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# TENTATIVE SPECIFICATIONS FOR STONE MATRIX ASPHALT

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# TENTATIVE SPECIFICATIONS FOR STONE MATRIX ASPHALT

## 1. INTRODUCTION

Stone Matrix Asphalt (SMA) was developed in Germany in the mid 1960s and it has been used successfully by many countries in the world as a highly rut-resistant bituminous course, both for binder (intermediate) and wearing courses, for heavy traffic roads. The Flexible Pavement Committee (FPC) of the Indian Roads Congress (IRC) decided in its meeting held on 22nd April, 2006 that a specification be developed for SMA suited to Indian conditions. Prof. P. S. Kandhal developed the first draft of the specification with input from Dr. Sunil Bose. The first draft was circulated among the FPC members for comments. The FPC in its meeting on 9th September, 2006 discussed all comments in detail. The revised draft was published in the February, 2007 issue of the "Indian Highways" to solicit comments from users at large. The FPC in its meeting on 5th May, 2007 reviewed those comments and authorized Prof. P. S. Kandhal to prepare a final draft with input from Dr. P. K. Jain incorporating all comments. The draft document was considered in the Highways Specifications and Standards Committee on 26th May, 2007 and approved. The draft was, thereafter, approved by the IRC Council on 18th August, 2007 subject to modifications keeping in view the comments of members and approval by the Convenor, Highways Specifications and Standards Committee.

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## 2. SCOPE

This work shall consist of construction in a single or multiple layers of fibre-stabilized SMA on a previously prepared bituminous bound surface. SMA is based on the concept of designing a coarse aggregate skeleton so that stone-on-stone contact is obtained, which provides a highly rut-resistant bituminous course for heavy traffic roads. The 13 mm SMA in this specification (Table 3) is intended for wearing course with nominal layer thickness of 40 to 50 mm. The 19 mm SMA (Table 3) is intended for binder (or intermediate) course with nominal layer thickness of 45 to 75 mm.

## 3. MATERIALS

**3.1 Bitumen:** The bitumen for fibre-stabilized SMA shall be viscosity grade VG-30 complying with Indian Standard Specification for paving bitumen IS:73 or Polymer Modified Bitumen (PMB) Grade 40 complying with the Indian Roads Congress Specification IRC:SP:53.

**3.2 Coarse Aggregate:** The coarse aggregate shall consist of crushed rock retained on 2.36 mm sieve. It shall be clean, hard, durable of cubical shape and free from dust and soft organic and other deleterious substances. The aggregate shall satisfy the physical requirements given in **Table 1.**

**3.3 Fine Aggregate:** Fine aggregate (passing 2.36 mm sieve and retained on 0.075 mm sieve) shall consist of 100% crushed, manufactured sand resulting from crushing operations. The fine aggregate shall be clean, hard, durable, of fairly cubical shape and free from soft pieces, organic or other deleterious substances. The Sand Equivalent Test (IS:2720, Part 37) value for the fine aggregate shall not be less than 50. The fine aggregate shall be nonplastic.

**3.4 Mineral Filler:** Mineral filler shall consist of finely divided mineral matter such as stone dust and/or hydrated lime. Fly ash will not be permitted as a filler in SMA. The filler shall be graded within the limits indicated in the **Table 2.**

**Table 1. Physical Requirements for Coarse Aggregates for Stone Matrix Asphalt**

| Property | Test | Method | Specification |
|---|---|---|---|
| Cleanliness | Grain Size Analysis | IS:2386 (P-1) | < 2% passing 0.075 mm sieve |
| Particle Shape | Combined Flakiness and Elongation Index | IS:2386 (P-1) | < 30% |
| Strength | Los Angeles Abrasion Value | IS:2386 (P-4) | < 25% |
| | Aggregate Impact Value | IS:2386 (P-4) | < 18% |
| Polishing* | Polished Stone Value | IS:2386 (P-114) | > 55% |
| Durability | Soundness (either Sodium or Magnesium) – 5 cycles | | |
| | Sodium Sulphate | IS:2386 (P-5) | < 12% |
| | Magnesium Sulphate | IS:2386 (P-5) | < 18% |
| Water Absorption | Water Absorption | IS:2386 (P-3) | < 2% |

* Polishing requirement does not apply when the coarse aggregate is used in the 19 mm SMA, which is used as an intermediate (binder) course.

**Table 2. Grading Requirement of Mineral Filler**

| IS Sieve (mm) | Cumulative % passing by weight of total aggregate |
|---|---|
| 0.6 | 100 |
| 0.3 | 95 - 100 |
| 0.075 | 85 - 100 |

**3.4.1** The filler shall be inert material free from organic impurities and shall have plasticity index not greater than 4. Plasticity index requirement will not apply if filler is hydrated lime. Where the complete SMA mixture fails to satisfy the requirement of Moisture Susceptibility Test (AASHTO T 283) (see **Annex E** for the outline of the test), at least 2% by total weight of aggregate of hydrated lime shall be used and the percentage of fine aggregate reduced accordingly.

**3.5 Stabilizer Additive:** Only pelletized cellulose fibres shall be utilized. The dosage rate for cellulose fibres is 0.3% minimum by weight (on loose fibre basis) of the total mix. The dosage rate shall be confirmed so that the bitumen draindown does not exceed 0.3% when the designed mix is tested in accordance with ASTM D 6390, "Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures" (see **Annex C** for the outline of the test) or the Schellenberg Binder Drainage Test given in **Annex D**.

**3.5.1** The cellulose fibres to be used in pellets shall meet the following requirements:

Maximum Fibre Length - 8 mm
Ash Content - maximum of 20 % nonvolatile
Oil Absorption - more than 4 times of the fibre weight Moisture Content - less than 5 % by weight

**3.5.2** When the Contractor submits the proposed job-mix formula for SMA for approval, it shall include the fibre manufacturer's most recently dated actual test data showing that the fibres meet the above requirements. The Contractor shall protect the cellulose from moisture and contamination prior to incorporating it into the SMA.

## 4. SMA MIX DESIGN

**4.1** The combined grading of the coarse aggregate, fine aggregate, and mineral filler (including hydrated lime if used) shall be within the limits shown in **Table 3**.

**4.2** The SMA mixture will be designed using AASHTO MP8 Standard Specification for Designing Stone Matrix Asphalt and AASHTO PP41. Standard Practice for Designing Stone Matrix Asphalt . The outline of SMA mix design is given in Sections 5.3 through 5.9. The SMA mixture shall be compacted with 50 blows on each side using the Marshall procedure given in the Asphalt Institute MS-2 (Sixth edition). The designed mix shall meet the requirements given in **Table 4**.

**4.3 Determination of Voids in the Coarse Aggregate (VCA)**: The coarse aggregate in SMA of nominal sizes 13 mm and 19 mm is defined (for SMA mix design purposes only) as all material retained on the 4.75 mm sieve. This sieve is also referred to as the breakpoint sieve. Wash the coarse aggregate and determine its Dry Rodded Unit Weight in accordance with ASTM C 29 (see **Annex A** for the outline of the test). Calculate the dry-rodded VCA of the coarse aggregate fraction by the following equation.

$$\mathbf{VCA_{DRC} = [(G_{ca}\ Y_w - Y_s) / G_{ca}\ Y_w] * 100}$$

Where,

$VCA_{DRC}$ = voids in the coarse aggregate in the dry-rodded condition,

$G_{ca}$ = bulk specific gravity of the coarse aggregate,

$Y_w$ = unit weight of water (998 kg/m$^3$), and

$Y_s$ = unit weight of coarse aggregate fraction in dry-rodded condition (kg/m$^3$).

**Table 3. Composition of Stone Matrix Asphalt**

| SMA Designation | 13 mm SMA | 19 mm SMA |
|---|---|---|
| Course where used | Wearing Course | Binder (Intermediate) Course |
| Nominal Aggregate Size | 13 mm | 19 mm |
| Nominal Layer Thickness | 40-50 mm | 45-75 mm |
| IS Sieve (mm) | Cumulative % by weight of total aggregate passing | Cumulative % by weight of total aggregate passing |
| 26.5 | — | 100 |
| 19 | 100 | 90-100 |
| 13.2 | 90-100 | 45-70 |
| 9.5 | 50-75 | 25-60 |
| 4.75 | 20-28 | 20-28 |
| 2.36 | 16-24 | 16-24 |
| 1.18 | 13-21 | 13-21 |
| 0.600 | 12-18 | 12-18 |
| 0.300 | 10-20 | 10-20 |
| 0.075 | 8-12 | 8-12 |

**Table 4. SMA Mix Requirements**

| Mix Design Parameters | Requirement |
|---|---|
| Air void content, per cent | 4.0 |
| Bitumen content, per cent | 5.8 min. |
| Celluloid fibres | 0.3 per cent minimum by weight of total mix |
| Voids in mineral aggregate (VMA), percent | 17 min. |
| VCA mix, per cent | Less than VCA (dry rodded) |
| Asphalt draindown, per cent AASHTO T 305 (see Annex C) | 0.3 max. |
| Tensile Strength Ratio (TSR), per cent AASHTO T 283 (see Annex D) | 85 min. |

**4.4 Selection of Trial Bitumen Content:** The initial bitumen content of the mixture for the gradation selection phase of the design should be a minimum 6%. It is suggested that a good starting point be 6.0% for mixtures with aggregate specific gravities equal to or less than 2.75. If the bulk specific gravity of the aggregate exceeds 2.75 the asphalt content can be reduced slightly. The VMA of the mixture must still meet the specified minimum value.

**4.5 Sample Preparation and Testing:** Twelve samples are required; four samples at each of the three trial gradations at the bitumen content selected above. The aggregates and fibres should be dry mixed before adding the bitumen. The mixing and compaction temperatures should be $160^0$C and $150^0$C, respectively. Three samples from each trial gradation shall be compacted with 50 blows on each side and used to determine the volumetric properties of Marshall samples. The fourth sample shall be used to determine the theoretical maximum specific gravity according to ASTM D 2041 (see Annex B for the outline of the test).

**4.6 Selection of the Job Mix Gradation:** Compact the specimens, remove from the moulds, and allow to cool. Determine the bulk specific gravity, $G_{mb}$ of the specimens (AASHTO T 166). The uncompacted mix samples are used to determine the theoretical maximum specific gravity, $G_{mm}$ (ASTM D 2041). See **Annex B** for the outline of ASTM D 2041. Using $G_{mb}$ and $G_{mm}$, the percent air voids (Va*)*, VMA, and $VCA_{mix}$ are calculated by the following formulae:

Voids in Mineral Aggregate,
$$\mathbf{VMA = 100 - [(G_{mb}/G_{sb})*P_s]}$$
Percent Air Voids,
$$\mathbf{V_a = 100*(1 - G_{mb}/G_{mm})}$$
Voids in Coarse Aggregate, mix,
$$\mathbf{VCA_{MIX} = 100 \quad [(G_{mb}/G_{ca})*P_{CA}]}$$

Where,

$P_s$ = Percent of aggregate in mixture
$P_{CA}$ = Percent coarse aggregate in the total mixture
$G_{mb}$ = Bulk specific gravity of compacted mixture
$G_{mm}$ = Theoretical maximum density of the mixture
$G_{sb}$ = Bulk specific gravity of total aggregate, and
$G_{ca}$ = Bulk specific gravity of the coarse aggregate fraction.

The blend that exceeds the minimum VMA requirement and has a $VCA_{mix}$ that is less than the $VCA_{DRC}$ should be selected as the desired mix design aggregate blend. To ensure stone-on-stone contact within the coarse aggregate it is very essential that $VCA_{mix}$ is less than $VCA_{DRC}$.

**4.7 Determination of the Optimum Bitumen Content:** The optimum bitumen content shall be determined by corresponding to the design air void content, $V_a$, of 4.0%. The remaining mix properties should meet those specified in Table 4. A good starting point for the mix design is 6.0% bitumen content by weight of mix.

**4.8 Draindown Test**: Draindown of the loose SMA mix shall be determined according to ASTM D 6390 (see Annex C for the outline of the test) or by the Schellenberg Binder Drainage Test given in Annex D. The drainage test should be performed at the anticipated plant production temperature and should satisfy the specified maximum draindown of 0.30%. If the mixture fails to meet this requirement then the percent fibres should be increased to a level that reduces draindown to the acceptable limit.

**4.9 Tensile Strength Ratio:** Determine the Tensile Strength Ratio (TSR) in accordance with AASHTO T 283, "Resistance of Compacted Bituminous Mixtures to Moisture-Induced Damage" following the freeze and thaw option. See **Annex E** for the outline of the test.

## 5. SMA PRODUCTION

**5.1 Mixing :** The SMA mix shall be prepared in a hot mix plant of adequate capacity and capable of yielding a mix of proper and uniform quality with thoroughly coated aggregate.

When viscosity graded VG-30 bitumen is used, the mix temperature shall range from $150^0$C to $165^0$C. In case of polymer modified bitumen, the temperature of mixing and compaction shall be higher than the mix with VG-30 bitumen as binder. The exact temperature depends upon the type and amount of polymer used and shall be adopted as per the recommendations of the manufacturer. In order to ensure uniform quality of mix the plant shall be calibrated from time to time.

**5.2 Handling Mineral Filler:** Adequate dry storage will be provided for the mineral filler and provisions shall be made for proportioning the filler into the mixture uniformly and in the desired quantities. This is necessary because relatively large amounts of mineral filler are required in SMA mixes.

**5.3. Fibre Additive:** For batch plant, the fibre will be added directly into the weigh hopper above the pugmill. Adequate dry mixing time is required to disperse the fibre uniformly throughout the hot aggregate. Dry mixing time will be increased by 5 to 10 seconds. Wet mixing time shall be increased by at least 5 seconds. For drum mix plant, a separate fibre feeding system shall be utilized that can accurately and uniformly introduce fibre into the drum at such a rate as not to limit the normal production of mix through the drum. At no time shall there be any evidence of fibre in the baghouse/wasted baghouse fines.

## 6. SMA PLACEMENT AND COMPACTION

**6.1 Preparation of Existing Bituminous Surface:** The existing bituminous surface shall be cleaned of all loose extraneous matter by means of mechanical broom and high-pressure air jet from compressor or any other approved equipment/method. Any potholes and/or cracks shall be repaired and sealed.

**6.2 Tack Coat:** A bitumen emulsion complying with IS:8887 of a type and grade or viscosity grade bitumen VG-10 shall be applied as a tack coat on the existing bituminous layer. Quantity of liquid bituminous material shall vary from 0.20 to 0.30 kg/sqm in case of emulsion and 0.30 to 0.40 kg/sqm in case of bitumen. In this regard IRC:16 may be referred. The tack coat shall be applied by a self propelled or towed bitumen pressure sprayer equipped for spraying the bitumen binder uniformly at a specified rate. The emulsion tack coat shall be allowed to set (turn black from brown) before laying the hot mix.

**6.3 Transportation:** The SMA shall be transported in clean, insulated covered vehicles. An asphalt release agent, which does not adversely affect the bituminous mix may be applied to the interior of the vehicle to prevent sticking and to facilitate discharge of the material.

**6.4 Laying**

**6.4.1 Weather and seasonal limitations**: The SMA mix shall not be laid:

- in presence of standing water on the surface.
- when rain is imminent and during rains, fog, or dust storm.
- when the base/binder course is damp.
- when the air temperature on the surface on which it is to be laid is less than 10°C for mix with conventional bitumen as binder and is less than 15°C for mix with polymer modified bitumen as binder.
- When the wind speed at any temperature exceeds 40 km/h at 2 m height.

**6.4.2 Spreading:** Except in areas where paver cannot access bituminous material shall be spread, levelled and tamped by self-propelled hydrostatic paver finisher preferably with sensor. As soon as possible after arrival at site the material shall be supplied continuously to the paver and laid without delay. The rate of delivery of material to the paver shall be regulated to enable the paver to operate continuously. The travel rate of paver and the method of operation shall be adjusted to ensure even and uniform flow of bituminous material across the screed, free from dragging, tearing and segregation.

Restricted areas (such as confined space, footways, irregular shape and varying thickness, approaches to expansion joints etc) where paver cannot be used, the material shall be spread, raked and levelled with suitable hand tool by trained staff.

When laying SMA mix near expansion joint, the machine laying shall be stopped about 300 mm short of joint. The remaining pavement up to the joint and the corresponding area beyond it shall be laid manually.

## 6.5 Compaction

**6.5.1** Compaction shall commence immediately after laying and shall be completed before the temperature falls below 100$^0$C. Rolling of the longitudinal joints shall be done immediately behind the paving operation. After this, the rolling shall commence at the edge and progress towards the center longitudinally except at sections with unidirectional camber, where it shall progress from lower edge to upper edge parallel to centerline of the pavement.

**6.5.2** All deficiencies in the surface after laying shall be made good by the attendant behind the paver, before initial rolling is commenced. The initial or breakdown rolling shall be done with the 8 to 10 tonnes dead weight or vibratory steel wheel roller. The intermediate rolling shall also be done with 8 to 10 tonnes dead weight or vibratory roller. Pneumatic rolling shall not be used on SMA because of potential pickup problems. The finished rolling shall be done with 6 to 8 tonne smooth wheel roller. Rolling shall continue till all the roller marks are removed from the surface and the minimum specified field density is achieved.

**6.5.3** The SMA mix shall be rolled in the longitudinal direction, with the roller as close as possible to the paver. The overlap on successive passes should be at least one-third of the width of the rear wheel. The roller should move at a speed of not more than 5 km/h. The roller shall not be permitted to stand on pavement, which has not been fully compacted. All precautions shall be taken to prevent dropping of oil, grease, petrol or other foreign material on the pavement. The wheel of the rollers shall be kept moist with the water or spray system provided with the machine to prevent the mixture from adhering to the wheels. Minimum moisture to prevent adhesion between wheels and mixture shall be used and surplus water shall not be allowed to stand on the partially completed pavement.

**6.5.4** The density of the finished paving layer shall be determined by taking 150 mm diameter cores. The density of finished paving layer shall not be less than the 94% of the average (sample size N=2) theoretical maximum specific gravity of the loose mix ($G_{mm}$) obtained on that day in accordance with ASTM D2041. That is, no more than 6% air voids shall be allowed in the compacted SMA mat. See **Annex B** for the outline of ASTM D 2041.

## 6.6 Joints

**6.6.1** Where joints are made, the material shall be fully compacted and the joint made flush in one of the following ways.

**6.6.2** All joints shall be cut vertical to the full thickness of the previously laid mix. All loosened material shall be discarded and the vertical face be coated with any viscosity grade bitumen or cold applied emulsified bitumen or rubberized asphalt tack coat (minimum thickness 3 mm), prior to laying the adjacent lane. While spreading the material along the joint the material spread shall overlap 25 mm to 30 mm on the previously laid mix beyond the vertical face of the joint. The thickness of the loose overlap material should be approximately a quarter more than the final compacted thickness. The overlapped mix should be bumped back with a lute just across the joint so that the excess material on the hot side can be pressed to obtain a high joint density.

**6.6.3** By using two or more pavers in echelon, where this is practicable and in sufficient proximity for adjacent width to be fully compacted by continuous rolling.

**6.6.4** By heating the joints with an approved infrared joint heater when the adjacent lane is being laid, but without cutting back or coating with the binder. The heater shall raise the temperature of the full depth of material, to minimum rolling temperature for a width of 75 mm. The temperature shall not exceed 175$^0$C.

**6.6.5** For transverse joints, the method suggested in Section 6.6.2 can be adopted. In multi-layer construction, the joint in one layer shall offset the joint in the underlying layer by about 150 mm. However the joint in the top layer shall be along the centre line of the pavement.

**6.7 Arrangement for Traffic:** It shall be ensured that traffic is not allowed on the SMA surface until the paved mat has cooled to ambient temperature in its entire depth.

## 7. CONTROLS

### 7.1 Surface Finish

**7.1.1** The levels of the SMA mix shall not vary from those calculated with reference to longitudinal and cross profile of the roads as per the Contract beyond $\pm$ 6 mm provided that the negative tolerance shall not be permitted in conjunction with the positive tolerance for the base course if the thickness of the former is thereby reduced by more than 6 mm.

**7.1.2** For checking the compliance with the above requirement, measurements of the surface level shall be taken on a grid of points spaced 6.25 m along the length and 0.5 m from the edges and at the centre of the pavement. The compliance shall be deemed to be met for the final road surface only if the tolerance given above is satisfied for any point on the surface.

**7.1.3** In case, where surface levels fall outside the specified tolerance, the Contractor shall be liable to rectify these by replacing the full depth of layer. In all cases of replacement the area treated shall not be less than 5 m in length and not less than 3.5 m in width.

### 7.2 Surface Evenness

**7.2.1** The measurement and checking of surface evenness shall be done by a 3 m straight edge in accordance with the procedures in IRC:SP:16-2004.

**7.2.2** The maximum permissible surface unevenness using longitudinal profile 3 m straight edge shall be 5 mm for SMA. The maximum permissible unevenness using transverse profile camber shall be 4 mm.

**7.2.3** The maximum permissible frequency of surface unevenness (3-5 mm) in 300 m length in longitudinal profile shall be 15.

**7.2.4** Where the surface unevenness falls outside the tolerance, in either case i.e. the surface is low or high, the full depth of the layer shall be removed and replaced with fresh material and compacted to the specification.

**7.2.5** In all cases of removal and replacement the area treated shall not be less than 5 m in length and 3.5 m in width.

### 7.3 Surface Roughness

**7.3.1** Surface roughness shall be checked in accordance with procedures in IRC : SP : 16 - 2004.

**7.3.2** The maximum permissible value of surface roughness measured with a bump integrator shall be less than 2000 mm/km.

### 7.4 Quality Control during Construction

**7.4.1** The material supplied and the work shall conform to the specifications prescribed in the preceding Clauses. To ensure the quality of the material and the work, control tests shall be conducted during the execution of the paving project. The tests and minimum frequency for each test is indicated in **Table 5**.

### 7.5 Acceptance Criteria

**7.5.1** The acceptance criteria for test on density (N = 3 minimum) and laboratory air voids and VMA (N = 2 minimum) shall be subjected to the condition that the mean value of N samples is not less than the specified value plus
$[1.65 - 1.65/(\text{No. of samples})^{0.5}]$ x standard deviation

## 8. TRIAL/EXPERIMENTAL SECTION

Trial section(s), a minimum of 150 m each, shall be constructed off site to examine the mixing plant process control to meet the job mix formula within tolerances, placement procedures, SMA surface appearance, and compaction patterns. Work on the main project will be allowed after satisfactory test results (especially mix composition, gradation, and volumetrics) have been obtained on the test section.

**Table 5. Control Tests for SMA Mix and their Minimum Frequency**

| Sl. No. | Test | Frequency |
|---|---|---|
| 1. | Quality of binder | Number of samples per lot and tests as per IS:73 or IRC:SP 53 |
| 2. | Aggregate impact value/Los Angels Abrasion value | One test per 50 $m^3$ of aggregate |
| 3. | Flakiness index | One test per 50 $m^3$ of aggregate |
| 4. | Soundness test (Sodium and Magnesium Sulphate test) | One test for each method for each source and when ever there is change in the quality of aggregate |
| 5. | Water absorption of aggregate | One test for each source and when ever there is change in the quality of aggregate |
| 6. | Sand equivalent test | One test for each source |
| 7. | Plasticity Index | One test for each source |
| 8. | Polished stone value | One test for each source |
| 9. | Percent of fractured faces | One test per 50 $m^3$ of aggregate when crushed gravel is used. |
| 10. | Mix grading | One set for individual constituent and mixed aggregate from dryer for each 400 tonnes of mix subject to minimum of two tests per day per plant |
| 11. | Air voids and VMA analysis of mix including theoretical maximum specific gravity of loose mix | Three tests for density and void contents for each 400 tonnesof mix subject to minimum of two tests per day per plant |
| 12. | Moisture Susceptibility of mix (AASHTO T 283) | One test for each mix type whenever there is change in the quality or source of coarse or fine aggregate |
| 13. | Temperature of binder in boiler, aggregate in dryer and mix at the time of laying and compaction | At regular intervals |
| 14. | Binder content | One set for each 400 tonnes of mix subject to minimum of two tests per day per plant |
| 15. | Rate of spread of mix material | After every $5^{th}$ truck load |
| 16. | Density of compacted layer | One test per 250 $m^2$ area. |

## ANNEX A

## Outline of ASTM C 29, "Bulk Density (Unit Weight) and Voids in Aggregate"

**A. Scope and Summary of Test**

This method covers the determination of bulk density (unit weight) of a coarse aggregate in a specified compacted condition and calculated voids between aggregate particles based on this determination. The amount of calculated voids are used in the mix design of stone matrix asphalt (SMA). Only the dry rodded compaction is covered in this outline of the test method.

**B. Testing Equipment**

1. Balance or scale accurate up to 0.1 percent of the test load.

2. Tamping rod : a round, straight steel rod, 16 mm(5/8 inch) in diameter and approximately 600 mm in length. Tamping end shall be rounded to a hemispherical tip with a diameter of 16 mm.

3. A sturdy, cylindrical metal measure with a capacity of 10 *l* ($m^3$). The height and diameter of the measure should be approximately equal.

4. Shovel or scoop for filling the measure with aggregate.

5. Piece of plate glass at least 6 mm thick and at least 25 mm larger than the diameter of the measure.

**C. Testing Procedure**

1. Calibrate the measure and determine its capacity in $mm^3$ by filling it with water and covering with plate glass to eliminate air bubbles and excess water. Determine the mass of water in the measure. Calculate the volume of the measure, V, by dividing the mass of the water by its density.

2. Use the dry rodding procedure to place and compact the oven-dry coarse aggregate in the measure. Fill the measure 1/3 full with aggregate and level the surface with fingers. Rod the layer of the aggregate with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure 2/3 full, level with fingers and rod as above again. Finally, fill the measure slightly overflowing the measure and rod again as before. Level the surface of aggregate with fingers in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

3. Determine the mass of the measure plus its contents and the mass of the measure alone and record the values to the nearest 0.05 kg.

4. Calculate the unit weight of the coarse aggregate by the dry rodding procedure as follows:

$$Y_s = (G - T) / V$$

Where,

$Y_s$ = unit weight of the coarse aggregate in dry rodded condition, $kg/m^3$

G = mass of the measure plus aggregate, kg

T = mass of the measure, kg

V = volume of the measure, $m^3$

## ANNEX B

## Outline of ASTM D 2041, "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures"

**A. Scope and Summary of the Test Method**

This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 25°C. The theoretical maximum specific gravity ($G_{mm}$) is used: (a) to calculate air voids in compacted bituminous mixtures, (b) to calculate the amount of bitumen absorbed by the aggregate, and (c) to provide target value for the compaction of paving mixtures in the field.

A sample of loose paving mixture is placed in a tared vacuum vessel. Water at 25°C is added to completely submerge the sample. A specified amount of vacuum is gradually applied to remove the air bubbles entrapped between asphalt mix particles. After the vacuum is released, the volume of the sample of the voidless paving mixture is obtained by either immersing the vacuum container with the sample in a water bath and weighing or by filling the calibrated vacuum container level full of water and weighing in air.

**B. Testing Equipment**

1. Container (either a or b below)

(a) **Vacuum bowls**: Either a metal or plastic bowl with a diameter ranging from 180 to 260 mm and a bowl height of at least 160 mm. The bowl shall be equipped with a stiff, transparent cover fitted with a rubber gasket and a connection for the vacuum line. The hose connection shall be covered with a small piece of fine wire mesh to minimize loss of any fine material from the mix.

(b) Vacuum flask for weighing in air only. A thick-walled volumetric glass flask with a capacity of approx. 4000 ml, fitted with a rubber stopper with a connection for the vacuum line. The hose connection shall be covered with a small piece of fine wire mesh to minimize loss of any fine material from the mix.

2. Balance capable of being read to the nearest 0.1 g. If weighing is to be done under water, a suitable suspension arrangement shall be provided for weighing the sample while suspended from the center of the balance.

3. Vacuum pump, capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm of Hg) or less. Provide a suitable trap between the pump and container to minimize water vapour entering the vacuum pump.

4. Residual pressure manometer or calibrated absolute pressure gauge with a bleed valve to adjust the vacuum level.

5. Water bath capable of maintaining a constant temperature of 25±1°C and suitable for immersion of the suspended container.

**C. Calibration of Containers**

**1. Bowls**: Determine the mass (B) of the container immersed in water at 25±1°C. If the bowl is used for weighing in air, place the volumetric lid on the bowl while under water. Remove the water-filled bowl with the lid in place and dry prior to determining the combined mass of the bowl, lid and water. Repeat 3 times and average the 3 masses. Designate the average mass as D.

2. **Flasks:** Calibrate the volumetric flask by accurately determining the mass of the flask filled with water at $25\pm1^{\circ}C$. Use a glass cover plate to ensure the flask is completely full.

**D. Testing Procedure**

1. Separate the particles of the loose paving mixture (while it is warm) by hand so that the particles are not larger than about 6 mm. Don't fracture the aggregate. Place the mix sample directly into the tarred bowl or flask. Weigh the container with the sample and designate the net mass of the sample only as A.
[Note: The minimum sample size shall be 1500 g for mixes with nominal maximum aggregate sizes of 12.5 mm or smaller; and shall be 2500 g for mixes with nominal maximum aggregate sizes from 19 to 25 mm.]

2. Add sufficient water at $25^{\circ}C$ to cover the sample completely. Place the cover (bowls) or stopper (flasks) on the containers.

3. Place the container with the sample and water on a mechanical agitation device or agitate manually at frequent intervals (2 to 3 minutes). Begin removing entrapped air by gradually applying vacuum and increasing the vacuum pressure until the residual manometer reads $3.7\pm0.3$ kPa ($27.5\pm2.5$ mm of Hg). After achieving this level within 2 minutes, continue the vacuum and agitation for $15\pm2$ minutes. Gradually release the vacuum with the bleed valve.

4. **Weighing in water** : Suspend the bowl (without lid) and contents in water for $10 \pm 1$ minute and then determine mass. Designate the mass under water of the bowl and sample as C.

5. **Weighing in air**

**(a) Bowl:** Submerge the bowl and sample slowly in the $25\pm1^{\circ}C$ water bath. Keep it there for $10\pm1$ minutes. Immerse the lid in water and slide it onto the bowl without removing water from the bowl so that no air is trapped inside the bowl. Remove the bowl with the lid in place from the water bath. Dry the bowl and lid with a dry cloth. Determine the mass of the bowl, sample, and lid and designate it as E.

**(b) Flask:** Fill the flask slowly with water ensuring not to introduce any air into the sample. Place the flask in water bath for $10\pm1$ minutes to stabilize the temperature at $250^{\circ}C$ without submerging the top of the flask. Completely fill the flask with water using a cover plate without entrapping air beneath the cover plate. Wipe the exterior of the flask and cover plate. Determine the mass of the flask, plate and its contents completely filled with water. Designate this mass as E.

6. **Calculations:** Calculate the maximum specific gravity of the sample of loose paving mixture as follows:

**(a) Bowls Used Under Water Determination:**

$$G_{mm} = A / [A-(C-B)$$

Where,

$G_{mm}$ = maximum specific gravity of the mixture

A = mass of the dry sample in air, g

B = mass of bowl under water, g

C = mass of bowl and sample under water, g

**(b) Bowls in Air Determination:**

$$G_{mm} = A/(A+D-E)$$

Where,

$G_{mm}$ = maximum specific gravity of the mixture

A = mass of dry sample in air, g

D = mass of lid and bowl with water at 25°C, g

E = mass of lid, bowl, sample and water at 25°C, g

**(c) Flask Determination**

$$G_{mm} = A/(A+D-E)$$

Where,

$G_{mm}$ = maximum specific gravity of the mixture

A = mass of dry sample in air, g

D = mass of cover plate and flask filled with water at 25°C, g

E = mass of flask, cover, sample and water at 25°C, g

## ANNEX C

## Outline of ASTM D 6390, "Determination of Draindown Characteristics in Uncompacted Asphalt mixtures"

### A. Scope and Summary of Test

This method determines the amount of draindown in an uncompacted asphalt mixture sample when the sample is held at elevated temperatures, which are encountered during the production, transportation, and placement of the mixture. This test is especially applicable to open-graded asphalt mixtures (such as open-graded friction course) and gap-graded mixtures such as SMA.

A fresh sample of the asphalt mixture (either made in the laboratory or from an asphalt plant) is placed in a wire basket. The wire basket is hung in a forced draft oven for one hour at a pre-selected temperature. A catch plate of known mass is placed below the basket to collect material drained from the sample. The mass of the drained material is determined to calculate the amount of draindown as a percentage of the mass of the total asphalt mix sample.

### B. Testing Equipment

1. Forced draft oven, capable of maintaining temperatures in a range of 120° to 175°C with ± 2°C of the set temperature.

2. Plates to collect the drained material

3. Standard wire basket meeting the dimensions shown in Figure 1. A standard 6.3 mm sieve cloth shall be used to make the basket. The dimensions shown in the figure can vary by ±10 %.

4. Balance readable to 0.1 g.

### C. Testing Procedure

1. For each mixture to be tested, the draindown characteristics shall be determined at two temperatures: at the anticipated plant production temperature and at a temperature 10°C higher than the anticipated production temperature. Duplicate samples shall be tested at each temperature. Therefore, a minimum of 4 samples shall be tested.

2. Weigh the empty wire basket (Mass A).

3. Place in the wire basket 1200 ± 200 g of fresh, hot asphalt mixture (either prepared in the laboratory or from an asphalt plant) as soon as possible without losing its temperature. Place the mix loosely in the basket without consolidating it. Determine the mass of the wire basket plus sample to the nearest 0.1 g (Mass B).

4. Determine the mass of the empty plate to be placed under the basket to nearest 0.1g (Mass C).

5. Hang the basket with the mix in the oven preheated to a selected temperature. Place the catch plate beneath the wire basket. Keep the basket in the oven for 1 hour ± 5 minutes.

6. Remove the basket and catch plate from the oven. Let it cool to ambient temperature. Determine the mass of the catch plate plus the drained material to the nearest 0.1 g (Mass D).

7. Calculate the percentage of mixture which drained to the nearest 0.1% as

follows:

**Draindown (per cent) =**
$$\{(D-C)/(B-A)\} \times 100$$

Where,

A = mass of the empty wire basket, g

B = mass of the wire basket plus sample, g

C = mass of the empty catch plate, g

D = mass of the catch plate plus drained material, g

8. Average the two drain down results at each temperature and report the average to nearest 0.1%.

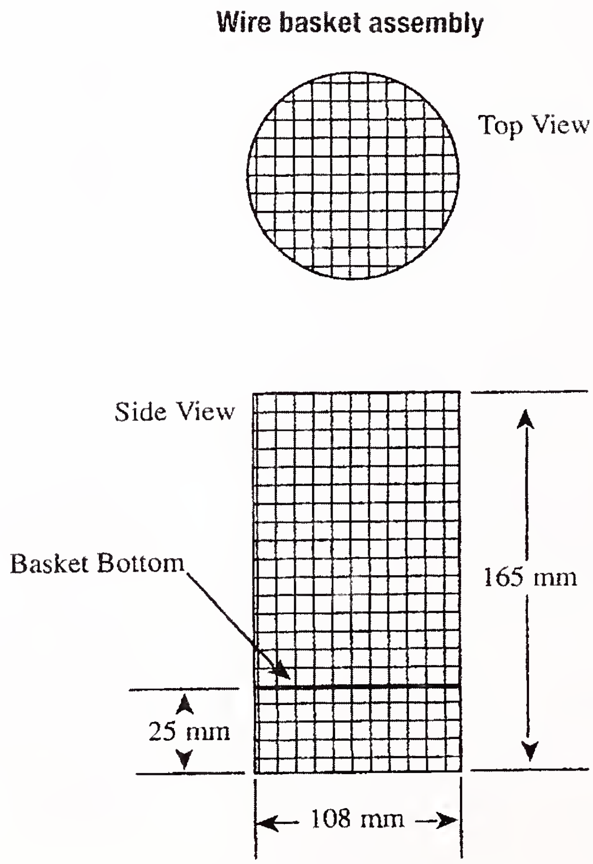


**Figure 1. Wire Basket Assembly for Draindown Test**

## ANNEX D
## The Schellenberg Binder Drainage Test

1. Determine the mass (A) of an empty 850 ml glass beaker, approximately 98 mm diameter by 136 mm high, to the nearest 0.1 g.

2. Pour approximately 1 kg of the SMA mix immediately into the glass beaker after mixing at the anticipated field mixing temperature. Re-weigh the beaker together with SMA (B) to the nearest 0.1 g.

3. Place the glass beaker with a glass or tin cover in an oven maintained at $170^0C \pm 1^0C$ for 1 hour $\pm 1$ minute.

4. At the end of 1hour period, immediately remove the glass beaker from the oven and empty the beaker without the use of any shaking or vibration. Re-weigh the beaker (C) to the nearest 0.1 g.

5. Calculate the percentage of binder draindown (defined as the percentage of mass of the SMA deposited in the beaker) as follows:

   Binder Draindown (%) = (C-A)/(B-A) multiplied by 100

## ANNEX E

## Outline of AASHTO T 283, "Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage"

### A. Scope and Summary of Test Method

This method covers preparation of compacted bituminous mixtures and the measurement of the change of diametral tensile strength resulting from the effects of water saturation and laboratory accelerated stripping phenomenon with a freeze-thaw cycle. The result may be used to predict long-term stripping susceptibility of bituminous mixtures and evaluate liquid anti-stripping additives that are added to bitumen or pulverized mineral materials such as hydrated lime, which are added to the mineral aggregate.

Each set of 6 compacted specimens is divided into two equal subsets. One subset is tested in dry condition for indirect tensile strength. The other subset is subjected to vacuum saturation and a freeze-thaw cycle (thawing in a hot water bath) before testing for indirect tensile strength. Numerical indices of retained indirect tensile strength properties are calculated from the test data obtained by testing the two subsets viz. dry and conditioned.

### B. Testing Equipment

1. Vacuum container, vacuum pump, manometer, and other accessories as specified in ASTM D2041, "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures".

2. Balance or scale accurate to 0.1% of the test load

3. Two water baths capable of maintaining temperatures of $60^{0}C \pm 1^{0}C$ and $25^{0}C \pm 0.5^{0}C$

4. Freezer maintained at $18\,^{0}C \pm 3^{0}C$

5. 10-ml graduate cylinder

6. Loading jack and ring dynamometer (Marshall stability testing machine can be used) to provide a vertical rate of deformation of 50 mm (2 inches) per minute and capable of reading the maximum failure load.

7. Steel loading strips with a concave surface having a radius equal to the normal radius of the test specimen. The loading strips shall be 12.7 mm (0.5 inch) wide for specimens 100 mm (4 inches) in diameter. The loading strips for 150 mm (6 inches) diameter specimens shall be 19.05 mm (0.75 inch) wide. The length of the loading strips shall exceed the thickness of the specimens. Steel strips are provided at the top and bottom of specimens during indirect tensile testing.

### C. Testing Procedure

1. Make at least 6 compacted specimens for each mixture, 3 to be tested dry and 3 to be tested after partial saturation and moisture conditioning with a freeze-thaw cycle. Some extra specimens will need to be made to establish compaction procedures in order to obtain specified air void contents in the test specimens by trial and error.

2. Compact the 6 specimens with a Marshall compactor so that the compacted specimens have air voids of $7.0 \pm 0.5\%$. This level of high air voids can be obtained by adjusting the number of Marshall blows applied on each side of the specimen by trial and error (start at about 10 blows as a starting point). Air void content must be calculated from the bulk specific gravity of the compacted specimen (determined by saturated surface dry method as per procedure given in the Asphalt Institute MS-2) and the maximum theoretical specific gravity of the loose bituminous mixture obtained by ASTM D 2041.

3. Separate the 6 specimens into 2 subsets so that the average air voids of the two subsets are approximately equal.

4. One set will be tested dry. Keep it at room temperature and then place in a $25^{0}C \pm 0.5^{0}C$ water bath for 2 hours prior to determining their indirect tensile strength.

5. The other subset will be conditioned as follows:

(a) Place and submerge the 3 specimens in the vacuum container filled with water at room temperature. Apply a vacuum of 13-67 kPa absolute pressure (10-26 inche Hg partial pressure) for 30 minute. Remove the vacuum and leave the specimens submerged in water for 5 to 10 minutes. [Note: The water saturation procedure noted above deviates from AASHTO T 283, which obtains a specified degree of saturation. The above procedure keeps the time of saturation constant.]

(b) Wrap a plastic film around each saturated specimen and place the wrapped specimen in a plastic bag containing 10 ml of water and seal the plastic bag. Place the plastic bag in a freezer at temperature of $18^{0}C \pm 3^{0}C$ for a minimum of 16 hour. Remove the specimens from the freezer.

(c) Place the specimens in a water bath maintained at $60^{0}C \pm 1^{0}C$ for 24 hour. Remove the plastic bag and the plastic film from each specimen after placing the specimens under water.

(d) Remove the specimens from hot water bath and place in a water bath maintained at $25^{0}C \pm 0.5^{0}C$ for 2 hour.

(e) Remove the conditioned specimens and test for indirect tensile strength.

6. Determine the indirect tensile strength of the 3 dry and 3 conditioned specimens at $25^{0}C \pm 0.5^{0}C$ after removing from water bath. First, measure their mean thicknesses (t). Then place the two steel loading strips on the bottom and top of the specimens across diameter and place in the Marshall testing machine or a compression-testing machine. Apply load to the specimens diametrally at a vertical rate of 50 mm per minute.

7. Record the maximum compressive strength noted on the testing machine and continue loading until a vertical crack appears in the specimen. Remove the cracked specimen from the machine and visually estimate the approximate degree of moisture damage (extent of stripped or bare aggregate) on the fractured faces of the specimen on a scale of 0 to 5 (5 being the most stripping).

8. Calculate the tensile strength of each specimen as follows in SI units:

$$\mathbf{St = 2000\, P/\pi\, t\, d}$$

Where,

St = tensile strength, kPa
P = maximum loads, N
t = specimen thickness, mm
d = specimen diameter, mm

9. Express the numerical index of resistance of bituminous mixture to the detrimental effects of water as the ratio of the original strength that is retained after accelerated moisture and freeze-thaw conditioning.

Calculate the tensile strength ratio (TSR) as follows:

$$\mathbf{TSR = S_2 / S_1}$$

Where,

$S_1$ = average tensile strength of the dry subset, kPa
$S_2$ = average tensile strength of the conditioned subset, kPa

## REFERENCES


### AASHTO Standards

1. MP8 Standard Specification for Designing Stone Matrix Asphalt

2. PP41 Standard Practice for Designing Stone Matrix Asphalt

3. T 166 Bulk Specific Gravity of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens.

4. T 283 Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage

### ASTM Standards

5. C 29 Bulk Density ("Unit Weight") and Voids in Aggregate

6. D 2041 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

7. D 6390 Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures

### Asphalt Institute Publications

8. MS-2 Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types(Sixth Edition)

### National Asphalt Pavement Association

9. Quality Improvement Series 122. Designing and Constructing SMA Mixtures: State-of-the-Practice by P. S. Kandhal, March 2002.

(The official amendments to this document would be published by the IRC in its periodical, "Indian Highways" which shall be considered as effective and as part of the code/guidelines/manual, etc. from the date specified therein)