110 ± 5°C) prior to extraction instead of determining the moisture content (Section 9).

## 9. Moisture Content

9.1 Determine the moisture content of the mixture (see 8.2.2) in accordance using the procedure described in Test Method D 1461.

9.2 Calculate the mass of water, $W_2$, (12.1) in the extraction test portion by multiplying mass percent water (9.1) by the mass of the extraction test portion, $W_1$, (12.1).

## TEST METHOD A

## 10. Apparatus

10.1 In addition to the apparatus listed in Section 5, the following apparatus is required for Test Method A:

10.1.1 *Extraction Apparatus*, consisting of a bowl approximating that shown in Fig. 1 and an apparatus in which the bowl may be revolved at controlled variable speeds up to 3600 r/min. The speed may be controlled manually or with a preset speed control. The apparatus should be provided with a container for catching the solvent thrown from the bowl and a drain for removing the solvent. The apparatus preferably shall be provided with explosion-proof features and installed in a hood or an effective surface exhaust system to provide ventilation.

NOTE 4—Similar apparatus of larger size may be used.

10.1.2 *Filter Rings*, felt or paper, to fit the rim of the bowl.

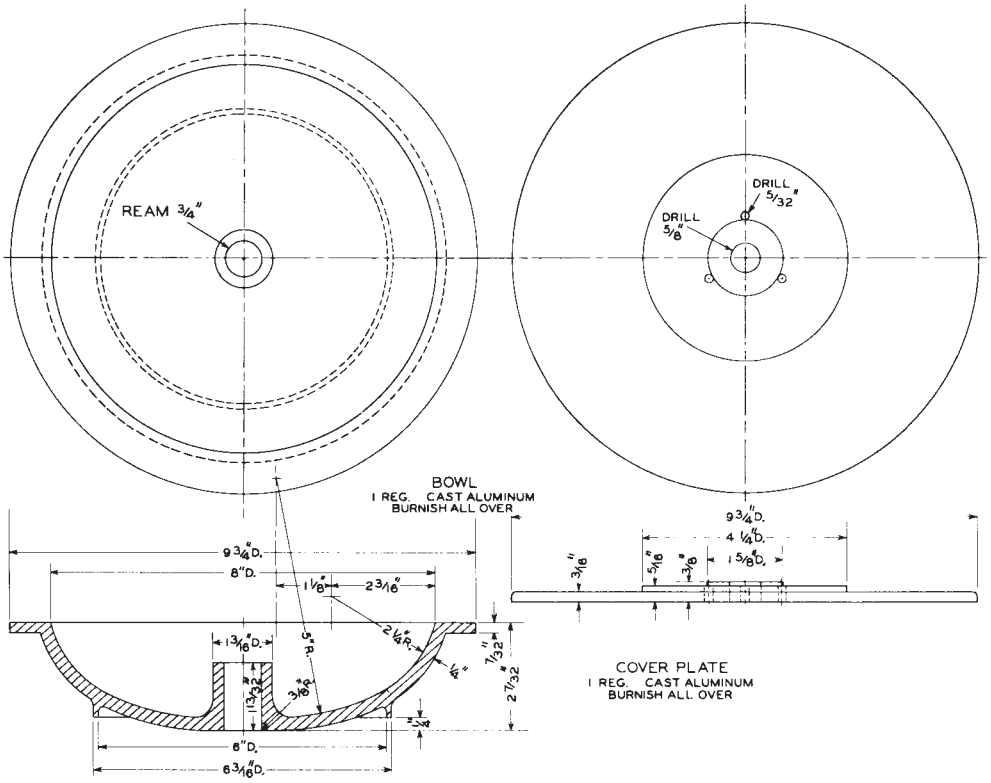
10.1.3 Low-ash paper filter rings may be used in place of the felt filter ring (10.1.2). Such filter rings shall consist of low ash filter paper stock 0.05 ± 0.005 in. thick. The nominal base weight of the paper shall be 330 ± 30 lb for a ream (500 sheets—25 by 38 in.). The ash content of the paper should not exceed 0.2 % (approximately 0.034 g per ring).

**TABLE 1 Size of Sample**

| Nominal Maximum Aggregate Size Standard, mm | Sieve Size | Minimum Mass of Sample, kg |
|---|---|---|
| 4.75 | (No. 4) | 0.5 |
| 9.5 | ⅜ in. | 1 |
| 12.5 | ½ in. | 1.5 |
| 19.0 | ¾ in. | 2 |
| 25.0 | 1 in. | 3 |
| 37.5 | 1½ in. | 4 |

[7] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

[8] Available from American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240, (513) 742–2020, (www.acgih.org).




NOTE 1—See Table 2 for metric equivalents.

**FIG. 1 Extraction Unit Bowl (Test Method A)**

## 11. Procedure

11.1 Determine the moisture content of the material in accordance with Section 9.

11.2 Place a 650 to 2500-g test portion into a bowl. See Annex A1 for alternative procedures to those prescribed herein and in 11.5.

11.3 Cover the test portion in the bowl with trichloroethylene, normal Propyl Bromide, or methylene chloride and allow sufficient time for the solvent to disintegrate the test portion (not over 1 h). Place the bowl containing the test portion and the solvent in the extraction apparatus. Dry and determine the mass of the filter ring and fit it around the edge of the bowl. Clamp the cover on the bowl tightly and place a beaker under the drain to collect the extract.

11.4 Start the centrifuge revolving slowly and gradually increase the speed to a maximum of 3600 r/min or until solvent ceases to flow from the drain. Allow the machine to stop, add 200 mL of trichloroethylene, normal Propyl Bromide, or methylene chloride and repeat the procedure. Use sufficient 200-mL solvent additions (not less than three) so that the extract is not darker than a light straw color. Collect the extract and the washings in a suitable graduate.

11.5 Remove the filter ring from the bowl and dry in air. If felt filter rings are used, brush off mineral matter adhering to the surface of the ring and add to the extracted aggregate. Dry the ring to constant mass in an oven at 230 ± 9°F (110 ± 5°C). Carefully remove all the contents of the bowl into a metal pan and dry on a steam bath and then, dry to constant mass in an oven or on a hot plate at 230± 9°F (110 ± 5°C). If trichloroethylene or normal Propyl Bromide is used as the extraction solvent, the preliminary drying on a steam bath may be omitted. The mass of the extracted aggregate, $W_3$, is equal to the mass of the aggregate in the pan plus the increase in mass of the filter rings.

11.5.1 Use the following alternative procedure when low-ash filter rings are used: Place the aggregate and filter rings in a clean metal pan. Dry as specified above. Carefully fold the dried filter ring and stand it on the aggregate. Burn the filter ring by igniting with a bunsen burner or match. Determine the mass of the extracted aggregate in the pan, $W_3$.

NOTE 5—Since dry aggregate absorbs moisture when exposed to air containing moisture, determine the mass of the extracted aggregate immediately after cooling to a suitable temperature.

11.6 Determine the amount of mineral matter in the extract by any of the following test methods:

11.6.1 *Ashing Method*:

11.6.1.1 Record the volume of the total extract in the graduate (11.4). Determine the mass of an ignition dish. Agitate the extract thoroughly and immediately measure approximately 100 mL into the ignition dish. Evaporate to dryness on a steam bath or hot plate, except use a steam bath when the solvent is benzene. Ash residue at a dull red heat (500 to 600°C), cool, and add 5 mL of saturated ammonium carbonate solution per gram of ash. Digest at room temperature for 1 h. Dry in an oven at 100°C to constant mass, cool in a desiccator, and determine the mass.

11.6.1.2 Calculate the mass of mineral matter in the total volume of extract, $W_4$, as follows:

**TABLE 2 Metric Equivalents for Figures**

| Inch-Pound Units, in. | Metric Equivalent, cm | Inch-Pound Units, in. | Metric Equivalent, cm | Inch-Pound Units, in. | Metric Equivalent, cm |
|---|---|---|---|---|---|
| ⅛ | 0.32 | 1 11/16 | 4.3 | 5⅞ | 14.9 |
| 3/16 | 0.48 | 1¾ | 4.4 | 6 | 15.2 |
| 7/32 | 0.56 | 2 9/16 | 5.5 | 6⅛ | 15.5 |
| ¼ | 0.63 | 2 7/32 | 5.6 | 6 3/16 | 15.7 |
| 5/16 | 0.79 | 2 5/16 | 5.9 | 6¼ | 15.9 |
| ⅜ | 0.95 | 2½ | 6.4 | 6½ | 16.5 |
| ½ | 1.27 | 2⅝ | 6.9 | 7⅜ | 18.7 |
| ⅝ | 1.59 | 2 13/16 | 7.2 | 8 | 20.7 |
| ¾ | 1.9 | 3 | 7.6 | 9¾ | 24.7 |
| 1 | 2.5 | 3¾ | 9.6 | 10 | 25.4 |
| 1⅛ | 2.86 | 4 | 10.2 | 10⅛ | 25.7 |
| 1 3/16 | 3.02 | 4¼ | 10.8 | 12 | 30.5 |
| 1 13/32 | 3.57 | 5 | 12.7 | 14 | 35.5 |
| 1½ | 3.8 | 5 7/16 | 13.8 | 14½ | 37 |
| 1⅝ | 4.1 | | | | |

$$W_4 = G[V_1/(V_1 - V_2)] \quad (1)$$

where:
$G$ = ash in aliquot, g,
$V_1$ = total volume, mL, and
$V_2$ = volume after removing aliquot, mL.

11.6.2 *Centrifuge Method*:

11.6.2.1 For this test method use any suitable high-speed (3000 *g* or higher) centrifuge of the continuous-flow type.[9]

11.6.2.2 Determine the mass of a clean empty centrifuge cup (or bowl) to 0.01 ± 0.005 g and place in the centrifuge. Position a container at the appropriate spout to catch the effluent from the centrifuging operation. Transfer all of the extract (from Test Methods A, B, C, D, or E as appropriate) to an appropriate (feed) container suitably equipped with a feed control (valve or clamp, etc.). To ensure quantitative transfer of the extract to the feed container, the receptacle containing the extract should be washed several times with small amounts of clean solvent and the washings added to the feed container. Start the centrifuge and allow to reach a constant operational speed (for example, 9000 r/min for the SMM type and 20 000 + r/min for the Sharples type). Open the feed line and feed the extract into the centrifuge at a rate of 100 to 150 mL/min. After all the extract has passed through the centrifuge, wash the feed mechanism (with centrifuge still running) with several increments of clean solvent, allowing each increment to run through the centrifuge until the effluent is essentially colorless.

11.6.2.3 Allow the centrifuge to stop and remove the cup (or bowl). Clean the outside with fresh solvent. Allow the residual solvent to evaporate in a funnel or steam hood and then dry the container in an oven controlled at 230 ± 9°F (110 ± 5°C). Cool the container and redetermine the mass immediately. The increase in mass is the mass of mineral matter, $W_4$, (12.1) in the extract.

11.6.3 *Volumetric Method*:

11.6.3.1 Place the extract in a previously tared and calibrated flask. Place the flask in a controlled-temperature bath controlled to 0.2°F (±0.1°C), and allow to come to the temperature at which the flask was calibrated. When the desired temperature has been reached, fill the flask with solvent which has been kept at the same temperature. Bring the level of the liquid in the flask up to the neck, insert the stopper, making sure the liquid overflows the capillary, and remove from the bath. Wipe the flask dry, determine the mass to the nearest 0.1 g, and record this mass as the mass of flask plus extract. See Annex A2 for a volumetric test method alternative procedure if a controlled-temperature bath is not used as prescribed herein.

11.6.3.2 Calculate the volume of asphalt and fines in the extract as follows:

$$V_1 = V_2 - \frac{(M_1 - M_2)}{(G_1)} \quad (2)$$

where:
$V_1$ = volume of asphalt and fines in the extract,
$V_2$ = volume of the flask,
$M_1$ = mass of the contents of the flask,
$M_2$ = mass of the asphalt and fines in the extract = mass of the total samples minus the mass of the extracted aggregate, and
$G_1$ = specific gravity of the solvent determined to the nearest 0.001 in accordance with Test Methods D 2111.

11.6.3.3 Calculate the mass of fines in the extract as follows:

$$M_3 = K\,(M_2 - G_3 V_1) \quad (3)$$

where:
$M_3$ = mass of fines in the extract,
$G_2$ = specific gravity of fines as determined in accordance with Test Method C 128,
$G_3$ = specific gravity of asphalts as determined in accordance with Test Method D 70,
$K$ = $G_2 / G_2 - G_3$,
$V_1$ = as given in 11.6.3.2, and
$M_2$ = as given in 11.6.3.2.

## 12. Calculation of Bitumen Content

12.1 Calculate the percent bitumen in the test portion as follows:

$$\text{Bitumen content, \%} = \left[\frac{(W_1 - W_2) - (W_3 + W_4)}{W_1 - W_2}\right] \times 100 \quad (4)$$

where:

[9] The Sharples Supercentrifuge and the SMM continuous-flow centrifuge have been found suitable for this test method.

$W_1$ = mass of test portion,
$W_2$ = mass of water in the test portion,
$W_3$ = mass of the extracted mineral aggregate, and
$W_4$ = mass of the mineral matter in the extract.

NOTE 6—When ashless filter rings are not used, add the increase in mass of the felt filter ring to $W_4$.

NOTE 7—For paving mixtures in which tar is used as the binder, a modification of Test Method A is given in Annex A3.

## TEST METHOD B

### 13. Apparatus

13.1 In addition to the apparatus listed in Section 5, the following apparatus is required for Test Method B:

13.1.1 *Extraction Apparatus*, similar to that shown in Fig. 2.

13.1.1.1 *Glass Jar*, cylindrical, plain, made of heat-resistant glass. The jar shall be free of cracks, scratches, or other evidence of flaws that might cause breakage during heating.

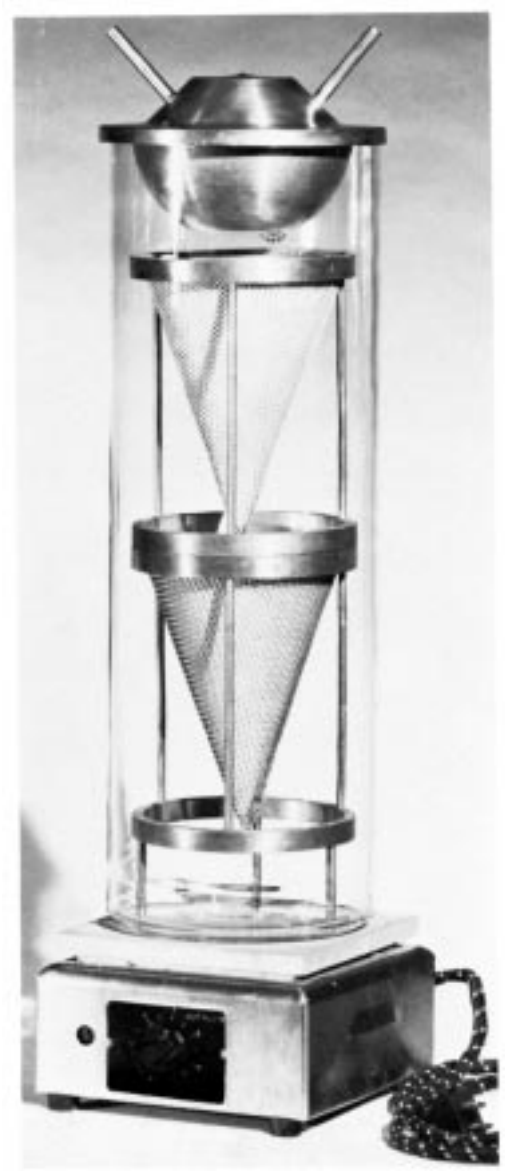


**FIG. 2 Extraction Apparatus (Test Method B)**

13.1.1.2 *Cylindrical Metal Frames*, one or two. The lower frame shall have legs of sufficient length to support the frame, including the apex of the metal cone and paper cone liner above the solvent level. When two frames are used, the upper frame shall have legs of sufficient length to support the metal cone and paper cone liner at or above the top rim of the lower frame. The legs of the upper frame shall fit securely in the top rim of the lower frame. A bail handle may be provided on the inside of the top rim of each frame for convenient handling. The metal used in fabricating the frames shall be essentially inactive to the solvents used in the test method.

13.1.1.3 *Condenser*, fabricated with a truncated hemispherical condensing surface and a truncated conical top. Other suitable geometric shapes may also be used provided they accomplish the condensing and flow functions intended. The material used in fabricating the condenser shall be essentially unreactive to water and to the solvent used and shall be provided with suitable water inlet and outlet.

13.1.1.4 *Filter Paper*, medium-grade, fast-filtering. The diameter of the paper shall be such that when folded in accordance with the directions given below, it shall completely line the metal cones in the frames.

13.1.1.5 *Asbestos-Coated Wire Mesh*, approximately 3 mm thick for use as insulation between the glass jar and hot plate.

13.1.1.6 *Electric Hot Plate, Thermostatically Controlled*, of sufficient dimensions and heat capacity to permit refluxing of the solvent as described in 15.2.5.

### 14. Preparation of Test Portion

14.1 Prepare a test portion for moisture determination and extraction in accordance with the procedure described in Section 8.

### 15. Procedure

15.1 *Moisture*—Determine the moisture content of the mixture (see 8.2) in accordance with the test method described in Section 9.

15.2 *Extraction*:

15.2.1 Dry and determine the mass of one sheet of filter paper for each frame to be used. Fold each paper on its diameter, fold the ends over, and spread it open to form a proper size to fit inside the metal cones.

15.2.2 Determine the mass of each frame with its filter paper liner to the nearest 0.5 g. Record the mass, identifying each frame by number.

15.2.3 Place the test portion in the frame or frames. If two frames are used, distribute the test portion approximately equally between the two. The top of the test portion must be below the upper edge of the paper liner. Determine the mass of each loaded frame separately to the nearest 0.5 g. Again, record the mass.

15.2.4 Use one of the solvents specified in 6.3, 6.4, or 6.5. Pour the solvent into the glass cylinder and place the bottom frame into it. The solvent level should be below the apex of the one in the (lower) frame. If two frames are used, place the upper frame in the lower frame, fitting its legs into the holes in the upper rim of the lower frame.

NOTE 8—Sufficient denatured ethyl alcohol may be poured over the test portion(s) to wet the filter paper.

15.2.5 Place the thermal insulating pad on the hot plate and then the cylinder on the pad. Cover the condenser. Circulate a gentle steady stream of cool water through the condenser. Adjust the temperature of the hot plate so that the solvent will boil gently and a steady stream of condensed solvent flows into the cone. If necessary, adjust the temperature of the hot plate to maintain the solvent stream at a rate necessary to keep the test portions in the cone(s) completely covered with condensed solvent. Take care not to allow condensed solvent to overflow the filter cone(s). Continue the refluxing until the solvent flowing from the lower cone is light straw color (when viewed against a white background). At this point, turn off the hot plate and allow the apparatus to cool with the water running in the condenser. When boiling has ceased and the cylinder is cool enough to handle, turn off the condenser and remove from the cylinder.

15.2.6 Remove the frame assembly from the cylinder. Allow to dry in air (hood) and dry to constant mass in an oven at 230 ± 9°F (110 ± 5°C) (see Note 5).

15.2.7 Transfer the extract quantitatively to the graduated cylinder (5.5) and determine mineral matter in the extract in accordance with 11.6.1. Alternatively, mineral matter in the extract may be determined by the method described in 11.6.2 or 11.6.3. In this case, it is not necessary to transfer the extract from the extraction cylinder to a graduated cylinder. The extract may be transferred directly from the extraction cylinder to the centrifuge feed container (11.6.2.2).

## 16. Calculation of Bitumen Content

16.1 Calculate the percent bitumen in the test portion in accordance with the procedure described in Section 12.

## TEST METHOD C

## 17. Apparatus

17.1 In addition to the apparatus listed in Section 5, the following is required for Test Method C:

17.1.1 *Extraction Apparatus*, consisting of a container, condenser lid, and stand. Suitable types are shown in Fig. 3 and Fig. 4; however, other extractors of differing shapes may also be used successfully. A standard 26-qt (25-L) aluminum cooking utensil has been found to be suitable. The important features regardless of shape are that the extractors have snug-fitting lids, be of sufficiently large size to accommodate the required test portion, and include cooling fins arranged so as to provide for efficient refluxing.

17.1.2 *Basket*, for test portion as shown in Fig. 3 or one designed for use with an extractor of different shape.

17.1.3 *Filter Cloth*,[10] of approximately 185 mesh, placed over the No. 4 screen and shaped to cover the inside of the basket completely to ensure retention of all aggregate sizes greater than the cloth mesh during extraction.

[10] A 16XX Swiss Stencil Cloth, available from the Atlas Silk Screen Supply Co., 1733 Milwaukee Ave., Chicago, IL 60647, is suitable for this purpose.

## 18. Preparation of Test Portions

18.1 Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 8.

## 19. Procedure

19.1 *Moisture*—Determine the moisture content of the mixture (see 8.2) in accordance with the test method described in Section 9.

19.2 *Extraction*:

19.2.1 Determine the mass of the sample (3500 to 10 000 g) in the tared basket assembly to the nearest 1 g and place in the extractor. Pour 1150 to 1250 mL of trichloroethylene, normal Propyl Bromide, or methylene chloride (Section 6) over the test portion. Fit the extractor lid tightly in place and allow water to circulate freely in the top. Apply heat from either a gas burner or an electric hot plate.

19.2.2 Reflux the sample 1.5 to 3 h until all bitumen is extracted from the aggregate. Shut down the extractor after 1.5 h and inspect the test portion. Mix the test portion with a trowel and continue extraction to completion.

NOTE 9—The test portion is completely extracted when, upon inspection, no discoloration is found on the aggregate or on the surface of a trowel that has thoroughly mixed the test portion.

19.2.3 Remove the basket with the test portion, dry in air and then to constant mass on a hot plate or in an oven at 230 ± 9°F (110± 5°C).

19.2.4 Drain the extract from the extractor and wash clean with fresh solvent. Combine the extract and the washings in a graduated cylinder.

19.2.5 Determine the mass of mineral matter in the extract in accordance with the test method described in 11.6.1, 11.6.2, or 11.6.3.

## 20. Calculation of Bitumen Content

20.1 Calculate the percent bitumen in the test portion in accordance with the procedure described in Section 12.

## TEST METHOD D

## 21. Apparatus

21.1 In addition to the apparatus listed in Section 5, the following apparatus is required for Test Method D:

21.1.1 *Extraction apparatus*, Fig. 5 consisting of an extraction kettle of metal or borosilicate glass, fitted with a perforated basket and a condenser top. The underside of the condenser shall be covered with numerous rounded knobs to distribute the condensed solvent uniformly over the surface of the sample. The suspension of the basket shall be arranged to support the basket ½ in. (12.7 mm) above the bottom of the kettle, for immersion of test portion in the solvent, and at least 3 in. (76.5 mm) above the bottom of the kettle for refluxing (see Note 4).

21.1.2 *Cloth Filter Sacks*, with an elastic hem for lining the basket.

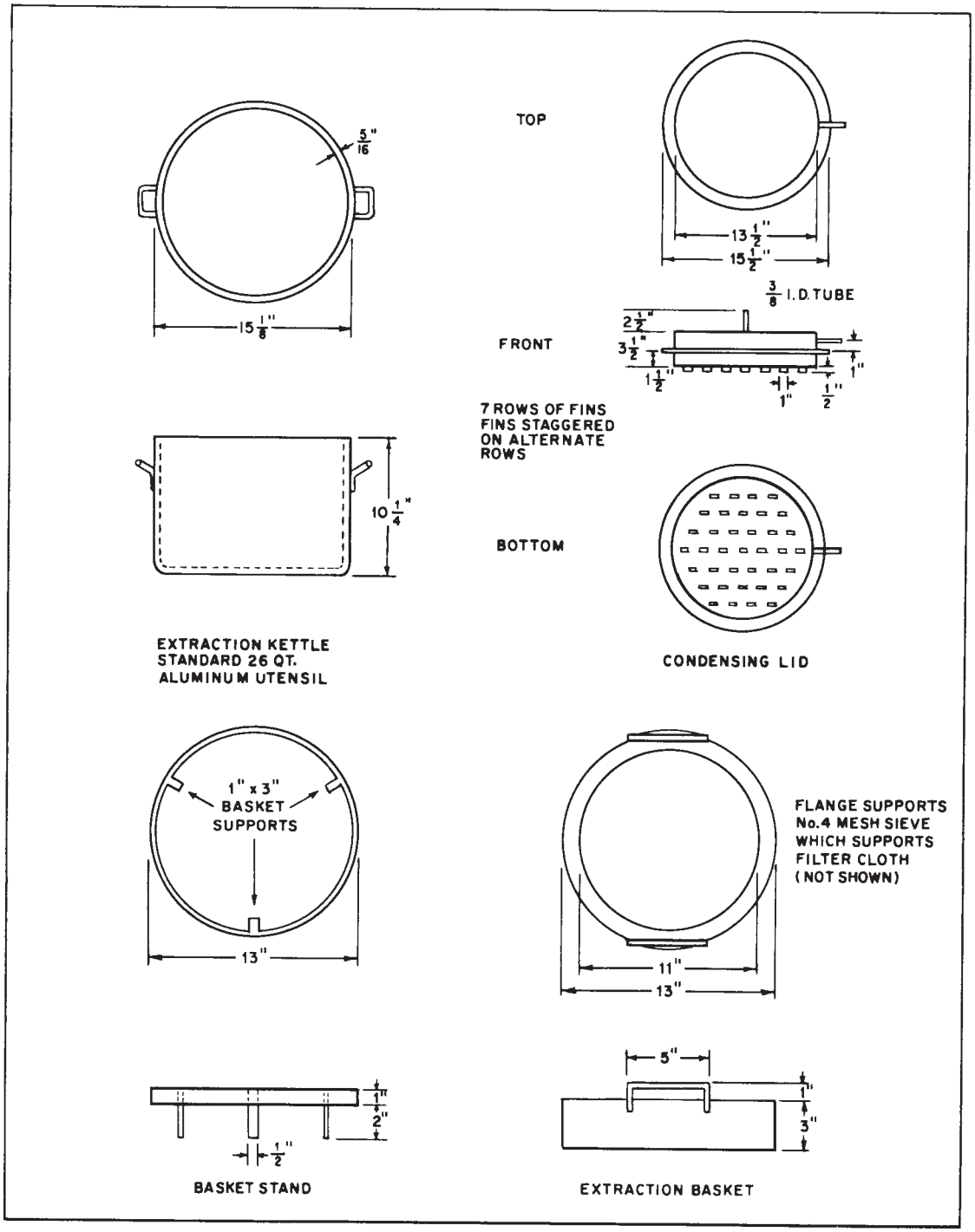



**FIG. 3 Extraction Apparatus (Test Method C)**

## 22. Preparation of Test Portions

22.1 Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 8.

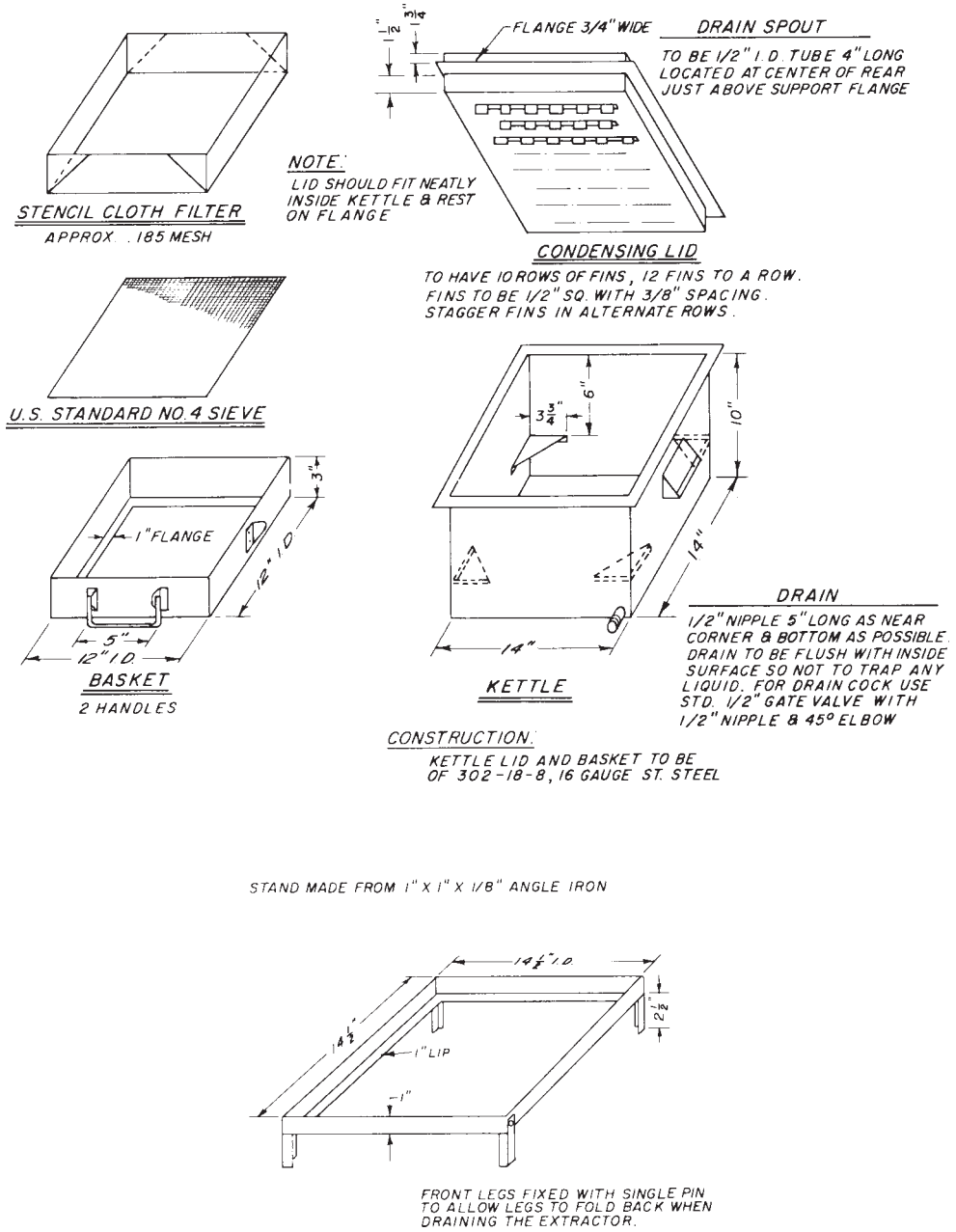
## 23. Procedure

23.1 *Moisture*—Determine the moisture content of the mixtures (see 8.2) in accordance with the test method described in Section 9.

23.2 *Extraction*:

23.2.1 Insert a filter sack in the extraction basket and determine the mass with the tare pan to determine the total tare weight. Place the test portion (Note 2) in the filter sack and determine the total mass. Calculate the mass of the test portion.

23.2.2 Attach the suspension rod to the loaded basket and set the assembly into the extraction kettle. Pour approximately 600 mL of solvent (6.2, 6.3, or 6.4) over the test portion. Set the condenser cover in place on the kettle. Provide a flow of cold water through the condenser lid. Raise the basket to immersion level, for example ½ in. (13 mm) above the bottom




NOTE 1—See Table 2 for metric equivalents.

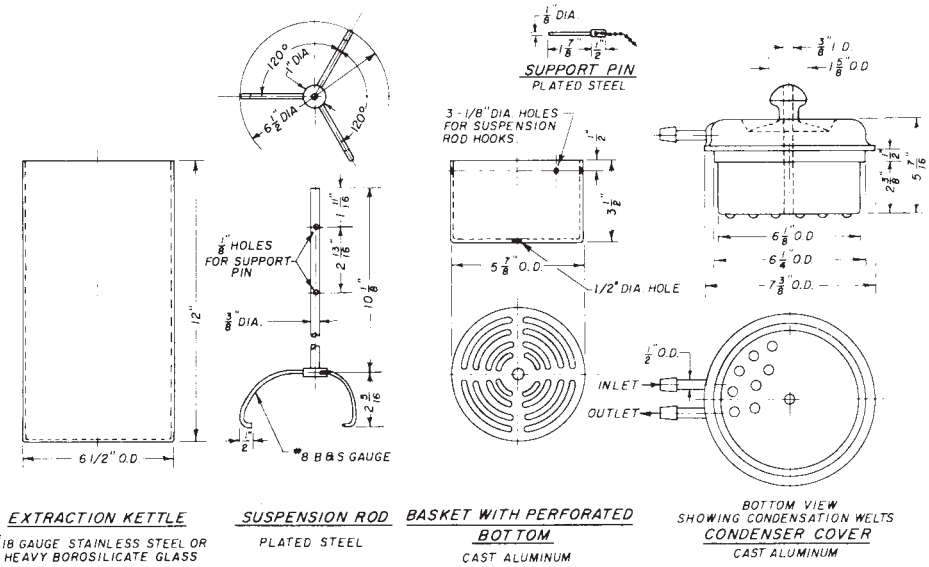
**FIG. 4 Extractor Unit (Test Method C)**

of kettle, by inserting the support pin through the upper hole of the suspension rod. Place the extractor on the hot plate and adjust the heating rate so that solvent is maintained at a gentle boil, avoiding vigorous boiling which might wash fines over sides of basket.

23.2.3 Continue heating with the test portion in immersion position for 15 to 30 min and then raise the basket to refluxing level. Increase the heat and maintain active boiling until solvent dripping from the basket appears light straw color when viewed against a white background. If a stainless steel kettle is used, lift out the basket and the condenser cover assembly for examination of the solvent.

23.2.4 Remove the extractor from the hot plate and allow to cool for several minutes. Lift out the basket and condenser assembly. Cover the kettle, remove the filter sack, distribute its contents onto the tared pan in which the mass of the test portion was originally determined. Place the filter sack on top of the recovered aggregate. Dry on a steam bath and then in an oven at 230 ± 9°F (110 ± 5°C) to constant mass. Transfer the extraction to a 1000-mL graduate. Wash the extractor clean with solvent and add the washings to the extract.

23.2.5 Determine the mineral matter in the extract in accordance with any of the procedures in 11.6.




NOTE 1—See Table 2 for metric equivalents.

**FIG. 5 Extractor Unit (Test Method D)**

## 24. Calculation of Bitumen Content

24.1 Calculate the percent bitumen in the test portion in accordance with the procedure described in Section 12.

## TEST METHOD E

## 25. Apparatus

25.1 In addition to the apparatus listed in Section 5, the following apparatus is required for Test Method E:

25.1.1 *Vacuum Extractor*, complete with the vacuum pump, gasket, rubber tubing, filter paper, support plate, and funnel ring, similar to that shown in Fig. 6.

25.1.2 *Filter Paper*, medium-grade, fast-filtering, 330 mm in diameter.

25.1.3 *Stainless Steel Beaker*, having a capacity of 9 qt (8.5 L).

25.1.4 *Erlenmeyer Flasks*, glass, two, having a capacity of 4000 mL each.

25.1.5 *Graduate*, glass, having a capacity of 500 mL.

25.1.6 *Wash Bottle*, plastic, having a capacity of 500 mL.

25.1.7 *Dial Thermometer*, having a range from 50 to 180°F (10 to 82°C).

25.1.8 *Mixing Spoon*, 12 in. (305 mm) long.

25.1.9 *Spatula*, 9 in. (229 mm) long.

25.1.10 *Stiff Bristled Brush*, 1 in. (25 mm) wide.

25.1.11 *Erlenmeyer Flask*, glass, having a capacity of 1000 mL.

25.1.12 *Watch Glass*, having a 4-in. (102-mm) diameter.

25.1.13 *Metal Tongs*, 6 to 8 in. (152 to 203 mm) long.

NOTE 10—Use apparatus and materials listed under 25.1.11, 25.1.12, 25.1.13, and 26.1.2 only with paving mixtures hard to filter, as in Method E-II.

## 26. Reagents and Materials

26.1 *Diatomaceous Silica Filtering Aid* conforming to Type B of Specification D 604.[11]

26.2 *Ethyl Alcohol*, denatured.

26.3 *Methylene Chloride*.

## 27. Preparation of Test Portions

27.1 Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 8.

## 28. Procedure

28.1 *Moisture*—Determine the moisture content of the mixture (see 8.2) in accordance with the test method described in Section 9.

28.2 *Extraction*:

28.2.1 Place the extraction test portion into the tared stainless steel beaker and determine the mass.

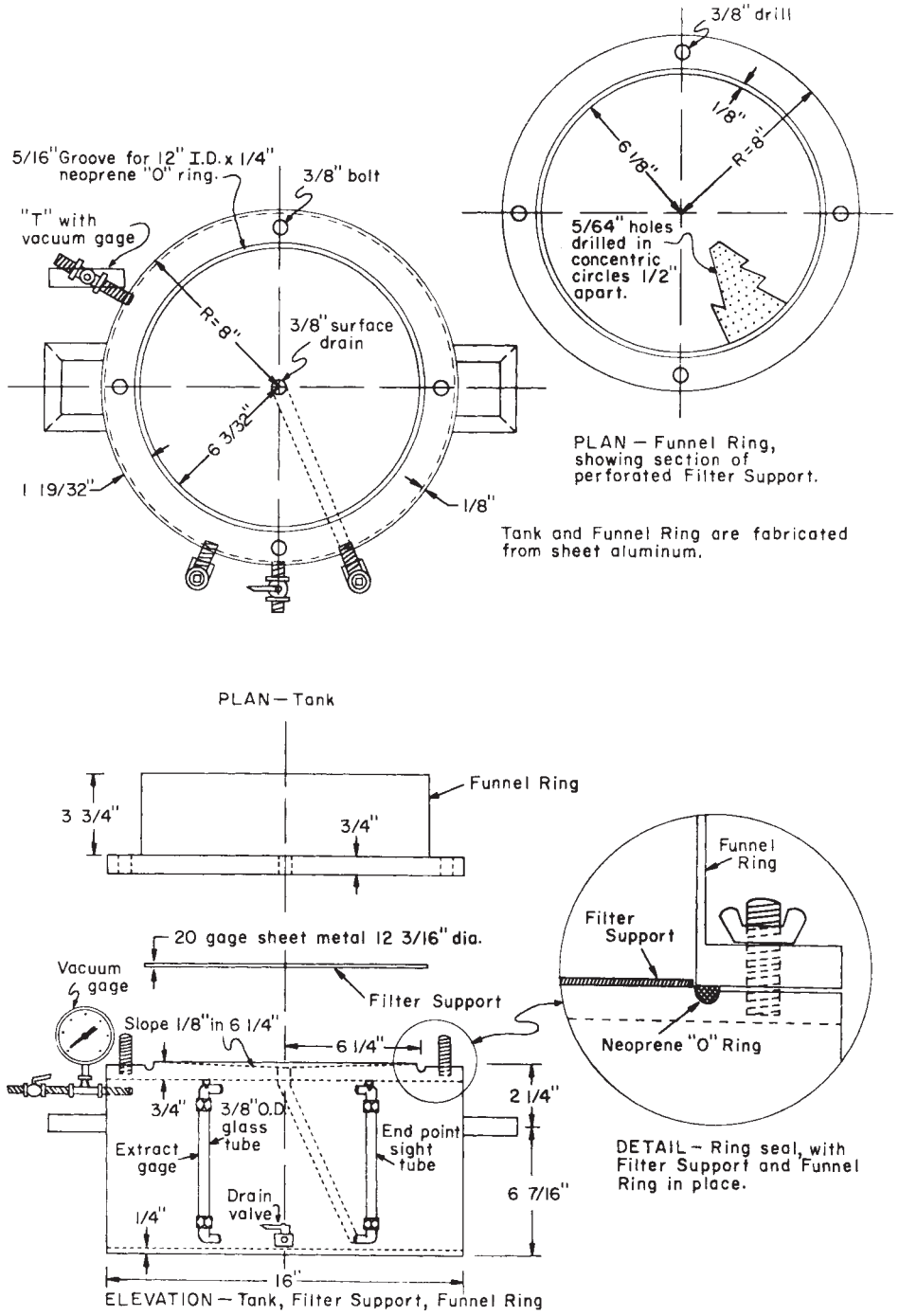
28.2.2 If the test portion is above 130°F (54°C), allow it to cool to a temperature less than 130°F (54°C). When sufficiently cool, pour 200 mL of denatured alcohol over the specimen. Add approximately 700 mL of methylene chloride and stir until the asphalt is visually in solution.

NOTE 11—If equipment is available, an ultrasonic cleaning tank may be used instead of the beaker (28.2.1) and the bitumen brought into solution (28.2.2) in the cleaning apparatus.

## TEST METHOD E-I

28.2.3 Place a dry tared filter paper on the vacuum extractor, taking care to center the filter, and tighten the wing nuts finger tight.

[11] Celite 110, manufactured by Johns-Manville, has been found satisfactory for this purpose.




NOTE 1—The detail, dimensions, and materials shown have been found satisfactory. Modifications are permissible, provided it can be demonstrated that performance of the equipment is not adversely affected.

**FIG. 6 Vacuum Extractor (Test Method E)**

28.2.4 Start the vacuum pump and decant the solvent from the beaker into the extractor, taking care not to transfer the aggregate from the beaker to the extractor. Stop the vacuum when all solvent has been removed.

28.2.5 Add another 700 mL of methylene chloride to the sample container and stir.

28.2.6 Repeat 28.2.4 and 28.2.5 until the solution is a light straw color and the aggregate is visually clean. After the last wash, gently pour the entire sample into the extractor and thoroughly rinse all aggregate particles from the sample container. Carefully spread the aggregate evenly over the filter.

28.2.7 Operate the vacuum pump for a few minutes after the last wash to aid in drying the test portion. Scrape the aggregate away from the side of the funnel ring toward the center of the filter to avoid loss when the ring is removed. Remove the ring and brush the clinging aggregate into the drying pan. Then pick

up the filter paper and aggregate by holding the paper on opposite sides and raising it straight up. Place the test portion in the tared pan and brush the clinging aggregate from the filter into the pan.

28.2.8 Dry the extracted aggregate and filter to a constant mass in an oven at 230 ± 9°F (110 ± 5°C).

28.2.9 Determine the mass of the filter and aggregate in the pan and record. Subtract the mass of the filter and pan to determine the mass of the extracted aggregate.

28.2.10 Transfer the extract to the graduated cylinder (5.5) and determine the mineral matter in the extract in accordance with the test method described in 11.6.1. Alternatively, mineral matter in the extract may be determined in accordance with the test method described in 11.6.2 or 11.6.3. In this case, it is not necessary to transfer the extract to the graduated cylinder. The extract may be transferred directly from the extractor to the centrifuge feed container (11.6.2.2).

NOTE 12—Sections 28.2.10 and 28.2.16 may be omitted when this test method is used only for control of paving mixture bitumen content during construction (plant control).

**TEST METHOD E-II**

28.2.11 To extract a slow-filtering paving mixture efficiently, prepare the test portion as in 28.2.1 and 28.2.2.

28.2.12 Place a dry tared filter paper on the vacuum extractor, taking care to center the filter, and tighten the wing nuts finger tight.

28.2.13 Weigh 50 g of oven-dried diatomaceous silica filtering aid into a 100-mL Erlenmeyer flask and add 500 mL of methylene chloride. Swirl until the diatomaceous silica is completely in suspension.

28.2.14 Immediately pour the diatomaceous silica and methylene chloride over the filter. Start the vacuum pump and let it run until the pad formed by the diatomaceous silica is surface dry and begins to crack slightly.

28.2.15 Place the watch glass in the extractor and gently pour the solvent from the test portion over it. Remove it with tongs and wash with the wash bottle. Add the rest of the sample and proceed as in 28.2.4-28.2.9. Subtract the mass of the drying pan, filter paper, and diatomaceous silica from the total mass to determine the (dry) mass of aggregate.

28.2.16 Determine the amount of mineral matter in the extract in accordance with the procedure described in 28.2.10 (see Note 12).

## 29. Calculation of Bitumen Content (Applicable to Both Method E-I and Method E-II)

29.1 Calculate the percent bitumen in the test portion in accordance with the procedure described in Section 12.

## 30. Precision and Bias

30.1 *Mixtures with Aggregate Water Absorption Capacities of Less than 1.25 %* (Note 13)*:*

| Test and Type Index | Standard Deviation, (1s)[A] | Acceptable Range of Two Test Results (d2s)[A] |
|---|---|---|
| Single-operator precision (Note 15) | | |
| Method A (centrifuge) | 0.21 | 0.59 |
| Method B, C, and D (reflux) | 0.19 | 0.54 |
| Method E (vacuum) | 0.21 | 0.59 |

| Test and Type Index | Standard Deviation, (1s)[A] | Acceptable Range of Two Test Results (d2s)[A] |
|---|---|---|
| Multilaboratory precision (Note 15) | | |
| Method A (centrifuge) | 0.22 | 0.62 |
| Method B, C, and D (reflux) | 0.23 | 0.65 |
| Method E (vacuum) | 0.22 | 0.59 |

[A] These numbers represent, respectively, the (1s%) and (d2s%) limits as described in Practice C 670.

NOTE 13—These precision statements are based on an analysis of the AMRL[12] data base from 1974 through 1985. Asphalt cements used over the years included AC-10, AC-15, AC-20, AR-2000, AR-4000, and AR-8000. Gradations consistently had a nominal maximum aggregate size of at most ¾-in. stone. Water absorption capacities were consistently below 1.25 %.

NOTE 14—A statistical evaluation showed no difference in precision between various solvents. Therefore the precision statement for each test method includes data obtained using any of the following solvents: benzene, trichloroethane, trichloroethylene, methylene chloride.

30.2 *Mixtures with Aggregate Water Absorption Capacities Greater than 1.25 and Less than 2.5 %*:

30.2.1 The precision and bias statements for aggregates with these properties are currently being developed.

30.3 *Mixtures with Aggregate Water Absorption Capacities Greater than 2.5 %* (Note 15):

| Test and Type Index | Standard Deviation, (1s)[A] | Acceptable Range of Two Test Results (d2s)[A] |
|---|---|---|
| Single-operator precision | | |
| Method A (centrifuge) | 0.30 | 0.85 |
| Method B, C, and D (reflux) | 0.19 | 0.54 |
| Method E (vacuum) | 0.27 | 0.76 |
| Multilaboratory precision | | |
| Method A (centrifuge) | 0.37 | 1.05 |
| Method B, C, and D (reflux) | 0.37 | 1.05 |
| Method E (vacuum) | 0.29 | 0.82 |

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670.

NOTE 15—These precision statements are based on 1 material, 2 replicates, and 112, 42, and 30 laboratories for the centrifuge, reflux, and vacuum extraction methods, respectively. The data were obtained from the AASHTO Materials Reference Laboratory (AMRL)[12] results for sample pair 37 and 38, distributed in 1992 for the Bituminous Mixture Design proficiency program.

30.4 *Bias*—Since there is no acceptable reference material suitable for determining the bias for this test method, no statement of bias can be made.

[12] AASHTO Materials Reference Laboratory (AMRL), National Institute of Standards and Technology (NIST), Gathersburg, MD 20899.

## ANNEXES

**(Mandatory Information)**

### A1. TEST METHOD A ALTERNATIVE PROCEDURE

A1.1 In 11.2 place a 650 to 2500-g test portion in a bowl that has been previously dried to a constant mass with the filter ring.

A1.2 In 11.5 instead of removing the filter ring from the bowl and drying in air, dry the bowl with the filter ring to a constant mass under an infrared lamp or in an oven at 230 ± 9°F (110 + 5°C).

### A2. TEST METHOD A (VOLUMETRIC METHOD) ALTERNATIVE PROCEDURE

A2.1 Instead of using a controlled-temperature bath as prescribed in 11.6.3.1, measure the temperature of the extract and make necessary corrections to the volume of the flask and density of asphalt and the solvent.

### A3. TEST METHOD A MODIFICATION FOR DETERMINATION OF TAR

A3.1 Cover the test portion in the bowl with crystal-free creosote and place the bowl for 1 h on a hot plate or in an oven maintained at 240°F (116°C). Proceed in accordance with 11.3 and 11.4 except use two 200-mL additions of creosote previously heated to 240°F (116°C). Treat the test portion in the bowl with three 200-mL additions of trichloroethylene, following the same procedure.

A3.2 Continue in accordance with 11.5 and 11.6.1 except evaporate the aliquot portion of the solvent (11.6.1) on the steam bath until trichloroethylene is removed. Then evaporate the remaining solvent to dryness on a hot plate and ash as directed in 11.6.1.

A3.3 Calculate the percent tar in the sample in accordance with Section 12.

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