JKR/SPJ/2008-S4
JKR 20403 0003 07

KERAJAAN MALAYSIA
JABATAN KERJA RAYA MALAYSIA

STANDARD SPECIFICATION FOR ROAD WORKS

SPJ SECTION 4: FLEXIBLE PAVEMENT

ADDENDUM NO.1: BITUMEN PENETRATION GRADE 60-70

ADDENDUM NO.2: CLAUSE 4.16 NATURAL RUBBER MODIFIEDASPHALT
CLAUSE 4.17 CRUMB RUBBER MODIFIED ASPHALT

KETUA PENGARAH KERJA RAYA
JABATAN KERJA RAYA MALAYSIA
JALAN SULTAN SALAHUDDIN,
50582 KUALA LUMPUR.

Addendum No. 1

SAKPKR BIL. 1/2017 BERTARIKH 7 FEBRUARI 2017

ARAHAN PENGGUNAAN BITUMEN PENETRATION GRADE 60 – 70 DALAM KERJA PENURAPAN JALAN

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Rujukan: JKR.KPKR:121.010/05 Jld. 7(5)
Tarikh: 7 Februari 2017

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SURAT ARAHAN KPKR BIL. 1/2017

ARAHAN PENGGUNAAN BITUMEN *PENETRATION GRADE* 60 – 70 DALAM KERJA PENURAPAN JALAN

1.0 TUJUAN

Surat Arahan ini bertujuan untuk menetapkan satu (1) gred bitumen sahaja digunakan iaitu bitumen *penetration grade* 60 – 70 dalam kerja penurapan jalan. Sehubungan itu, penggunaan bitumen *penetration grade* 80 – 100 tidak lagi dibenarkan.

Rujukan: JKR.KPKR:121.010/05 Jld. 7(5)
Tarikh: 7 Februari 2017

2.0 LATAR BELAKANG

2.1 Spesifikasi Piawaian Jalan JKR/SPJ/2008-S4 (SPJ) klausa 4.3.3.2 (c) menetapkan bahawa *bituminous binder* bagi *asphaltic concrete* seharusnya bitumen *penetration grade* 60 – 70 atau 80 – 100 atau *polymer modified binder*.

2.2 Bagi penggunaan bitumen konvensional, terdapat dua (2) pilihan iaitu *bitumen penetration grade* 60 – 70 atau 80 – 100, di mana gred 60 – 70 mempunyai nilai kepekatan yang lebih tinggi berbanding gred 80 – 100. Sehubungan itu bagi *asphalt* yang mengunakan bitumen *penetration grade* 60 - 70, SPJ telah menetapkan suhu pembancuhan *asphalt* di kuari, serta suhu penurapan dan pemadatan *asphalt* di tapak ditingkatkan sehingga 10 °C berbanding suhu jika bitumen *penetration grade* 80 – 100 digunakan.

2.3 Kajian di luar negara menunjukkan *asphalt* yang dibancuh dengan bitumen *penetration grade* 60 – 70 dapat meningkatkan keupayaan turapan dalam menampung beban trafik sehingga 21% dan memanjangkan jangka hayat turapan sehingga 18% berbanding bitumen *penetration grade* 80 – 100.

3.0 PENETAPAN PENGGUNAAN BITUMEN *PENETRATION GRADE* 60–70

3.1 Bagi memastikan penggunaan bitumen yang seragam sama ada jalan utama dengan beban trafik yang tinggi atau jalan luar bandar dengan beban trafik yang lebih rendah dan sama ada *asphalt* digunakan sebagai

binder course atau *wearing course*, hanya satu (1) gred bitumen sahaja seharusnya digunakan. Gred bitumen itu ialah bitumen *penetration grade* 60 – 70.

3.2 Bitumen *penetration grade* 60 – 70 seharusnya mematuhi spesifikasi terkini *Malaysian Standard MS 124 'Specification for penetration grade of bitumen for use in pavement construction.'*

3.3 *Asphalt* menggunakan bitumen *penetration grade* 60 – 70 seharusnya mematuhi Spesifikasi Piawaian Jalan (SPJ) yang terkini.

4.0 KUAT KUASA

4.1 Surat Arahan ini berkuat kuasa mulai **1 Mei 2017**. Tarikh ini ditetapkan dengan mengambil kira masa secukupnya yang diperlukan oleh syarikat-syarikat pengeluar bitumen di negara ini bagi membuat perubahan yang sewajarnya ke atas cara pemprosesan minyak mentah di loji penapis bagi menghasilkan bitumen *penetration grade* 60 – 70.

Sekian, terima kasih.

'BERKHIDMAT UNTUK NEGARA'

DATO' SRI Ir. Dr. ROSLAN BIN MD TAHA

Rujukan: JKR.KPKR:121.010/05 Jld. 7(5)

Tarikh: 7 Februari 2017

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- Ketua Setiausaha, Kementerian Kerja Raya
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- Timbalan Ketua Pengarah Kerja Raya (Sektor Pakar)
- Pengarah Cawangan Dasar dan Pengurusan Korporat

Addendum No. 2

SAKPKR BIL. 11/2019 BERTARIKH 7 MAC 2019

ADDITIONAL OF:

CLAUSE 4.16 NATURAL RUBBER MODIFIED ASPHALT
CLAUSE 4.17 CRUMB RUBBER MODIFIED ASPHALT

KETUA PENGARAH KERJA RAYA

DIRECTOR-GENERAL OF PUBLIC WORKS

Rujukan : JKR.KPKR:121.010/05 Jld. 16 (1)
Tarikh : 7 Mac 2019

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SURAT ARAHAN KPKR BIL. 11 / 2019

PINDAAN KEPADA SURAT ARAHAN KPKR BIL.14/2011 ARAHAN PENGGUNAAN *STANDARD SPECIFICATION FOR ROAD WORKS SECTION 4: FLEXIBLE PAVEMENT* (JKR/SPJ/2008-S4)

1.0 TUJUAN

1.1 Surat Arahan ini bertujuan untuk membuat pindaan kepada Surat Arahan KPKR Bil. 14/2011 bertarikh 21 November 2011.

1.2 Surat Arahan ini dikeluarkan adalah khusus untuk membuat penambahan baru iaitu Klausa 4.16: *Natural Rubber Modified Asphalt* dan Klausa 4.17: *Crumb Rubber Modified Asphalt.*

2.0 LATAR BELAKANG

2.1 Spesifikasi Piawai Jalan *Section 4: Felxible Pavement* (JKR/SPJ/2008-S4) yang telah disiapkan pada Februari 2008 merupakan pindaan kepada spesifikasi lama JKR/SPJ/1998-S4. Spesifikasi tersebut telah diedarkan melalui surat daripada Pengarah Cawangan Jalan, rujukan no: (23) JKR.PCJ/UKJ/STD/Sec 4 bertarikh 19 Februari 2008.

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2.2 Addendum kepada spesifikasi sedia ada ini telah dibentang dan diluluskan dalam Mesyuarat Jawatankuasa Pemandu Pengurusan Bil. 3/2018 pada 21 Mac 2018.

2.3 Antara matlamat pembangunan addendum yang dibuat di dalam spesifikasi ini adalah seperti berikut:-

a) Membangunkan spesifikasi baru melibatkan penggunaan *Natural Rubber Modified Asphalt* dan *Crumb Rubber Modified Asphalt* sebagai jenis turapan yang boleh digunapakai dalam pembinaan jalan;

b) Menfokuskan kepada penggunaan *Natural Rubber* dan *Crumb Rubber* sebagai antara alternatif turapan jalan;

c) Menerangkan kaedah penyediaan *Natural Rubber Modified Binder* dan *Crumb Rubber Modified Binder*;

c) Mencirikan kaedah *Mix Design* bagi *Natural Rubber Modified Asphalt* dan *Crumb Rubber Modified Asphalt*; dan

e) Penetapan penggunaan peralatan *(equipment)* dan kaedah pembinaan dalam menggunakan turapan jenis *Natural Rubber Modified Asphalt* dan *Crumb Rubber Modified Asphalt.*

3.0 ARAHAN PENGGUNAAN

3.1 Dengan Surat Arahan ini, **SEMUA** projek jalan baru dan juga kontrak bagi kerja-kerja penyelenggaraan jalan yang dipanggil tawaran selepas Surat Arahan ini dikeluarkan adalah dikehendaki menggunakan garis panduan baru ini bagi memastikan kritieria penggunaan turapan *Natural Rubber Modified Asphalt* dan *Crumb Rubber Modified Asphalt* memenuhi spesifikasi yang ditetapkan. Surat Arahan ini diguna pakai bagi projek pembinaan jalan yang dikendalikan oleh JKR.

3.2 Sebarang pertanyaan berhubung dengan Addendum No.2 *to Standard Specification for Road Works Section 4: Flexible Pavement* (JKR/SPJ/2008-S6) dan pindaan ini boleh diajukan melalui emel ussj.jkr@1govuc.gov.my atau secara bertulis kepada Unit Standard & Spesifikasi, Bahagian Pembangunan Inovasi & Standard, Pakar Kejuruteraan Jalan & Jambatan, Cawangan Jalan.

Rujukan : JKR.KPKR:121.010/05 Jld. 16 (1)
Tarikh : 7 Mac 2019

4.0 KUAT KUASA

4.1 Surat Arahan ini berkuat kuasa pada tarikh ia ditandatangani dan akan disemak sekiranya terdapat arahan dasar terkini atau perkembangan terbaru yang memerlukannya dikaji semula dan dikemaskini.

4.2 Dengan berkuatkuasanya arahan ini, Surat Arahan KPKR Bil. 14/2011 bertarikh 21 November 2011 adalah **DIBATALKAN.**

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

(DATO' SRI Ir. Dr. ROSLAN BIN MD TAHA)

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ACKNOWLEDGEMENT

This specification on Rubber Modified Asphalt has been prepared by a committee consisting of engineers and specialists from Centre of Excellence for Engineering and Technology (CREaTE), Cawangan Senggara Fasiliti Jalan (CSFJ) and Cawangan Jalan (CJ), Public Works Department (PWD) Malaysia, and industrial players; their cooperation is greatly acknowledged.

The members of the comittee involved in preparing the **Standard Specification for Road Works - Section 4.16: Natural Rubber Modified Asphalt** are:-

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The committee would also like to thank all other individuals who had contributed towards the successful completion of this specification.

RUBBER MODIFIED ASPHALT

PAGE

4.17 CRUMB RUBBER MODIFIED ASPHALT

4.16 NATURAL RUBBER MODIFIED ASPHALT

4.16.1 DESCRIPTION

This work shall consist of furnishing, placing, shaping and compacting natural rubber modified asphalt (hereinafter referred to as asphaltic concrete) wearing course on a prepared and accepted bituminous pavement course, and shall include careful and thorough cleaning of surfaces which are to be covered prior to the application of bituminous tack coat. The work shall be carried out all in accordance with this Specification and the lines, levels, grades, dimensions and cross-sections as shown on the Drawings and/or as required by the S.O.

Natural rubber modified asphaltic concrete is a mixture of continuously graded aggregate and natural rubber modified binder. The binder is produced by incorporating an appropriate quantity of natural rubber into the conventional bitumen.

4.16.2 MATERIALS

a) Aggregates

Aggregates for natural rubber modified asphaltic concrete shall be a mixture of coarse and fine aggregates, and mineral filler. The individual aggregate shall be of sizes suitable for blending to produce the required gradation of the combined aggregates, all to the satisfaction of the S.O.

Coarse aggregates shall be screened crushed hard rock, angular in shape and free from dust, clay, vegetative and other organic matter, and other deleterious substances. They shall conform to the following physical and mechanical quality requirements;

i) the Los Angeles abrasion value when tested in accordance with ASTM C 131 shall be not more than 25%.

ii) the weighted average loss of weight in the magnesium sulfate soundness test (5 cycles) when tested in accordance with AASHTO Test Method T 104 shall be not more than 18%.

iii) the flakiness index when tested in accordance with MS 30 shall be not more than 25%.

iv) the water absorption when tested in accordance with MS 30 shall be not more than 2%.

v) the polished stone value when tested in accordance with MS 30 shall be not less than 40.

Fine aggregates shall be clean screened quarry dusts. Other types of fine aggregate may be used subject to the approval of the S.O. Fine aggregates shall be non-plastic and free from clay, loam, aggregation of material, vegetative and other organic matter, and other deleterious substances. They shall conform to the following physical and mechanical quality requirements;

i) the sand equivalent of aggregate fraction passing the No. 4 (4.75mm) sieve when tested in accordance with ASTM D 2419 shall be not less than 45%.

ii) the fine aggregate angularity when tested in accordance with ASTM C 1252 shall be not less than 45%.

iii) the Methylene Blue value when tested in accordance with Ohio Department of Transportation Standard Test Method shall be not more than 10 mg/g.

iv) the weighted average loss of weight in the magnesium sulfate soundness test (5 cycles) when tested in accordance with AASHTO Test Method T 104 shall be not more than 20%.

v) the water absorption when tested in accordance with MS 30 shall be not more than 2%.

Notwithstanding compliance with the requirements of this Specification, limestone aggregates shall not be permitted.

The gradation of the combined coarse and fine aggregates and mineral filler, shall conform to the appropriate envelope shown in Table 1.

Table 1 *Combined aggregate gradation for asphaltic concrete*

Mix Designation	**AC 10**	**AC 14**
BS Sieve Size, mm	**Percentage Passing (by weight)**	
28.0	-	-
20.0	-	100
14.0	100	90 – 100
10.0	90 – 100	76 – 86
5.0	58 – 72	50 – 62
3.35	48 – 64	40 – 54
1.18	22 – 40	18 – 34
0.425	12 – 26	12 – 24
0.150	6 – 14	6 – 14
0.075	4 – 8	4 – 8

For each type of mix required in the Works, the Contractor shall propose a laboratory design mix gradation which shall consist of a single definite percentage passing for each sieve size in Table 1 and shall produce a smooth curve within the appropriate gradation envelope. This job laboratory design mix gradation, with the allowable tolerances for a single test as specified in sub-section 4.16.5 (c), shall then become the job standard mix or job mix formula.

b) Mineral Filler

Mineral filler shall be incorporated as part of the combined aggregate gradation. It shall be hydrated lime (calcium hydroxide). At the time of mixing with bitumen, it shall be sufficiently dry to flow freely and shall be essentially free from agglomerations. Not less than 70% by weight shall pass the BS 75 µm sieve. The total amount of mineral

filler shall be approximately 2% by weight of the combined coarse and fine aggregates. The mineral filler shall also be treated as an anti-stripping agent.

If hydrated lime is not available, ordinary Portland cement shall be used as an alternative, subject to approval by the S.O.

c) Natural Rubber Modified Binder

Natural rubber modified binder shall be of performance grade PG 76 or higher in compliance with AASHTO Standard M320-02. This premium grade binder shall be produced by pre-blending conventional bitumen, penetration grade 60 - 70 which shall conform to MS 124, with an appropriate quantity of natural rubber.

4.16.3 NATURAL RUBBER

Natural rubber shall be the material extracted from rubber trees. It shall be either in the form of natural rubber latex or dry natural rubber.

a) Natural Rubber Latex

Natural rubber latex is a sticky, milky colloid obtained by tapping rubber trees. The latex is collected before it coagulates and transferred into air-tight containers with sieving for ammoniation. The ammoniation is necessary to preserve the latex in a colloidal state for longer periods of time. Natural rubber latex shall be either centrifuged latex which has a minimum rubber content of 60% or evaporated latex which has a higher rubber content.

b) Dry Natural Rubber

Dry natural rubber is natural rubber latex that has dried. After tapping the rubber trees, the latex will drip for usually about four hours into a cup and will stop as the latex coagulates naturally on the tapping cut. After the liquid latex is collected from the cup, some trees will continue to drip and this leads to a small amount of 'cup lump' which is collected at the next tapping. The latex that coagulates on the tapping cut is also collected as 'tree lace'. Rubber collected by smallholders and coagulated by any means is called 'smallholders' lump'. Latex that drips onto the ground is collected too as 'earth scrap'. The following paragraphs describe the four types of dry natural rubber;

i) Cup Lump

Cup lump is the coagulated latex found in the collection cup when the tapper next visits the tree to tap it again. It arises from latex clinging to the wall of the cup after the liquid latex was last collected, and from late-dripping latex before the latex coagulates on the cut, or from latex which is purposely left to coagulate in the cup and collected on the following day. It is of higher purity and of greater value than the other three types.

ii) Tree Lace

Tree lace is the latex that has coagulated on the tapping cut that the tapper peels off the previous cut before making a new cut. It usually has higher

copper and manganese contents than cup lump. Both copper and manganese are pro-oxidants and can lower the physical properties of the natural rubber.

iii) Smallholders' Lump

Smallholders' lump is produced by smallholders who collect rubber from trees far away from the nearest factory. As it is often impossible to preserve the latex sufficiently to get it to the factory that processes latex in time for it to be used to make high quality products, and as the latex would anyway have coagulated by the time it reaches the factory, the smallholder will coagulate it by any means available, in any container like small buckets. Often the latex is coagulated in holes in the ground, which are usually lined with plastic sheeting. Acidic materials and fermented fruit juices are used to coagulate the latex, a form of assisted biological coagulation. Little care is taken to exclude leaves, barks etc. from the lumps that are formed.

iv) Earth Scrap

Earth scrap is the latex that gathers around the base of the tree. It arises from latex overflowing from the cut and running down the bark of the tree, from rain flooding a collection cup containing latex, and from spillage from tappers buckets during collection. It contains soil and other contaminants, and has variable rubber content, depending on the amount of contaminants mixed with it. Earth scrap is collected by the field workers two or three times a year and will be cleaned to recover the rubber. However, the product is of very low quality.

Of the four types of dry natural rubber described above, only cup lump shall be allowed to be used as additive to bitumen. However, of the two forms of natural rubber described above, latex is the most effective additive to bitumen. Whether natural rubber latex or dry natural rubber cup lump is used as additive to bitumen, the modified binder shall comply with performance grade PG 76 or higher in compliance with AASHTO Standard M320-02.

c) Properties of Natural Rubber

Natural Rubber Latex

Natural rubber latex shall be a sticky, milky colloid obtained from rubber trees. Initially when collected after tapping the rubber tree, the latex usually contains 30% dry rubber and 70% water. It shall be collected before it coagulates and shall then be transferred into air-tight containers with sieving for ammoniation whereby an ammonia solution shall be used to preserve the latex in a colloidal state for longer periods of time. The latex shall then be processed into high quality latex concentrate by centrifugation or evaporation. The dry rubber content of the latex shall be not less than 60%. The latex shall be of low ammonia with a maximum ammonia content of 0.3%. The complete requirements for the natural rubber latex are shown in Table 2.

Table 2 *Properties of natural rubber latex*

Characteristic	Requirement	Test Specification
Total solid content, % by mass, min.	61.5	ISO 124
Dry rubber content, % by mass, min.	60.0	ISO 126
Coagulum content, % by mass, max.	0.03	ISO 706
Ammonia content, % by mass, max.	0.3	ISO 125
Mechanical stability time (MST) @ 55% TSC, seconds, min.	650	ISO 35

The Contractor shall submit full technical details of the natural rubber latex and obtain the S.O.'s approval of the material prior to the commencement of works.

Natural Rubber Cup Lump

Natural rubber cup lump, for use as bitumen additive, shall be produced through stringent quality control of the raw cup lump collected from the plantations. The production shall involve cleaning, size reduction via wet pre-breaker, creeper and shredder, and drying. The requirements for the processed natural rubber cup lump are shown in Table 3.

Table 3 *Properties of natural rubber cup lump*

Characteristic	Requirement	Test Specification
Dirt retained on 44 aperture, % by mass, max.	0.16	ISO 249
Ash content, % by mass, max.	1.00	ISO 247
Nitrogen content, % by mass, max.	0.60	ISO 1656
Volatile matter content, % by mass, max.	0.80	ISO 248-1
Wallace rapid plasticity (Po), min.	30	ISO 2007
Plasticity retention index (PRI), %, min.	40	ISO 2930

The Contractor shall submit full technical details of the processed natural rubber cup lump and obtain the S.O.'s approval of the material prior to the commencement of works.

4.16.4 PREPARATION OF NATURAL RUBBER MODIFIED BINDER

Natural rubber shall be pre-blended with conventional bitumen before mixing with the aggregate in the asphalt mixing plant. The Contractor shall either provide a blending equipment system or tank close to the asphalt mixing plant whereby natural rubber modified binder can be manufactured on site, or shall obtain natural rubber modified binder from an approved source which is referred to as terminal blend. The terminal blend shall be transported in a well insulated tanker, and transferred into a binder storage tank at the asphalt mixing plant as described below. In either case, the Contractor shall provide a binder storage tank equipped with a suitable mechanical agitator close to the asphalt mixing plant. This tank shall also include distribution and circulation pipes that are properly insulated or heated. Continuous agitation of the binder during prolonged storage is essential to prevent separation. A suitable sampling point shall be provided at a convenient point in the storage tank system for taking samples. Samples shall be taken after prolonged storage or at any other

circumstances deemed necessary by the S.O. and tested for the properties as shown in Table 5 at an approved laboratory. Sampling shall be done in accordance with MS 539.

The blending equipment system or tank shall be of adequate capacity which will allow for at least 50% increase in volume when natural rubber, in particular natural rubber latex, is added. It shall be fitted with piping inside for heating with hot oil that are capable of raising the temperature of the bitumen to a maximum of 200℃. The tank shall be insulated with a minimum of 75 mm thick rockwool and aluminium cladding. The tank shall also be equipped with a mechanical agitator, either a paddle wheel type which will sweep the natural rubber down through the depth of the tank or a propeller type stirrer which will create a vortex, drawing the natural rubber down into the body of the bitumen. Either type of agitator shall be able to produce a homogenous bitumen – natural rubber blend.

a) Blending Natural Rubber Latex into Bitumen

Natural rubber latex has a water content of up to 40% which will cause foaming, irrespective of whether it is first added to cold bitumen which is then heated, or whether it is added to bitumen already heated to above the boiling point of water.

Bitumen shall be heated to a temperature of 150 – 170℃. Natural rubber latex shall be added gradually into the blending equipment system or tank, through a pump and spray or through a sprinkler system or poured manually, at an appropriate rate so as not to cause excessive foaming. Whichever method is used, the natural rubber latex shall fall gently onto the surface of the bitumen and not splash into the bitumen. It shall be allowed to float on the bitumen surface for about 20 seconds to allow its constituent water to evaporate (flash off) before being drawn into the bitumen by the mechanical agitator. It should not float on the surface for a longer period as, once the water has evaporated, coagulation will start and a lumpy mixture result. When the intensity of foaming has been gauged, the remainder of the natural rubber latex shall be added as fast as seems desirable to ensure that the foaming is not too great for the capacity of the blending tank, and agitated vigorously into the bitumen. As long as the latex is added slowly and the degree of foaming assessed, there will be no danger of the bitumen foaming over. Alternatively, anti-foaming agent shall be used as approved by the S.O..

Stirring shall be continued for a minimum period of 20 minutes after complete addition of the natural rubber latex. After blending is complete, the natural rubber modified binder shall be allowed to cool to below 120℃ but with continuous stirring unless it is to be used immediately. After storage, the binder shall be heated to a temperature of 150 – 170℃ before use.

b) Blending Dry Natural Rubber into Bitumen

Bitumen shall be heated to a temperature of 150 – 170℃. Dry natural rubber shall be dispersed over the surface of the bitumen in a thin layer. It is then drawn into the bitumen by the mechanical agitator. Further dry natural rubber shall be added when the previous thin layer has been drawn down away from the surface.

c) Completion of Blending

Blending shall be deemed to be complete when a small drop of natural rubber modified binder from the tank, placed on an impervious surface, shows only a few specks of rubber which are soft enough to be spread into the binder by a knife or spatula. If the rubber particles still preserve their entity and cannot be rubbed away into the binder, blending is considered incomplete and further heating and agitation are necessary.

d) Storage of Natural Rubber Modified Binder

The natural rubber molecule consists of a very long chain of many isoprene units which can be broken into several smaller ones by various processes; the natural rubber is said to be degraded or broken down chemically. Heating is one of the processes which lead to degradation of natural rubber. It degrades with time at high temperatures. It is recommended that the effective rubber content should not be allowed to drop below about half of the original rubber content added to ensure that the extent of degradation of the natural rubber modified binder will not significantly affect the properties of the asphaltic concrete. Therefore, it is recommended that the binder after blending is complete shall not be stored at elevated temperatures for longer than the periods shown in Table 4 as given in Road Research Laboratory Road Note 36. The total storage time allowable at different temperatures shall be calculated as follows; after storage at one temperature, the allowable storage time at any subsequent temperature shall be reduced by the following ratio;

$$\frac{\text{Time at first temperature}}{\text{Time allowable at first temperature}}$$

Table 4 *Allowable storage time for natural rubber modified binder*

Temperature (°C)	**Storage Time (hours)**
200	1
180	3
160	12
140	48
120 or below[1]	7 days
Ambient	Indefinitely

e) Application of Natural Rubber Modified Binder

At the time of application, the rubber additive shall be thoroughly dissolved in and dispersed uniformly throughout the bitumen without any coagulation of the rubber particles or the presence of undissolved lumps.

The properties of the natural rubber modified binder shall be as given in Table 5.

[1] *Above ambient temperatures.*

***Table 5** Properties of natural rubber modified binder*

Test	Requirement	Test Specification
Natural rubber modified binder prior to rolling thin film oven test (RTFOT)		
[3]Viscosity, max. 3 Pa.s, test temperature ℃	135[2]	ASTM D 4402
[3]Dynamic shear, G*/sin δ min. 1.00 kPa, 10 rad/s, test temperature ℃	76	AASHTO T 315
[4]Penetration, 100 g, 5 s, 25 ℃, 0.1 mm	Report[5]	ASTM D 5
[4]Ring and ball softening point, min. ℃	Report[5]	ASTM D 36
[4]Flash point, min. ℃	230	AASTHO T 48
Natural rubber modified binder after RTFOT (AASHTO T 240) or ASTM D 2872		
[3]Mass loss, max. %	1.00	AASHTO T 240 or ASTM D 2872
[3]Dynamic shear, G*/sin δ min. 2.20 kPa, 10 rad/s, test temperature ℃	76	AASHTO T 315

A viscosity-temperature relationship shall be established, using suitable rheometer, for the natural rubber modified binder. The temperatures to which the natural rubber modified binder must be heated to produce a viscosity of 0.2 Pa.S shall be the mixing temperatures. The temperatures to which the natural rubber modified binder must be heated to produce a viscosity of 2 – 20 Pa.S shall be the compaction temperatures.

4.16.5 MIX DESIGN

a) Job Mix Formula

The Contractor shall propose a job mix formula for each type of mix required in the Works. In order to obtain optimum quality of the mixtures, the job mix formula for each type of mix shall be prepared on the basis of testing several laboratory design mix gradations within the limits set in Table 1 at an appropriate range of natural rubber modified binder content. As a guide to the testing range of the binder content, the design binder content will usually be in the range given in Table 6.

***Table 6** Range of design binder contents*

AC 10 - Wearing Course	5.5 – 7.5%
AC 14 - Wearing Course	4.5 – 6.5%

[2] *The requirement may be waived at the discretion of the S.O. if the supplier warrants that the natural rubber modified binder can be adequately pumped and mixed at the temperatures that meet all applicable safety standards.*

[3] *These tests shall be carried out as and when required by the S.O. but shall be not less than one test per 30 tons of binder produced or at least once per project if the total quantity of binder produced is less than 30 tons. The binder samples shall be taken immediately prior to the production of asphalt. Test frequency may be reduced if test results consistently conform to the requirements.*

[4] *These tests shall be carried out minimum once for each blending process for quality control purposes during blending at the asphalt mixing plant or terminal blending.*

[5] *The penetration and softening point values shall be taken as reference for consistency check on the production.*

Each combination of laboratory design mix aggregate gradation and binder content shall be subject to the Marshall test procedure and volumetric analysis as follows;

i) Preparation of Marshall specimens for the standard stability and flow test in accordance with ASTM D 1559 using 75-blows/face compaction standard at compaction temperature as determined from the above viscosity-temperature relationship,

ii) Determination of the bulk specific gravity of the specimens in accordance with ASTM D 2726,

iii) Determination of the stability and flow of the specimens in accordance with ASTM D 1559,

iv) Analysis of the specific gravity and air voids parameters to determine the percentage air voids in the compacted aggregate, the percentage air voids in the compacted aggregate filled with the binder and the percentage air voids in the compacted mix.

For each laboratory design mix gradation, four Marshall specimens shall be prepared for each binder content within the range given in Table 6[6] at increments of 0.5 percent, in accordance with ASTM D 1559 using 75 blows/face compaction standard. All binder contents shall be in percentage by weight of the total mix.

As soon as the freshly compacted Marshall specimens have cooled to room temperature, the bulk specific gravity of each specimen shall be determined in accordance with ASTM D 2726.
The stability and flow value of each specimen shall then be determined in accordance with ASTM D 1559.

After the completion of the stability and flow test, specific gravity and voids analysis shall be carried out for each specimen to determine the percentage air voids in the compacted aggregate filled with binder (VFB) and the percentage air voids in the compacted mix (VIM).

Values which are obviously erratic shall be discarded before averaging. Where two or more specimens in any group of four are so rejected, four more specimens shall be prepared and tested.

The mean values of bulk specific gravity, stability, flow, VFB and VIM obtained above shall be plotted separately against the binder content and a smooth curve drawn through the plotted values.

The mean optimum binder content shall be determined by averaging five optimum binder contents so determined as follows;

i) Peak of curve taken from the stability graph[7],
ii) Flow equals to 3.5 mm from the flow graph,

[6] *The range of binder content shall be extended if necessary to ensure that the curves of stability and bulk specific gravity have their peak within the range selected.*
[7] *Where the stability curve exhibits more than one peak, the binder content chosen for the determination of the mean optimum binder content shall be the one which satisfies the voids requirements better. It is sometimes necessary where no peak stability is obtained, to prepare and test supplementary specimens at intervals of 0.25% binder content on either side of the expected optimum.*

iii) Peak of curve taken from the bulk specific gravity graph[8],
iv) VFB equals to 75.0% from the VFB graph, and
v) VIM equals to 4.0% from the VIM graph.

The individual test values at the mean optimum binder content shall then be read from the plotted smooth curves and shall comply with the design parameters given in Table 7.

If any of the values does not comply with Table 7, the mix design procedure shall be repeated using a different aggregate gradation until all design parameters are satisfied.

Table 7 *Test and analysis parameters for natural rubber modified asphaltic concrete*

Parameter	Requirement
Stability (S)	> 13,000 N
Flow (F)	2.0 – 5.0 mm
Stiffness (S/F)	> 2,600 N/mm
Voids in mix (VIM)	3.0 – 5.0%
Voids in aggregate filled with bitumen (VFB)	70 – 80%

Additional eight Marshall specimens shall be prepared using the same aggregate gradation and compaction effort, with the mean optimum binder content established during the mix design stage. Four of these specimens shall be tested for resilient modulus and another four specimens for dynamic, unconfined, compressive creep as described below;

i) Indirect tensile test for resilient modulus (ASTM D 4123)

Total resilient modulus	> 3,000 MPa
Test temperature	25℃
Applied load (max. 1,500 N)	20 N/mm of specimen thickness
Loading frequency	1 Hz
Loading time	0.1 s
Rest period	0.9 s
Rise time	70 ms
Poisson's ratio	0.35
No. of preconditioning pulses	50
No. of test pulses	5
Rotation of specimen	90°

Report mean value of total resilient modulus (E_{RT}) from two alignments (rotation). Disregard test result if E_{RT} values for the same test specimen differ by more than 10% from the mean value.

[8] *With highly absorptive aggregates, some difficulty in determining peak bulk specific gravity may occur. In such cases, the binder content at which the increase in bulk specific gravity shows a marked falling off shall be adopted.*

ii) Dynamic, unconfined, compressive creep test (EN 12697-25)

Dynamic creep modulus	> 75 MPa
Slope at steady state	< 0.25

Pre-conditioning;

Test temperature	40℃
Applied axial stress	150 kPa
Loading frequency	0.5 Hz
Loading time	0.2 s
Rest period	1.8 s
No. of load cycles	30

Testing;

Test temperature	40℃
Applied axial stress	300 kPa
Loading frequency	0.5 Hz
Loading time	0.2 s
Rest period	1.8 s
No. of load cycles	3,600

Report dynamic creep modulus and slope at steady state, the latter shall be log strain divided by log load cycles between 2,000 and 3,600 load cycles.

b) Plant Trials

After having received the S.O. preliminary approval of his proposed job mix formula, the Contractor shall arrange to mix, lay and compact natural rubber modified asphaltic concrete conforming to the proposed formula for each type of mix required in the Works. A minimum of 20 tons of the mix shall be placed in trial areas to demonstrate to the satisfaction of the S.O. that the mixing, laying and compacting equipment conforms to the requirements of this Specification, and that the proposed mix is satisfactory. The trial areas shall not be part of the Contract Works but shall be provided by the Contractor at his own expense. The proposed trial area shall be approved by the S.O..

As directed by the S.O., comprehensive sampling and testing of the mix shall be carried out to check for satisfactory compliance with its job mix formula, and for a satisfactory degree of compaction. In order to demonstrate to the satisfaction of the S.O. that mixing, laying and compacting equipment conform to the requirements of the specification, and that the proposed mix is satisfactory, the following observations and tests shall be carried out.

i) Record the type and weight of rollers. Check the tyre pressure of the pneumatic tyre roller (shall comply with sub-section 4.16.6 (g)).

ii) Record the type of paver (shall comply with sub-section 4.16.6 (f)).

iii) Check that the trial area is suitable (not on soft ground, uneven surface or actual contract site).

iv) Take sample of the mix and carry out the following tests;

- Binder content and aggregate grading (shall comply with sub-section 4.16.5 (c)).
- Preparation of Marshall specimens.
- Bulk specific gravity of Marshall specimens.
- Volumetric properties of Marshall specimens (shall comply with Table 7).
- Marshall stability and flow (shall comply with Table 7).
- Resilient modulus.
- Dynamic, unconfined, compressive creep.

v) Record temperatures of mix on the lorry, at plant and site (shall not exceed 180℃ at any time and shall be not less than 150℃ immediately before unloading into the paver hopper).

vi) Record laying (uncompacted) thickness.

vii) Check texture of paved surface before rolling (there shall be no substantial blemishes and irregularities).

viii) Record temperatures immediately before rolling starts (rolling temperatures)

ix) Record rolling pattern.

x) Check texture of compacted surface.

xi) Cut core samples after the laid material has sufficiently hardened (at least three samples from each lorry load).

xii) Record compacted thickness and density from core samples (shall comply with sub-section 4.16.7 (i)).

As a result of the plant trials, the S.O. may require amendments to the job mix formula, further tests and analysis, and additional plant trials.

Upon satisfaction by the S.O., the Contractor shall be required to produce a full report of the plant trial and this document shall be used in full scale production in the Works.

c) Compliance with the Job Mix Formula

The S.O. final approval of the job mix formula shall bind the Contractor to produce natural rubber modified asphaltic concrete mixes conforming to the precise gradation and binder content specified in the formula within the tolerances set forth in Table 8 and using natural rubber modified binder that consistently comply with the properties as specified in Table 5.

Modifications to the job mix formula shall only be made with the approval of the S.O. Should the S.O. at any time have reasons to believe that the materials and methods of mixing and laying are different from those approved, he shall so advise the Contractor and may instruct that natural rubber modified asphaltic concrete works be discontinued pending further plant trials and testing.

Table 8 *Tolerances for natural rubber modified asphaltic concrete*

Parameter	Permissible Variation % By Weight of Total Mix
Binder content	± 0.2 %
Fractions of combined aggregates passing 5.0 mm and larger sieves	± 5.0 %
Fractions of combined aggregates passing 3.35 mm and 1.18 mm sieves	± 4.0 %
Fractions of combined aggregates passing 425 μm and 150 μm sieves	± 3.0 %
Fractions of combined aggregates passing 75 μm sieve	± 2.0 %

d) Sampling and Testing of Natural Rubber Modified Asphaltic Concrete

Frequency of sampling and testing shall be not less than that shown in Table 9. It provides for two levels of minimum frequency. The reduced frequency may only be adopted if the test results consistently conform to the requirements.

Table 9 *Frequency of sampling and testing of natural rubber modified asphaltic concrete*

Test	Normal Minimum Frequency	Reduced Minimum Frequency
Binder content, aggregate gradation, stability, flow, VIM and VFB	One test per 200 tons asphalt plant production.	One test per 300 tons asphalt plant production.
Resilient modulus and dynamic, unconfined, compressive creep	These tests shall be carried out as and when required by the S.O. but shall be not less than one test per 1,000 tons of asphalt produced or at least once per project if the quantity of asphalt produced is less than 1,000 tons. Test frequency may be reduced if test results consistently conform to the requirements.	
Temperature	Each loaded tip-truck.	Each loaded tip-truck.

4.16.6 EQUIPMENT

The Contractor shall provide all the plant and equipment necessary for executing the work in accordance with this Specification and shall furnish the S.O. with such details of particular items of equipment, e.g. manufacturer, model type, capacity, weight, operating features, etc., as the S.O. shall require.

a) Road Cleaning Equipment

Immediately prior to applying bituminous tack coat, the full width of the surface to be treated shall be swept using a power broom followed by a compressed air blower, and if necessary, scraped using hand tools, to remove all dirt, dust and other objectionable material, all to the satisfaction of the S.O.

b) Asphalt Mixing Plant

The asphalt plant shall be either a batch plant or a drum mix plant of recognised manufacturer and shall be approved by the S.O. It shall conform to the requirements described hereunder.

The mixing plant shall have a capacity suited to the Works and sufficient to enable the paver to operate more or less continuously when paving at normal speeds at the required thicknesses. The plant shall be designed so as to enable consistent production of natural rubber modified asphaltic concrete mixes within the tolerances prescribed in this Specification, all to the satisfaction of the S.O.

Mixes produced and delivered shall have actual tonnages of aggregates, filler and binder components recorded. The temperature of the mix leaving the plant shall be recorded for each batch or every 15 minutes. Where the control system incorporates a computer and a printer capable of printing the information, copies of the printouts shall be provided to the S.O. for quality assurance.

Tanks for storage of binder shall have a capacity suited to the proposed rate of utilizations of the material and the method and frequency of its delivery to the Works, all to the satisfaction of the S.O. The tanks shall be provided with means of measuring the volume of their contents at all times and of drawing off samples of the contents. The binder feeding system shall provide for continuous circulation of hot binder through the system and back into the feed tank. The end of the return line discharging into the feed tank shall always be kept submerged in the binder in the tank in order to prevent oxidation of the returning hot binder. The storage tanks, and where necessary barred decanters, and all elements of the binder feeding system shall be equipped with heating system or insulating jackets as necessary to provide for effective and positive control of the temperature of the binder at all times up to the temperature required for utilizations. The method of heating shall be such that neither flames nor the products of combustion shall come into direct contact with the binder or the casing of its immediate container, and such that no portion of the binder shall be subject to overheating.

Calibration of the plant load cells to an accuracy of $\pm$ 1% error must be carried out before the production of the trial mixes. This calibration is to test the integrity of all the weighing system of the aggregate bins, filler hoppers and binder hopper.

Temperature-measuring equipment, such as thermometers or electrical thermocouples, providing temperature measurements of plant processes and materials, shall also be calibrated accordingly.

Calibration is also required for the feeders to match the production capacity. Once the calibration is set and mixes production commence, calibration procedures shall be repeated every 30,000 tons or one month whichever is earlier.

c) Batch Plant

The plant shall be provided with accurate mechanical means for uniformly feeding the aggregate into the dryer so that uniform production and temperature of the heated aggregate will be obtained. A separate feed bin with an adjustable gate opening shall be provided for each aggregate to be included in the combined aggregate for the mix; normally four bins will be required. The feed bins and gates shall be constructed and equipped that they shall be readily accessible for calibrating at all times, and shall provide for a continuous and uniform flow of each aggregate required in the mix.

The plant shall have a rotary drum dryer of satisfactory design for drying and heating the combined aggregate so that its temperature will be at the required level at the time it is mixed with the bitumen. The burner shall be so designed that complete combustion of the fuel will be obtained, and the aggregate will remain clean and not become coated with soot or oil.

The plant shall be equipped with four (or more) screens, the smallest of which shall generally be not more than 3.2 mm. The screens shall have a normal capacity slightly in excess of the maximum output of the mixing plant. The screens shall be readily accessible for inspection.

The plant shall include four (or more) storage bins for screened aggregates, each with a capacity of not less than twice the pugmill dead load capacity. The bins shall be arranged so as to provide separate dry storage for each screened fraction of the aggregate. Each bin shall be provided with an overflow pipe of such size and location as to prevent any backing up of material into other bins. Each bin shall be so constructed that representative aggregate samples can be readily obtained, and shall have means for observing the aggregate level. Separate dry storage shall be provided for mineral filler, and the plant shall be satisfactorily equipped to feed filler into the mixer.

Accurate means of weighing by load cells shall be provided for weighing the aggregates and filler and also for weighing the bitumen required for each batch of mix.

Suitable means shall be provided for maintaining the prescribed temperature of the bitumen in the pipelines, weigh bucket of flow meter, and spray bars.

An armoured thermometer with a range of 30℃ to 200℃ shall be fitted in the bitumen feed line at a suitable location near the discharge valve at the mixer unit. Suitable dial-scale mercury actuated thermometer, electric pyrometers or other thermometer instruments shall be fitted at the discharge chute of the dryer and in each hot aggregate storage bin to indicate the temperature of the heated aggregate.

The plant shall be equipped with adequate and safe stairways to the mixing platform and sampling location and guarded ladders and cat-walks shall provide access to all other positions as necessary for proper operation, inspection and maintenance of the plant, all to the satisfaction of the S.O. All gear, pulley, chains, sprockets and other dangerous moving parts shall be property guarded and protected. Ample and unobstructed space shall be provided on the mixing platform, and clear and unobstructed passage shall be maintained at all times in and around the truck loading area, which shall, be kept free from drippings from the mixer.

Each storage bin for screened aggregate shall be provided with a bottom outlet gate so constructed as to prevent leakage when closed. These gates shall have a quick and complete closing action. The plant shall be equipped with a weigh box or hopper for accurately weighing out aggregate from each of the screened aggregate storage bins.

The weigh box or hopper shall be suspended from its scale's lever mechanism and shall be sufficiently large to holds a full batch equal to the pugmill capacity without hand raking of the aggregate. The discharge gate shall be so constructed as to allow rapid and complete emptying of the weigh box or hopper into the mixer, and prevent leakage when closed.

The plant shall be equipped with a binder weigh bucket which shall be charged through a fast acting non-dip valve in the binder feed pipe located directly over the bucket. The bucket shall be suspended from its scale's lever mechanism and shall have a capacity sufficient to weigh out binder up to 20% of the weight of the pugmill dead load capacity. The bucket shall have a discharge mechanism which shall provide for rapid and complete emptying of the bucket in a thin uniform sheet or multiple sprays over the full length and width of the mixer. The discharged shall not leak or drip when closed.

The batch mixer shall be a suitable twin-shaft pugmill, with a capacity of at least 500 kg of asphaltic concrete, capable of producing a thoroughly homogeneous mixture. The clearance of the paddle blades from all fixed and moving parts of the mixer shall be not more than 20 mm. If the pugmill is not enclosed, it shall be equipped with a dust hood to prevent loss of fines from the mixture. The discharge gate shall be so constructed as to allow rapid and complete emptying of the mixer, and prevent leakage of any mix constituent when closed.

The mixer shall be equipped with an accurate time lock system for controlling the operations of a complete mixing cycle. It shall lock the aggregate weigh box or hopper gate after charging the mixer with aggregate, until the closing of the mixer gate at the completion of the mixing cycle; it shall lock the binder weigh bucket discharge mechanism during the dry mixing and wet mixing period. The dry mixing period is defined as the interval of time between the opening of the aggregate weigh box of hopper gate and the start of discharging the binder weigh bucket. The wet mixing period is defined as the interval of time between the start of discharging the binder weigh bucket and the opening of the mixer gate. The dry and wet mixing periods shall both be adjustable in increments of not more than 5 seconds from zero to not more than 60 seconds total for dry and wet mixing.

The filler silo shall have suitable a screw conveyor system to discharge into the pugmill.

The control system for the plant shall be housed in a weather proof cabin with windows to view the plant operations. Control in the cabin shall have the capability to accurately batch the aggregates, filler and bitumen for the mix, transfer to the pugmill mixer and control the mixing time. The temperature of the heated aggregates, filler and bitumen shall also be displayed in this cabin and adjusted to meet the Specifications when required.

d) Drum Mix Plant

The cold material feeder unit shall consist of not less than 5 bins with suitable heaped capacity appropriate for the plant. Each bin shall be equipped with a variable speed weighing belt feeder (driven by variable speed electric motor fitter with a tachometer) with a load cell for accurate weight measurement of each type of aggregate used in the mix in equivalent dry tons per hour. The cold feed system shall incorporate a device for moisture compensation capable of producing an accurate and continuous blend of the individual aggregate sizes from the cold feed compartment. The cold feed system

shall also be equipped with a scalping screen of screed size of not more than 50 mm to discard any oversized aggregates before entering the dryer drum.

The drum mixer shall have flight designs to accomplish the proper transfer of heat from the exhaust gases of the burner to the aggregates and to blend the aggregates and bitumen together adequately. The flight, at the upper end of the drum, shall be able to direct the aggregate into the drum beyond the tip of the flame, thereafter the subsequent flight shall be efficient to lift and tumble the aggregates with the cumulation of a veil of aggregates across the whole cross-sectional area near the mid-point of the length of drum where the aggregate temperature shall have been raised to dew point. This veil of aggregates shall be sufficiently complete and dense to maximise heat transfer and to screen the bitumen from the direct flame to minimise hardening and oxidation of the bitumen during the mixing process. The downstream mixing flight designs shall complete the heat transfer process and raise the mix temperature to the desired level for discharge. The length to diameter ratio of the drum shall be appropriately designed to obtain more complete heat transfer; to enable the bitumen to be injected in an inert atmosphere where proper coating/adhesion onto aggregates can take place without severe oxidation or hardening of bitumen and effective mixing and sufficient designed mix temperatures are achieved. The drum shall be inclined, oil-fired and suitably and sufficiently insulated.

The control system of a drum mixer must be automatically computer controlled with a fully independent manual back-up system. The system shall be such that the operator able to view the operation of the whole plant and of the individual component stations. All relevant information of the plant operation and the progress of the tonnage of mix produced and mix design information shall be made available. The control system shall be possess a Quality Assurance package to act as an audit tool (when required to be used) whereby the information on Plant Monitor, Progress Monitor and Mix Temperature shall be made available at pre-set, variable time intervals.
Freshly mixed material shall be collected and delivered to be stored in a surge silo through a proper conveyor system.

e) Tip-Trucks

The Contractor shall provide a suitable number of tip-trucks of a type approved by the S.O. for transporting natural rubber modified asphaltic concrete from the mixing plant to the paving sites. The trucks shall have trays with smooth, flat beds and sides, and shall have load capacities of not less than 5 tons. Prior to loading, the inside of each truck tray shall be lightly and evenly coated with a soap or detergent solution, or such other liquid as the S.O. shall approve, to prevent adhesion of the natural rubber modified asphaltic concrete. The trucks shall be equipped with covers of canvas or other suitable material to protect the natural rubber modified asphaltic concrete.

f) Asphalt Paver

The asphalt paver shall be of recognised manufacturer and shall be approved by the S.O. It shall conform to the requirements described hereunder.

The paver shall be self-propelled and capable of reverse as well as forward travel. It shall be equipped with a hopper at the front designed to receive the paving mix from tip-trucks, and shall have a mechanical distribution system for spreading the mix evenly and without segregation over the surface to be paved in front of a screeding and

compacting unit which shall be equipped with a suitable heating device. The screeding and compacting mechanism shall be capable of confining the edges of the material being laid without the use of stationary side forms, shall be adjustable to strike off the mixture to the thickness and cross-section shape required, and shall be controlled by an automatic levelling device to produce an even carpet of bituminous mixture with a uniform surface texture free from indentations, ridges, tear marks or other irregularities. The paver shall be capable of laying the bituminous mixture in paving widths in the range 2.5 to 3.75 m and of finishing the pavement layer true to the required lines, grades, levels, dimensions and cross-sections, subject to compaction by rolling, all to the satisfaction of the S.O.

g) Rollers

A pneumatic-tyred roller and two steel-wheeled tandem rollers shall be provided. All rollers shall be of recognised manufacture and shall be approved by the S.O. They shall conform to the requirements described hereunder.

Pneumatic-Tyred Roller

Pneumatic-tyred roller shall be self-propelled and capable of being reversed without backlash; it shall be equipped with power steering and dual controls allowing operation from either the left or right side.

The roller shall have nine wheels equipped with smooth tyres all of the same size and construction. Five wheels shall be on the driven axle and four on the steering axle, all equally spaced on both axles and arranged so that the tyres on the steering axle track midway between those on the driven axle with a small overlap. The roller shall be ballasted to an operating weight of not less than 15 tons with a tyre inflation pressure of not less than 0.7 N/mm^2.

The Contractor shall provide the S.O. with a calibration chart for the roller showing the relationship between the quantity or depth of ballast and total weight, and also a chart showing the relationship between wheel load, tyre inflation pressure and contact pressure.

Pneumatic-tyred rollers shall be equipped with water tanks, sprinkler systems and scraper blades to keep all wheels evenly wetted and clean during operation. Soap or detergent solution, or such other liquid as the S.O. shall approve, shall be used to prevent the asphalt from sticking to the roller tyres.

Steel-Wheeled Tandem Rollers

Steel-wheeled tandem rollers shall be self-propelled and capable of being reversed without backlash; they shall be equipped with power steering and dual controls allowing operation from either the left or right side. They also shall be equipped with water tanks, sprinkler systems and scraper blades to keep all wheels evenly wetted and clean during operation. Soap or detergent solution, or such other liquid as the S.O. shall approve, shall be used to prevent the asphalt from sticking to the roller tyres.

Steel-wheeled tandem rollers shall be ballasted so that their total operating weight are in the range 8 to 10 tons and their driven roll (or rolls) shall exert a rolling force of not less than 3.5 tons/meter of roll width. The Contractor shall provide the S.O. with a

calibration chart for each roller showing the relationships between the quantity or depth of ballast and total weight and rolling force.

4.16.7 CONSTRUCTION METHODS

a) General Conditions

Natural rubber modified asphaltic concrete paving work shall only be carried out in dry weather when the surface to be covered is clean and dry, and has received a bituminous tack coat which shall have achieved a satisfactory degree of tackiness, all to the satisfaction of the S.O. All laying, rolling and finishing work shall be carried out during daylight hours, unless the Contractor shall have provided suitable flood-lighting for the job site, to the satisfaction of the S.O.
The S.O. may order the discontinuation of work on account of adverse weather, unsatisfactory condition of materials, equipment or surface to be paved, or such other conditions as he or she shall consider detrimental to the work.

b) Surface Preparation and Cleaning

Prior to constructing a natural rubber modified asphaltic concrete pavement layer, the surface to be covered shall have been prepared in accordance with the appropriate Sections of this Specification. Notwithstanding any earlier approval of this surface, any damage to or deterioration of it shall be made good before natural rubber modified asphaltic concrete paving work is commenced.

If the surface to be covered is to be provided with a bituminous tack coat, then this shall be applied all in accordance with the provisions of sub-section 4.3.2 in JKR/SPJ/2008-S4.

c) Aggregate Handling and Heating

Each aggregate to be used in the natural rubber modified asphaltic concrete mixes shall be stored in a separate stockpile near the mixing plant. Stockpiles of sand and other fine aggregates shall be kept dry using waterproof covers and other means as necessary. In placing the aggregates in the stockpiles and loading them into the mixing plant's cold aggregate feed bins, care shall be taken to prevent segregation or uncontrolled combination of materials of different gradation. Segregated or contaminated materials shall be rescreened or rejected for use in the Works and removed from the mixing plant site.

The aggregates shall be fed into the dryer at a uniform rate proportioned in accordance with the appropriate job mix formula. The rate of feed for each aggregate shall be maintained within 10% of the rate prescribed, and the total rate of feed shall be such that the plant's screens shall never be overloaded.

The aggregates shall be dried and heated so that when delivered to the mixer they shall be at a temperature in the range of 160℃ to 180℃.

Immediately after heating, the aggregates shall be screened into four (or more) fractions which shall be separately stored in the hot aggregate storage bins in readiness for mixing.

Mineral filler cum anti- stripping agent to be used in the mix shall be stored separately and kept completely dry. Its rate of feed into the plant shall be accurately controlled by weight or volumetric measurement, all to the satisfaction of the S.O.

d) Heating Natural Rubber Modified Binder

The natural rubber modified binder shall be heated so that when delivered to the mixer it shall be at a temperature in the range of 150℃ to 170℃.

e) Mixing Natural Rubber Modified Asphaltic Concrete

The mixing plant shall be so coordinated and operated as to consistently produce natural rubber modified asphaltic concrete mixes within the tolerances prescribed in this Specification, all to the satisfaction of the S.O.

Mixing in Batch Plants

For each batch the screened hot aggregates shall be weighed out into the aggregate weigh hopper in accordance with the proportions prescribed in the appropriate job mix formula; the sequence of weighing out shall commence with the largest sized aggregate and progress down to the fines, unless the S.O. shall otherwise approve. Mineral filler shall be weighed out into the filler weigh hopper, where this is provided, or added last to the aggregate weigh hopper, in accordance with the job mix formula proportions.

The hot binder shall be weighed out into the binder weigh bucket in accordance with the proportions prescribed in the job mix formula.

The hot aggregates and filler shall be discharged into the pugmill and mixed dry for the dry mixing time prescribed in the job mix formula, which shall usually be in the range five to 10 seconds. The hot binder shall then be added and wet mixing performed for the wet mixing time prescribed in the job mix formula; this shall be sufficient so that all particles of aggregate are uniformly coated with bitumen, and shall usually be 45 seconds or less for dense graded mixtures.

The volume of each batch shall be such that the tips of the pugmill paddle blades just break out of the mixture at the height of their action.

After the completion of wet mixing, each batch of natural rubber modified asphaltic concrete shall be discharged from the pugmill either into a storage hopper or directly into a truck for hauling to the paving site. Care shall be taken that no segregation of the mix occurs.

Mixing in Continuous Mix Plants

The screened hot aggregates and filler shall be fed continuously from their storage bins in accordance with the proportions prescribed in the appropriate job mix formula, combined in the plant, and fed continuously into the mixer. The hot binder shall be sprayed on to the combined aggregate as it enters the pugmill at the rate required to achieve the bitumen content prescribed in the job mix formula. The materials shall then be carried through the pugmill and in the process be thoroughly mixed by the action of the paddles and discharged over the dam into the storage hopper. The mixing time shall

be as prescribed in the job mix formula; this shall be sufficient so that all particles of aggregate are uniformly coated with the natural rubber modified binder, and shall usually be 45 seconds or less for dense graded mixtures.

The plant shall be so adjusted as to maintain the level of mixture in the pugmill such that the tips of the paddle blades just break out of the mixture at the height of their action.

f) Transporting Natural Rubber Modified Asphaltic Concrete

Natural rubber modified asphaltic concrete shall be transported from the mixing plant to the site of the paving works in loads of not less than 5 tons using tip-trucks as specified in sub-section 4.2.4.4 (c) of JKR/SPJ/2008-S4. Except where natural rubber modified asphaltic concrete is to be hand laid, it shall be discharged directly into the paver hopper, as required, from the tip-trucks. Care shall be taken in the truck loading, hauling and unloading operations to prevent segregation of the mix. During transportation, the natural rubber modified asphaltic concrete shall be protected from contamination by water, dust, dirt and other deleterious materials.

The temperature of natural rubber modified asphaltic concrete immediately before unloading from the truck either into the paver hopper or on to the road for hand spreading shall be not less than 150℃. Any load which has cooled below the specified temperature in the truck shall be rejected for use in the Works and removed from the Site of the Works.

g) Laying Natural Rubber Modified Asphaltic Concrete

The sequence of laying operations shall be planned in advance by the Contractor and approved by the S.O. Generally each paving layer shall have a compacted thickness of not less than twice the nominal maximum aggregate size of the mixture, and not more than 100 mm. Where applicable, e.g. on superelevated sections and on carriageways with cross-slope in one direction only, laying shall commence along the lower side of the carriageway and progress to the higher side. Laying shall not be carried out in a downhill direction along any section of road.

As far as is practicable, laying shall be carried out using a paver approved by the S.O. Hand-casting of bituminous mix on to the machine finished surface shall be kept to the practicable minimum necessary for correcting blemishes and irregularities. In any areas inaccessible to the paver, laying shall be carried out by hand methods using rakes, lutes and other hand tools, all to the satisfaction of the S.O. All laying of bituminous mix shall be such that after compaction by rolling the specified course or layer thickness and surface profile shall be achieved. Care shall be taken to achieve a uniform surface texture free from indentations, ridges, tear marks or other irregularities, and to prevent segregation of the mix.

At the commencement of initial rolling, the temperature of natural rubber modified asphaltic concrete shall be as determined form the viscosity-temperature relationship. Material which has cooled below the specified temperature before laying shall not be used and shall be removed from the Site of the Works. The Contractor shall provide accurate thermometers at the paving site at all times, and shall check the temperature

of asphaltic concrete in the paver hopper at regular intervals and before laying restarts after each interruption of the paving operation.

As far as is practicable, the paver shall be operated continuously and the supply of bituminous mix shall be regulated so as to enable continuous paving. Transverse joints in a paving lane shall be kept to a practicable minimum, and intermittent stopping and restarting of the paver shall be avoided as far as is practicable.

Care shall be taken that no bituminous mix is placed on expansion joints at bridges, inspection covers for utilities ducts, drainage and sewerage manholes and the like, and that catchpits, drainage openings through kerbs, etc., remain properly open and serviceable. During laying operations, such areas and openings shall be protected by suitably shaped and secured boards or other materials approved by the S.O., and compaction of mix in the immediately surrounding or adjacent areas shall be completed by hand methods, all to the satisfaction of the S.O. Alternatively, bituminous mix shall be laid and compacted by hand methods as necessary around surfacing discontinuities of these types, all to the satisfaction of the S.O.

h) Construction Joints

Existing bituminous surfacing which new bituminous mix is to adjoin shall be cut back to present a straight, vertical edge not less than 25 mm deep and a smooth transition section not less than 500 mm long against which to lay the new material. The specified thickness of the new surfacing shall be built up gradually from the vertical joint to avoid any bumps or ridges across the carriageway.

Where longitudinal or transverse joints are required in a layer of bituminous mix under construction, the material first laid and compacted shall be cut back to a vertical face for the full thickness of the layer on a line satisfactory to the S.O. before the adjacent area is paved.
At all construction joints, a thin uniform coating of bitumen emulsion of grade RS-1K shall be brushed on to the vertically cut joint faces some 10 to 15 minutes before laying the next section of bituminous mix commences to ensure good bonding. Also, all contact surfaces of kerbs, gutters, manholes, catchpits, etc. shall be similarly treated with a coating of bitumen emulsion before bituminous mix is placed against them.

Construction joints in a layer of bituminous mix shall be offset from those in any immediately underlying bituminous layer by at least 100 mm for longitudinal joints and at least 500 mm, for transverse joints.

Construction joints shall not be permitted along wheelpaths.

i) Compacting Natural Rubber Modified Asphaltic Concrete

For each layer of natural rubber modified asphaltic concrete, compaction by rolling shall commence at temperature as determined from the viscosity-temperature relationship during the mix design process.

In any areas inaccessible to the rollers, proper compaction shall be carried out using vibrating plate compactors, hand tampers or other suitable means, all to the satisfaction of the S.O.

Initial (or breakdown) rolling shall be carried out with an approved steel wheeled tandem roller. The principal heavy rolling shall be carried out with an approved pneumatic tyred roller immediately following the initial rolling; the pneumatic tyred roller shall be ballasted to an operating weight of not less than 15 tons and its tyre inflation pressure shall be not less than 0.7 N/mm^2. The final rolling shall be carried out with an approved steel wheeled tandem roller and shall serve to eliminate minor surface irregularities left by the pneumatic tyred roller.

All rollers shall operate in a longitudinal direction along the carriageway with their driven wheels towards the paver. Rolling shall generally commence at the lower edge of the paved width and progress uniformly to the higher edge, except that where there is a longitudinal construction joint at the higher edge, this shall be rolled first ahead of the normal pattern of rolling. Generally, successive roller passes shall overlap by half the width of the roller, and the points at which the roller is reversed shall be staggered. However, when operating on gradients in excess of 4%, the breakdown roller shall not pass over any previously unrolled mix when operating in the downhill direction.

In all cases, compaction shall be carried out in such a manner that each section receives equal compactive effort, all to the satisfaction of the S.O.

The steel wheeled rollers shall operate at speeds of not more than 5 km/h and the pneumatic tyred rollers shall operate at speeds of not more than 8 km/h. No roller or heavy vehicle shall be allowed to stand on newly laid bituminous mix before compaction has been completed and the material has thoroughly cooled and set. Rolling shall continue as long as is necessary to achieve the appropriate requirement as shown in Table 10.

Table 10 *Compacted density for natural rubber modified asphaltic concrete*

Type of Pavement Layer	Required Compacted Density
Wearing course	98 – 100% of Marshall density

Care shall be taken to prevent over-compaction of natural rubber modified asphaltic concrete.

Within 24 hours of laying and compacting the bituminous mix, the Contractor shall cut core samples of not less than 100 mm nominal diameter at locations selected by the S.O. The rate of sampling shall be one sample per 500 m^2 of mix laid, but not less than two samples for the work completed in each paving session. These core samples shall be used by the S.O. to determine the compacted thickness and density of the material in accordance with ASTM Test Method D 2726.

j) Finished Natural Rubber Modified Asphaltic Concrete

Natural rubber modified asphaltic concrete wearing courses shall be finished in a neat and workmanlike manner; their widths shall be everywhere at least those specified or shown on the Drawings on both sides of the centre-line; the average thickness over any

100-metre length shall be not less than the required thickness, and the minimum thickness at any point shall be not less than the required thickness minus 5 mm.

The top surface of a wearing or binder course shall have the required shape, superelevation, levels and grades, and shall be everywhere within the tolerances specified in sub-section 4.5 of JKR/SPJ/2008-S4.

The International Roughness Index (IRI) value of the finished wearing course surface shall be carried out as described in sub-section 4.5.3 of JKR/SPJ/2008-S4 of this specification and shall be not more than 2.0 m/km.

k) Opening to Traffic

Natural rubber modified asphaltic concrete shall not be opened to traffic until compaction has been completed and the material has thoroughly cooled and set in the opinion of the S.O. This will usually be not less than four hours after the commencement of rolling. Where it is necessary to allow earlier use of the finished surface to facilitate the movement of traffic, vehicles may be allowed to run on the work after rolling has been completed, provided that speeds are restricted to 30 km/h or less and sharp turning movements are prohibited.

4.17 CRUMB RUBBER MODIFIED ASPHALT

4.17.1 DESCRIPTION

This Specification provides information on the design, production and use of crumb rubber modified asphalt (CRMA).

Crumb rubber modified asphalt is a mixture of aggregates and crumb rubber modified binder (CRMB).

CRMB is a blend of hot bituminous binder and crumb rubber manufactured from reclaimed tyre rubber which are produced from tyres with a typical outside diameter greater than 660 mm and less than 1,520 mm used on commercial vehicles such as lorries and busses.

This Specification focuses on CRMB (asphalt-rubber) in ASTM D 8, which defines asphalt-rubber as "a blend of asphalt cement, reclaimed tyre rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles".

The CRMB is formulated and reacted at elevated temperatures and under high agitation to promote physical interaction of the bituminous binder and reclaimed tyre rubber constituents, and to keep the rubber particles suspended in the blend. The CRMB contains visible particles of reclaimed tyre rubber.

The application of CRMB as described in this Specification is for crumb rubber - stone mastic asphalt (CR-SMA), crumb rubber - gap graded asphalt (CR-GGA), crumb rubber - open graded friction course (CR-OGFC) and crumb rubber - stress absorbing membrane interlayer (CR-SAMI).

4.17.2 MATERIALS

a) Aggregates

Aggregates for CRMA shall be a combination of coarse and fine aggregates, and mineral filler. The individual aggregate shall be of sizes suitable for blending to produce the required gradation of the combined aggregates, all to the satisfaction of the S.O.

Coarse aggregates shall be screened crushed hard rocks, angular in shape and free from dust, clay, vegetative and other organic matters, and other deleterious substances. They shall conform to the following physical and mechanical quality requirements;

i. The Los Angeles abrasion value when tested in accordance with ASTM C 131 shall be not more than 25%.

ii. The weighted average loss of weight in the magnesium sulfate soundness test (5 cycles) when tested in accordance with AASHTO Test Method T 104 shall be not more than 18%.

iii. The flakiness index when tested in accordance with MS 30 shall be not more than 25%.

iv. The water absorption when tested in accordance with MS 30 shall be not more than 2%.

v. The polished stone value when tested in accordance with MS 30 shall be not less than 40 (for wearing course only).

Fine aggregates shall be clean screened quarry dust. Other types of fine aggregate may be used subject to the approval of the S.O. Fine aggregates shall be non-plastic and free from clay, loam, aggregation of materials, vegetative and other organic matters, and other deleterious substances. They shall conform to the following physical and mechanical quality requirements;

i. The sand equivalent of aggregate fraction passing the No. 4 (4.75mm) sieve when tested in accordance with ASTM D 2419 shall be not less than 45%.

ii. The fine aggregate angularity when tested in accordance with ASTM C 1252 shall be not less than 45%.

iii. The Methylene Blue value when tested in accordance with Ohio Department of Transportation Standard Test Method shall be not more than 10 mg/g.

iv. The weighted average loss of weight in the magnesium sulfate soundness test (5 cycles) when tested in accordance with AASHTO Test Method T 104 shall be not more than 20%.

v. The water absorption when tested in accordance with MS 30 shall be not more than 2%.

Notwithstanding compliance with the requirements of this Specification, limestone aggregates shall not be permitted for use in wearing course.

The gradation of the combined coarse and fine aggregates, and mineral filler, shall conform to the appropriate envelopes shown in Table 1.

Table 1 *Combined Aggregate Gradation for CRMA Mixtures*

Mix Designation	**CR-SMA**	**CR-GGA**	**CR-OGFC**	**CR-SAMI**
BS Sieve Size, mm	**Percentage Passing (by weight)**			
20.0	100	100	100	100
14.0	85 – 100	85 – 100	85 – 100	75 – 100
10.0	50 – 75	50 – 70	45 – 80	0 – 15
5.0	20 – 35	18 – 35	3 – 30	-
2.36	15 – 25	8 – 20	0 – 15	0 – 5
0.6	8 – 20	-	-	-
0.3	6 – 15	-	-	-
0.075	5 – 10	0 – 7	0 – 4	0 – 2

For CR-SMA, CR-GGA and CR-OGFC, the Contractor shall propose a laboratory design mix gradation which shall consist of a single definite percentage passing for each sieve size in Table 1 and shall produce a smooth curve within the appropriate gradation envelope. This job laboratory design

mix gradation, with the allowable tolerances for a single test as specified in Table 6 (for CR-SMA, CR-GGA) and Table 7 (for CR-OGFC), shall then become the job mix formula.

b) Mineral Filler

Mineral filler shall be incorporated as part of the combined aggregate gradation (except CR-SAMI) and shall be hydrated lime (calcium hydroxide). At the time of mixing with CRMA, it shall be sufficiently dry to flow freely and shall be essentially free from agglomerations. The quantity which pass the BS 0.075 mm sieve shall not be less than 75% by total weight of the hydrated lime.

If hydrated lime is not available, ordinary Portland cement shall be used as an alternative, subject to approval of the S.O.

The mineral filler shall also be treated as an anti-stripping agent.

c) Crumb Rubber Modified Binder (CRMB)

CRMB shall be of performance grade PG 76 or higher in compliance with AASHTO Standard M320-02. This premium grade binder shall be produced by pre-blending conventional bituminous binder of penetration grade 60 – 70 which shall conform to MS 124, with an appropriate quantity of crumb rubber.

Crumb Rubber

Crumb rubber shall be obtained by grinding reclaimed rubber tyres from heavy commercial vehicles to mesh sizes 20 to 40 (0.8 to 0.4 mm) because in general they contain higher proportion of natural rubber as compared to tyres from cars, pickups and small lorries which are made of styrene-butadiene synthetic rubber (SBR) or polybutadiene synthetic rubber.

Crumb rubber shall be either buffed crumb or whole tyre crumb.

i. **Buffed crumb**[1] shall be produced from worn tyres when the tyres are submitted for retreading. Rubber material shall be first removed from the tread in the form of 'buffing' or rasping. These buffing shall undergo ambient grinding process and shall be sieved to produce crumbs of various particle sizes. Since they are removed from the tyre tread, buffed crumb comprise high quality, abrasion resistant rubber material free from tyre reinforcement fabric or steel.

ii. **Whole tyre crumb rubber** shall be produced from reclaimed rubber tyres by ambient grinding process. The whole tyres shall be cut into large pieces and then shredded into chips about 3 to 5 mm in size. These chips shall be subsequently passed through a coarse mill or cutter, before being sent through fine grinding mills and screens.

[1] *When buffed crumb are used, contamination with excessive fibers, metals or minerals is generally negligible.*

Fiber content

The fiber content shall be less than 0.5% by weight. Fiber content shall be determined by weighing fiber agglomerations which are formed during the gradation test procedures. Rubber particles shall be removed from the fiber agglomerations before weighing.

Moisture content

The moisture content shall be less than 0.75% by weight after drying to constant mass at 60 ℃.

Mineral contaminants

The mineral contaminants shall not be greater than 0.25% by weight as determined by sedimentation analysis of a 100 g crumb rubber sample in a one-litre glass beaker filled with water.

Metal contaminants

The rubber shall contain no visible metal particles as indicated by thorough stirring of a 100 g crumb rubber sample with a magnet.

Chemical composition

The chemical composition of crumb rubber derived from different types and/or parts of tyres are shown in Table 2. For use as bituminous binder modifier, crumb rubber derived from different sources shall be mixed to obtain a satisfactory composition. After selecting and evaluating crumb rubber from a single or from multiple sources, the chemical composition shall remain the same throughout the project.

Table 2 *Chemical Composition of Crumb Rubber*

Test Parameter	Specification
Acetone Extract (%)	< 22
Rubber Hydrocarbon (%)	42 – 65
Carbon Black Content (%)	28 – 38
Natural Rubber Content (%)	> 30
Ash Content (%)	< 8.0

Source

Crumb rubber from more than one source may be used to ensure satisfactory compliance with gradation and compositional requirements. Whichever source or sources are used, they and their proportion shall remain the same as submitted to the S.O. and approved for the project. If the source of crumb rubber need to be changed, all relevant information shall be submitted to the S.O. and the new material shall not be used until approved by the S.O.

Packaging and labelling

Crumb rubber shall be supplied in reusable bulk containers or in weather (moisture) resistant disposable bags. If crumb rubber dosage is not controlled through a hopper equipped with accurate load cells (and connected through a screw feeder with the blending tank), the weight of bags containing crumb rubber shall be accurate to ± 2.0%. Stacking of crumb rubber containers and bags shall be minimised to avoid excessive consolidation of crumb rubber.

Each crumb rubber container or bag shall be labelled with the manufacturer's designation for the rubber, including the specific type and grade of rubber, the nominal rubber weight (per container or bag), the manufacturer's lot number designation and date, and any other information deemed pertinent by the crumb rubber supplier.

4.17.3 PREPARATION OF CRUMB RUBBER MODIFIED BINDER (CRMB)

a) Blending Equipment

The Contractor shall provide a blending equipment system located at the asphalt mixing plant.

The blending equipment shall have suitable heating system to raise the temperature of CRMB blend to its optimum blending temperature which shall be 170 to 190 ^{o}C. The blending equipment system, including its distribution and circulation pipes, shall be properly insulated to prevent rapid temperature drop during blending and discharging to the asphalt mixing plant. Suitable storage tank(s) that matches the capacity of the blending equipment and complete with suitable mechanical agitators shall be provided and the tank(s) shall be connected through the distribution and circulation pipes.

The blending equipment system shall be capable of producing CRMB with consistent required properties.

Alternatively, the CRMB shall be obtained from the supplier(s) approved by the S.O., hereafter referred to as terminal blend which is described in sub-section 4.17.3 (b).

b) Blending Process

CRMB shall be produced by blending hot bituminous binder with crumb rubber. The bituminous binder shall be penetration grade 60 – 70 and shall be heated to about 170 to 190 ^{o}C.

The crumb rubber shall be added to the hot bituminous binder and thoroughly mixed. The dosage of crumb rubber shall be at least 15% by weight of the bituminous binder. Other additives may also be incorporated into the blended bituminous binder and crumb rubber. Examples of such additive are natural rubber, extender oil and anti-stripping agent.

During heating and mixing of the bituminous binder and crumb rubber, the rubber particles will swell and softens as it reacts with the binder. This reaction is influenced by the blending temperature, the time the temperature remains

elevated, the type and amount of mechanical mixing, the size and texture of the crumb rubber, and the aromatic component of the binder. The crumb rubber absorbs aromatic oils and light fractions (small volatile or active molecules) from the binder and releases some of the similar oils used in the rubber production into the binder.
The resulting CRMB blend shall then be pumped into storage tank(s) where it shall be kept at a minimum temperature of 170 ºC for a period of 45 to 60 minutes to allow for further swelling of the crumb rubber.

Terminal Blend

Terminal blend is a mixture of bituminous binder and crumb rubber, which is finely ground to sizes less than 40 mesh. It shall be essentially produced elsewhere outside the asphalt mixing plant, hereafter referred to as the 'terminal', by using a wet process. The binder shall be heated in a tank to an elevated temperature and crumb rubber shall be introduced into the tank and digested into the binder using a high shear process. During this process, samples shall be taken and tested for solubility in accordance to ASTM D 2042 to ensure the crumb rubber has been completely digested. The solubility of the terminal blend after completion of blending shall be not less than 97.5%.

After completion of the blending, the terminal blend shall be transported in well insulated tankers, and transferred into storage tanks at the asphalt mixing plant as described above. The terminal blend may be held in the storage tanks for a maximum period of 3 days without agitation as the crumb rubber is considered completely digested into the binder. However, if the storage period exceed 3 days, proper agitation shall be provided.

The primary difference between terminal blend and the CRMB produced at the asphalt mixing plant (field blend) is the amount of crumb rubber used in the binder (terminal blend less than 10%; field blend at least 15%). However, the crumb rubber content in the terminal blend can be increased to 15 – 20% or more.

c) Formulation

The Contractor shall provide a blend formulation to the S.O. for approval at least 10 days before paving works is scheduled to commence. The blend formulation shall consist of the following information;

i. Bituminous binder
   - Source
   - Grade

ii. Crumb rubber
   - Source
   - Percentage by total weight of bituminous binder

d) Completion of Blending

The blending process shall be deemed to be complete when a small drop of CRMB from the blending system, placed on an impervious surface, shows only

a few specks of rubber which are soft enough to be spread into the CRMB by a knife or spatula. If the rubber particles still preserve their entity and cannot be rubbed away into the CRMB, blending is deemed incomplete, thus further heating and agitation are required.

e) Sampling of CRMB

The S.O. may, as and when required, instruct the Contractor to sample the CRMB from the blending system and send them for testing. Sampling points shall be provided at convenient points in the blending system. Sampling shall be done in accordance with MS 539. The Contractor shall bear all charges related to the testing as specified in Table 3.

f) Storage of CRMB

The Contractor shall provide a storage system capable of delivering the modified binder to the asphalt mixing plant. The storage system shall be located close to the asphalt mixing plant and it shall include distribution and circulation pipes that are properly insulated to prevent rapid temperature drop.

The storage tank shall have suitable mechanical agitator and be connected through delivery pipes and back-circulation pipes. Suitable sampling points shall be provided at convenient points in the storage system for taking samples. Sampling shall be done in accordance with MS 539.

The CRMB shall be used within 24 hours. If storage is necessary due to inevitable reasons, the binder shall be cooled to 145 – 155 ^{o}C and the storage time shall be limited to 3 days. During storage, the binder shall be continuously agitated.

If prolonged storage (more than 3 days) is unavoidable, the CRMB shall be tested for compliance as specified in Table 3. If non-compliance occurs, the CRMB shall be modified by adding more crumb rubber until the CRMB complies with the requirement.

g) Application of CRMB

At the time of application, the crumb rubber shall be dispersed uniformly throughout the bituminous binder. The properties of the CRMB, whether it is blended close to the asphalt mixing plant or produce by terminal blending, shall be as given in Table 3.

***Table 3** Properties of CRMB*

Test	Requirement	Test Specification
CRMB prior to rolling thin film oven test (RTFOT)		
[3]Viscosity, test temperature 177 °C, Pa.s	1.5 – 4.0[2]	ASTM D 4402
[3]Dynamic shear, G*/sin δ min. 1.00 kPa, 10 rad/s, test temperature °C	76	AASHTO T 315
[4]Penetration, 100 g, 5 s, 25 °C, x 0.1 mm, min.	25[5]	ASTM D 5
[4]Ring and ball softening point, °C, min.	60	ASTM D 36
[4]Flash point, °C, min.	240	AASTHO T 48
CRMB after RTFOT (AASHTO T 240) or ASTM D 2872		
[3]Mass loss, %, max.	1.00	AASHTO T 240 or ASTM D 2872
[3]Dynamic shear, G*/sin δ min. 2.20 kPa, 10 rad/s, test temperature °C	76	AASHTO T 315

4.17.4 CRUMB RUBBER - STONE MASTIC ASPHALT (CR-SMA) AND CRUMB RUBBER - GAP GRADED ASPHALT (CR-GGA)

a) Mix Design

Job Mix Formula

The Contractor shall propose a job mix formula required for the Works. In order to obtain optimum quality of the mixtures, the job mix formula shall be prepared on the basis of testing several laboratory design mix gradations within the limits as shown in Table 1 at an appropriate range of CRMB content. As a guide, the designed CRMB content for CR-SMA and CR-GGA will usually be in the range given in Table 4.

***Table 4** Range of Design Binder Contents*

Type of Asphalt Mixture	Design Binder Content
CR-SMA	5% – 7%
CR-GGA	6% – 8%

Each combination of laboratory design mix aggregate gradation and CRMB content shall be subject to the Marshall test procedure and volumetric analysis as follows;

[2] *The requirement may be waived at the discretion of the S.O. if the Contractor warrants that the CRMB can be adequately pumped and mixed at the temperatures that meet all applicable safety standards.*

[3] *These tests shall be carried out as and when required by the S.O. but shall be not less than one test per 30 tons of CRMB produced or at least once per project if the total quantity of CRMB produced is less than 30 tons. The CRMB samples shall be taken immediately prior to the production of CR-SMA or CR-GGA. Test frequency may be reduced if test results consistently conform to the requirements.*

[4] *These tests shall be carried out minimum once for each blending process for quality control purposes during blending at the asphalt mixing plant or terminal blending.*

[5] *The penetration and softening point values shall be taken as reference for consistency check on the production.*

i. Preparation of laboratory specimens for the standard stability and flow test in accordance with ASTM D 1559 using 75 blows/face compaction standard,

ii. Determination of the bulk density of the specimens in accordance with ASTM D 2726,

iii. Determination of the stability and flow values in accordance with ASTM D 1559,

iv. Analysis of the density and air voids parameters to determine the percentage air voids in the compacted aggregates, the percentage air voids in the compacted aggregates filled with CRMB and the percentage air voids in the compacted mix.

For the proposed design mix gradation, 4 specimens shall be prepared for each CRMB content within the range of Table 4[6] at increments of 0.5%, in accordance with ASTM D 1559 using 75 blows/face compaction standard. All CRMB content shall be in percentage by weight of the total mix. Prior to mixing with aggregates, the CRMB shall be heated to a temperature of 160 to 175 ^{o}C.

As soon as the freshly compacted specimens have cooled to room temperature, the bulk density of each test specimen shall be determined in accordance with ASTM D 2726.

The stability and flow value of each test specimen shall then be determined in accordance with ASTM D 1559.

After the completion of the stability and flow test, density and voids analysis shall be carried out for each test specimen to determine the percentage air voids in mineral aggregate (VMA) and the percentage air voids in the compacted mix (VIM).

Any erratic values shall be discarded before averaging. When 2 or more specimens in any group of 4 are so rejected, 4 more specimens shall be prepared and tested.

The average values of bulk density, stability, flow and VIM obtained above shall be plotted separately against the bitumen content and a smooth curve drawn through the plotted values.

The mean optimum CRMB content shall be determined by averaging 4 optimum CRMB contents so determined as follows;

i. Peak of curve taken from the stability graph[7],

ii. Flow equals to 3.5 mm from the flow graph,

[6] *The range of binder content shall be extended, if necessary, to ensure that the curves of stability and bulk density have their peak within the range selected.*

[7] *Where the stability curve exhibits more than one peak, the bitumen content chosen for the determination of the mean optimum bitumen content shall be the one which satisfies the voids requirements better. It is sometimes necessary, where no peak stability is obtained, to prepare and test supplementary specimens at intervals of 0.25% bitumen content on either side of the expected optimum.*

iii. Peak of curve taken from the bulk density graph[8],

iv. VIM equals to 4.5% (for CR-SMA) and 5.5% (for CR-GGA) from the VIM graph.

The individual test values (stability, flow and VIM) at the mean optimum CRMB content shall then be read from the plotted smooth curves and shall comply with the design parameters given in Table 5.

If all the values comply with Table 5, the mixture with the mean optimum CRMB content shall be used in plant trials. Otherwise, the mix design procedure shall be repeated using a different laboratory design mix aggregate gradation until all design parameters are satisfied.

Table 5 *CR-SMA and CR-GGA Requirements*

Test	Requirement	
	CR-SMA	**CR-GGA**
VIM	3 – 6%	4.5 – 6.5%
Stability	min. 6,000 N	min. 6,000 N
Flow	2.0 – 5.0 mm	2.0 – 5.0 mm
Binder drain-down	max. 0.2%	max. 0.2%
[9]Semi-Circular Bend, critical strain energy release rate, J_c, test temperature 25 ^oC, aged	min. 0.5 kJ/m^2	min. 0.5 kJ/m^2
[9]Hamburg Wheel-Tracking, rut depth @ 20,000 no. of passes, test temperature 50 ^oC	max. 12.5 mm	max. 12.5 mm

Binder Drain-Down Test

Binder drain-down test shall be conducted on 3 samples at mean optimum CRMB content to ascertain that the binder draining property of the mix is satisfactory.

Binder drain-down test shall be carried out in accordance with the test method as specified in Appendix A. A sample of CR-SMA and CR-GGA shall be placed in an oven for 3 hours at the anticipated asphalt mixing temperature in a wire basket fabricated using standard 6.3 mm sieve cloth. Any binder drain-down from the asphalt shall be collected in a pan. The binder drain-down shall be not more than 0.2% by weight of the total mix.

If the average binder drain-down exceeds 0.2%, the mix design procedure shall be repeated using a different laboratory design mix aggregate gradation until all design parameters are satisfied.

Alternatively, this test shall be carried out in accordance to the Schellenberg method. A sample of CR-SMA and CR-GGA (1 kg) shall be placed in 800 ml glass beaker in an oven at 170 ^oC for 1 hour. The beaker shall then be taken out from the oven and turned upside down to pour out the sample. Then, the beaker shall be weighed to get the mass of the binder which remain inside the beaker.

[8] *With highly absorptive aggregate, some difficulty in determining peak bulk density may occur. In such cases, the bitumen content at which the increase in bulk density shows a marked falling off shall be adopted.*

[9] *These tests shall be carried out once for each source (asphalt mixing plant) of CR-SMA or CR-GGA. Refer to Appendixes D and E for test procedures.*

The binder drain-down shall be calculated as a percentage loss of mass to the initial mass of sample (1 kg). The complete procedure of the test method is given in Appendix B.

Determination of Optimum Binder Content

The binder content that meet the criteria in Table 4 and satisfy the binder drain-down test requirement shall be selected as the optimum binder content. The aggregate gradation selected and the optimum binder content determined shall be proposed to the S.O. as the job mix formula.

Mixing and Compaction Temperatures

As a guide, the mixing temperature for CR-SMA and CR-GGA will usually be between 175 to 185 ºC. If higher than 195 ºC, the asphalt mixtures shall be disposed. The CR-SMA and CR-GGA mixtures shall be compacted immediately after laying and the compaction process shall be completed at temperature higher than 110 ºC. The mixing, laying and compaction temperature shall be determined during trial lay.

Trial Lay

After having received the S.O.'s preliminary approval of the proposed job mix formula, the Contractor shall arrange to mix, lay and compact the CR-SMA and CR-GGA mixtures. A minimum of 50 tons shall be placed at the job site to demonstrate to the satisfaction of the S.O. that the mixtures is satisfactory and the mixing, laying and compacting equipment conforms to the requirement of this specification.

As directed by the S.O., comprehensive sampling and testing of the CR-SMA and CR-GGA mixtures shall be carried out to check for satisfactory compliance with the job mix formula. If the asphalt mixture used in the trial lay complies with the job mix formula as well as compacted thickness and density requirements, the trial section shall be accepted as part of the Contract Works. Otherwise, the trial section shall not be considered as part of the Contract Works and shall be removed by the Contractor at his own expense.

The observations and tests to be carried out during trial lay shall be, but not restricted to the following;

i. Select a suitable location for the trial lay within the job site.

ii. Record the types and weight of roller.

iii. Record the type of paver.

iv. Carry out the following tests on the asphalt mixture;
   - Binder content and aggregate grading (ASTM D 2172/BS 598, ASTM C 136).
   - Theoretical maximum density (ASTM D 2041).
   - Preparation of Marshall specimens (ASTM D 1559).

- Bulk density of Marshall specimens (ASTM 3203).
- Calculation of air voids (ASTM D 3203).

v. Record temperatures of asphalt mixture on the tipper lorry, at plant and site.

vi. Record laying temperatures.

vii. Record laying thickness.

viii. Observe the surface texture of mixture laid behind paver.

ix. Record rolling temperatures i.e. immediately before rolling starts.

x. Record rolling pattern.

xi. Observe the surface texture of compacted mixture.

xii. Take at least 3 core samples from each tipper lorry load after the mixture has sufficiently hardened.

xiii. Record compacted thickness, density and air voids of the core samples.

xiv. Check at least one longitudinal joint to ensure that the joint is satisfactorily constructed.

Compliance with Job Mix Formula

The S.O.'s final approval of the job mix formula shall bind the Contractor to furnish the CR-SMA and CR-GGA mixtures meeting the precise aggregate gradation and CRMB content specified in the formula and within the tolerances set forth in Table 6.

Table 6 *Tolerances for CR-SMA and CR-GGA*

Parameter	**Permissible Variation** (% by weight of total mix)
CRMB content	± 0.3% **x CR**
Fractions of combined aggregate passing 5.00 mm and larger sieves	± 5.0%
Fractions of combined aggregate passing 2.36 mm sieve	± 4.0%
Fractions of combined aggregate passing 0.6 mm and 0.3 sieves	± 3.0%
Fraction of combined aggregate passing 0.075 mm sieve	± 2.0%

Note: ***CR*** *is the percentage of crumb rubber (by weight of the bituminous binder) blended with the binder. It shall be applicable to the lower limit only as there are discrepancies between the actual and the measured binder contents when tested in accordance to ASTM D 2172 due to the following causes;*

a) Most of the crumb rubber with mesh sizes 20 to 40 (0.8 - 0.4 mm) remains on the filter paper, and

b) A small amount of the binder remains in the extracted aggregate.

The upper limit shall be CRMB content as specified in the formula + 0.3%.

b) Construction Equipment

Mixing Plant

The contractor shall provide all the plant and equipment necessary for executing the work in accordance with this Specification and shall furnish the S.O. with such details of items of equipment, e.g. manufacturer, model type, capacity, weight, operating features etc.

The asphalt plant shall be either a batch plant or a drum mix plant or a continuous mix plant of a recognized manufacture and shall be approved by the S.O. It shall conform to the requirements described hereunder.

The mixing plant shall have a capacity suited to the Works and shall be sufficient to enable the paver operate more or less continuously when paving at normal speeds at the required thickness. The plant shall be designed so as to enable consistent production of asphalt mixtures within the tolerances prescribed in this Specification, all to the satisfaction of the S.O.

The plant shall also comply with the following requirements;

i. Handling mineral filler:
Adequate dry storage shall be provided for the mineral filler and provisions shall be made for proportioning the filler into the mixture uniformly in the desired quantities. Mineral filler in a batch plant will be added directly into the mixture uniformly in the desired quantities. Mineral filler in a batch plant will be added directly into the weigh hopper. In a drum plant mineral filler will be added directly into the drum mixer. Special attention is directed to providing appropriate equipment for accurately proportioning the relative large amounts of mineral filler required for CR-SMA mixture. Two separate silos shall be provided, one to keep the mineral filler (i.e. limestone powder) and another one to keep cement or hydrated lime.

ii. Hot-mixture storage:
When the hot mixture is not to be hauled immediately to the project and placed, suitable bins shall be provided. Such bins shall be either surge bins to balance production capacity with hauling and placing capacity or storage bins which are heated and insulated and which have a controlled atmosphere around the mixture. The holding time shall be within limitations imposed by the S.O., based on laboratory tests of the stored mixture. CR-SMA and CR-GGA mixtures shall not be stored overnight for paving on the next day.

Hauling Equipment

Hauling equipment should be of a type normally used for the transport of asphalt mixtures. Tipper lorry beds shall be covered and insulated if necessary, so that the mixture may be delivered on the road at the specified temperature.

Paver

The paver shall be of a type normally used for the placement of asphaltic

concrete. It shall be self-contained, power-propelled units provided with an adjustable activated screed, heated and capable of spreading and finishing courses of asphalt plant mix material in lane widths applicable to the specified typical section and thickness shown on the plans.

The paver shall be capable of being operated at forward speeds consistent with satisfactory placement and compaction of the mixture. The paver shall be capable of striking a smooth finish of uniform texture.

Steel Wheel Tandem Roller

The steel wheeled tandem roller shall be self-propelled and capable of being reversed without backlash; they shall be equipped with power steering and dual controls allowing operation from either the left or right side. The roller shall be equipped with water tanks, sprinkler systems and scraper blades to keep all wheels evenly wetted and clean during operation.

Each steel wheeled tandem roller shall be ballasted so that its total operating weight is in the range 8 to 10 tons and its driven roll(s) shall exert a rolling force of not less than 3.5 tons/m of roll width.

c) Construction Method

Surface Preparation

i. Immediately before placing the CR-SMA and CR-GGA mixtures, the surface shall be cleaned of loose or deleterious material by brooming or other approved means.

ii. A thin tack coat of bitumen emulsion RS-1K or similar material conforming to MS 161 shall be applied to ensure uniform and complete adherence of the overlay.

iii. Where the existing surface is non-uniform, a leveling course of asphaltic concrete shall be required to restore proper cross-section prior to construction of the overlay.

Weather Limitations

The CR-SMA and CR-GGA mixtures shall be placed on a dry clean surface when the atmospheric and the road surface temperatures are above 20 ^{o}C and the mixtures conforms to the applicable requirements as described in sub-section 4.17.4 (c).

Control of Asphalt Mixture

The CR-SMA and CR-GGA mixtures furnished by the Contractor shall conform to the job mix formula, within the allowable tolerances as shown in Table 5.

Laying

The temperature of asphalt mixture when delivered to the paver shall be greater than 160 ºC, measured in the tipper lorry immediately prior to dumping into the paver hopper. If the temperature drops to 140 ºC or below, the asphalt mixture shall be rejected.

The asphalt mixture shall be spread and struck off to the established grade and elevation with asphalt layers. Placing speed will be adjusted so that sufficient time is allowed for compaction operations and to provide continuity.

Compaction

Immediately after the asphalt mixture has been spread and struck off, it shall be thoroughly and uniformly compacted by rolling.

i. Due to the nature of CR-SMA and CR-GGA mixtures, the surface shall be rolled immediately. Rolling shall be accomplished with steel wheel tandem rollers of minimum weight of 8 tons. Pneumatic tyred rollers shall not be used. Rolling procedures shall be adjusted to provide the specified pavement density. Rollers shall move at a uniform speed not to exceed 5 km/h with the drive roller nearest the paver. Rolling shall be continued until all roller marks are eliminated and the minimum density has been obtained but not after the layer has cooled to 110 ºC or lower. The Contractor shall monitor density during the compaction process by using density gauges or approved rolling pattern to ensure that the minimum required compaction is obtained.

ii. To prevent adhesion of the mixture to the rollers, it shall be necessary to keep the wheels properly moistened with water mixed very small quantities of detergent or other approved material.

iii. The pavement shall be compacted to minimum 94% of theoretical maximum density which shall be determined using the Rice method as described in ASTM D 2041 or minimum 98% of Marshall density.

Opening to Traffic

Traffic shall not be allowed on the newly compacted surface until compaction has been completed and the material has thoroughly cooled to 60 ºC or lower. As a guide, this will usually be not less than 4 hours after the commencement of rolling. Where it is necessary to allow earlier use of the finished surface to facilitate the movement of traffic, vehicles may be allowed to run on the pavement after rolling has been completed, provided that speeds are restricted to 30 km/h or less and sharp turning movements are prohibited.

4.17.5 CRUMB RUBBER - OPEN GRADED FRICTION COURSE (CR-OGFC)

a) Mix Design

With high air voids and open-graded aggregates, high binder contents are essential to ensure mix integrity, increase resistance to oxidation and raveling, and improve durability. The quantity of binder shall be carefully balanced such that it is not deemed too excessive to cause binder drain-down during production, transport and laying, and neither is deemed too little to adversely affect durability.

Laboratory Compacted Specimens

CR-OGFC mixtures shall be compacted in the laboratory by using the Marshall method in accordance with ASTM D 1559. The specimens shall then be used for further analysis as described hereof.

Because of the limited compactive effort applied in the field on CR-OGFC mixture, the number of blows per face shall be 50.

Air Voids Requirements

The design and in-place air voids shall be in the range of 18 to 25%.

Binder Drain-Down Test

Binder drain-down test shall be conducted on 3 samples at mean optimum CRMB content to ascertain that the binder draining property of the mix is satisfactory.

Binder drain-down test shall be carried out in accordance with the test method as specified in Appendix A. A sample of CR-OGFC shall be placed in an oven for 3 hours at the anticipated asphalt mixing temperature in a wire basket fabricated using standard 6.3 mm sieve cloth. Any binder drain-down from the asphalt shall be collected in a pan and shall be not more than 0.2% by weight of the total mix.

If the average binder drain-down exceeds 0.2%, the mix design procedure shall be repeated using a different laboratory design mix aggregate gradation until all design parameters are satisfied.

Cantabro Test

Cantabro test shall be carried out in accordance with the procedure as given in Appendix C. 3 Marshall specimens shall be simultaneously subjected to 300 revolutions in the Los Angeles drum, without the steel balls, at 25 ^{o}C. The average loss of mass shall be not more than 15%.

Determination of Design Binder Content

Using a selected design aggregate gradation that comply with Table 1, prepare 9 laboratory mixtures at each binder content in the range 8 to 10%, in increments of 0.5%.

For each binder content, conduct binder drain-down test on the first 3 laboratory mixtures at the anticipated production temperature.

For each binder content, determine theoretical maximum density on the next 3 laboratory mixtures in accordance with ASTM D 2041.

Use the remaining laboratory mixtures to fabricate 3 Marshall specimens at each binder content. Apply 50 blows per side at the anticipated compaction temperature at site.

Determine the air voids of the Marshall specimens in accordance with ASTM D 3023.

Using the same Marshall specimens, conduct Cantabro test in accordance with the test method as given in Appendix C.

The lower limit of the design binder content shall be determined in accordance with the following two criteria;

i. Average loss of mass in the Cantabro test shall be not more than 15%.

ii. Average air voids shall be not more than 25%.

The upper limit of the design binder content shall be determined in accordance with the following two criteria;

i. Average binder drain-down shall be not more than 0.2%.

ii. Average air voids shall be not less than 18%.

Take the mean of the lower limit and upper limit of the design binder content as determined from the Cantabro test and binder drain-down test respectively as the initial design binder content. Use this value to check for air voids and make adjustment where necessary such that the air voids are between 18 to 25% but the design binder content shall be within the lower limit and upper limit.

The binder content that meets all the above criteria shall be recommended as the design binder content.

The aggregate gradation selected and the design binder content recommended shall be proposed to the S.O. as the job mix formula.

Trial Lay

After having received the S.O.'s preliminary approval of the proposed job mix formula, the Contractor shall arrange to mix, lay and compact the CR-OGFC mixture. A minimum of 50 tons shall be placed at the job site to demonstrate to the satisfaction of the S.O. that the mix is satisfactory and the mixing, laying

and compacting equipment conforms to the requirement of this specification. As directed by the S.O., comprehensive sampling and testing of the CR-OGFC mixture shall be carried out to check for satisfactory compliance with the job mix formula. If the asphalt mixture used in the trial lay comply with the job mix formula as well as compacted thickness and density requirements, the trial section shall be accepted as part of the Contract Works. Otherwise, the trial section shall not be considered as part of the Contract Works and shall be removed by the Contractor at his own expense.

The observations and tests to be carried out during trial lay shall be, but not restricted to the following;

i. Select a suitable location for the trial lay within the job site.

ii. Record the types and weight of roller.

iii. Record the type of paver.

iv. Carry out the following tests on the asphalt mixture;
   - Binder content and aggregate grading (ASTM D 2172/BS 598, ASTM C 136).
   - Theoretical maximum density (ASTM D 2041).
   - Preparation of Marshall specimens (ASTM D 1559).
   - Bulk density of Marshall specimens (ASTM 3203).
   - Calculation of air voids (ASTM D 3203).

v. Record temperatures of asphalt mixture on the tipper lorry, at plant and site.

vi. Record laying temperatures.

vii. Record laying thickness.

viii. Observe the surface texture of mix laid behind paver.

ix. Record rolling temperatures i.e. immediately before rolling starts.

x. Record rolling pattern.

xi. Observe the surface texture of compacted mix.

xii. Take at least 3 core samples from each tipper lorry load after the mix has sufficiently hardened.

xiii. Record compacted thickness, density and air voids of the core samples.

xiv. Check permeability of the compacted surfacing (refer to sub-section 4.17.5 (c)).

xv. Check at least one longitudinal joint to ensure that the joint is satisfactorily constructed.

Compliance with Job Mix Formula

The S.O.'s final approval of the job mix formula shall bind the Contractor to furnish the CR-OGFC meeting the precise aggregate gradation and CRMB content specified in the formula within the tolerances set forth in Table 7.

Table 7 *Tolerances for CR-OGFC*

Parameter	Permissible Variation (% by weight of total mix)
CRMB content	± 0.3% **x CR**
Fractions of combined aggregate passing 5.00 mm and larger sieves	± 5.0%
Fractions of combined aggregate passing 2.36 mm sieve	± 4.0%
Fraction of combined aggregate passing 0.075 mm sieve	± 2.0%

*Note: Refer to Table 6 with regards to **CR**.*

b) Sampling and Testing of CR-OGFC

Frequency of sampling and testing shall be not less than that shown in Table 8 which provides for two levels of minimum frequency. The reduced frequency may only be adopted as instructed by the S.O. if the test results consistently conform to the requirements.

Table 8 *Frequency of Sampling and Testing of CR-OGFC*

Test	Normal Minimum Frequency	Reduced Minimum Frequency
Aggregate gradation	One test per 300 tons of asphalt plant production.	One test per 500 tons asphalt plant production.
CRMB content	One test per 300 tons of asphalt plant production.	One test per 500 tons of asphalt plant production.
Binder drain-down	One test per 300 tons of asphalt plant production.	One test per 500 tons of asphalt plant production.
Temperature	Each loaded tipper lorry.	Each loaded tipper lorry.

c) Construction Method

Pavement Preparation

CR-OGFC shall be laid only on structurally sound pavement with minimal cracks, ruts and depressions.
A strong, durable bond of CR-OGFC to the underlying pavement surface is essential.
A thick tack coat is essential to ensure;

i. A good bonding of the relatively small surface area of contact of the open-graded CR-OGFC to the underlying pavement surface.

ii. A good resistance to damage induced by residual moisture which may be trapped at the bottom of the porous asphalt layer.

iii. Effective sealing of cracks and other surface deficiencies which may be present in the existing pavement surface, thus providing an impervious underlying surface.

CR-OGFC shall not be used to restore poor road profile.

Existing pavement surface shall be regulated with dense continuously graded asphalt mixture to remove depression which may trap and hold water under CR-OGFC layer.

Laying

CR-OGFC shall be laid only on impermeable and plane pavement surface with adequate cross fall. A minimum cross fall of 2.5% shall be provided.

CR-OGFC shall be laid by machine and compacted within 3 hours of mixing.

Laying shall commence on the low side of the carriageway.

CR-OGFC shall be laid to a minimum and maximum thickness of 25 mm and 40 mm respectively.

Hand casting shall be kept to minimum.

CR-OGFC shall not be laid directly over an existing concrete pavement because the difficulty in establishing an adequate bond. However, it shall be preceded with a layer of dense graded bituminous mixture on the existing concrete pavement to assist bonding.

When the rehabilitation of a deteriorated concrete pavement includes bituminous mixture overlay, CR-OGFC shall be used as the final wearing course.

CR-OGFC shall not be laid in areas where;

i. The pavement structural strength is sub-standard.

ii. There is considerable traction due to sudden acceleration, braking and turning like at major junctions.

iii. There are tight radius curves, loops of radius less than 75 m.

iv. The gradient exceeds 10%.

v. Excessive deposits of debris, oil and fuel may be experienced.

vi. Free drainage cannot be accommodated along the road shoulders.

vii. Length of roads less than 100 m because of spray carry-over from adjacent surfacing.

viii. There is high flexibility like on bridges.

ix. Frequent excavations by statutory undertakers may occur.

x. Traffic levels exceed 4,000 commercial vehicles per lane per day at opening.

xi. There is a 40 km/h speed limit because there is no beneficial reduction in spray or noise levels achieved at low speeds.

Compaction

CR-OGFC shall be compacted using static steel wheel tandem rollers only.

Vibratory rollers are not permitted because they lead to excessive compaction and the possibility of aggregate crushing.

Pneumatic tyred rollers are not permitted because they knead and close the surface, affecting the permeability of CR-OGFC. They also cause stripping of aggregates that stick to their tyres.

3 wheel steel rollers are not permitted because they leave roller marks that can be difficult to remove.

Compaction by rolling shall commence as soon after laying as the material will support the rollers without undue displacement; nevertheless, the temperature of the CR-OGFC at the commencement of rolling shall be not less than 110 ^{o}C.

In any areas inaccessible to the rollers, proper compaction shall be carried out using vibrating plate compactors, hand tampers or other suitable means, all to the satisfaction of the S.O.

The steel wheel tandem rollers shall operate in a longitudinal direction along the carriageway with their driven wheels towards the paver. Rolling shall generally commence at the lower edge of the paved width and progress uniformly to the higher edge, except that where there is a longitudinal construction joint at the higher edge, this shall be rolled first ahead of the normal pattern of rolling. Generally, successive roller passes shall overlap by quarter of the roller width, and the points at which the roller is reversed shall be staggered. However, when operating on gradients in excess of 4%, the breakdown roller shall not pass over any previously unrolled mix when operating in the downhill direction.

In all cases, compaction shall be carried out in such a manner that each section receives equal compactive effort, all to the satisfaction of the S.O.
The rollers shall operate at speeds of not more than 5 km/h. No roller or heavy vehicle shall be allowed to stand on newly laid bituminous mix before compaction has been completed and the material has thoroughly cooled and set. Rolling pattern shall be in accordance with trial lay carried out earlier and shall give field density not less than 97% of Marshall density.

The CR-OGFC layer shall be finished in a neat and workmanlike manner; their widths shall be everywhere at least those specified or shown on the Drawings on both sides of the centre-line; the average thickness over any 100 m length shall be not less than the required thickness, and the minimum thickness at any point shall be not less than the required thickness minus 5 mm.

Care shall be taken to prevent over-compaction of CR-OGFC.

Within 24 hours of laying and compacting the bituminous mixture, the Contractor shall cut core samples of not less than 100 mm nominal diameter at locations selected by the S.O. The rate of sampling shall be one sample per 500 m^2 of mixture laid, but not less than 2 samples for the work completed in each paving session. These core samples shall be used by the S.O. to determine the thickness of the compacted layer of mixture and the compacted density of the material in accordance with either ASTM D 1188 or ASTM D 6857.

Joint Construction

The formation of all joints shall be made in such a manner as to ensure a continuous bond between old and new sections of the course. All joints shall present the same texture, density, and smoothness as other sections of the course

Cold longitudinal joints shall not be cut as the inherent rough texture of the mixture will readily provide good bonding along the joints. Cutting the joints may incur damages to the mixture along the joints as the aggregate gradation of mixture is of open-graded nature. Application of tack coat along the joints is deemed unnecessary as it may clog the voids along the joints and impede the flow of water across the joints.

Shaping Edges

While the surface is being compacted and finished, the Contractor shall carefully trim the outside edges of the pavement to the proper alignment.

Edges so formed shall be beveled while still hot and compacted.

Permeability

Being the principle benefit of CR-OGFC, the permeability shall be sufficient to allow satisfactory drainage of rain water during heavy rainfall. The permeability of CR-OGFC wearing course having a minimum thickness of 25 mm shall be not less than 900 ml per 15 seconds immediately after construction if tested in accordance to the test procedure as described in Appendix F.

Opening to Traffic

Traffic shall not be allowed on the newly compacted surface until the layer has cooled to 60 ^oC or lower.

4.17.6 CRUMB RUBBER - STRESS ABSORBING MEMBRANE INTERLAYER (CR-SAMI)

Crumb rubber - stress absorbing membrane interlayer (CR-SAMI) is a pavement layer constructed by spraying CRMB on the surface of the existing pavement and then spreading and rolling in aggregate chipping prior to overlaying with asphalt mixture. The main function of the CR-SAMI is to retard propagation of cracks from the existing pavement into the new overlay.

a) Equipment

CRMB Distributor

The distributor shall be equipped with an internal heating device capable of heating the material evenly up to 220 °C; an internal mixing unit capable of maintaining a proper mixture of bituminous binder and crumb rubber; have adequate pump capacity to maintain a high rate of circulation in the tank and to spray the CRMB; have adequate pressure devices and suitable manifolds to provide constant positive cut-off to prevent dripping from the nozzles. The distributor shall be equipped with an electronically controlled computerised compensation unit for controlling application rates at various width and speed changes. The application unit shall have electronic controls and a digital read out installed and operated from the inside of the cab of the distributor. The distribution bar on the distributor shall be fully circulating. Any distributor that produces a streaked or irregular distribution of the material shall be promptly repaired or removed from the site.

Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, and a thermometer for reading temperature of tank contents. Controls for spray bar shall be located in cab of truck, for controlling width and rate of spray of product. It shall be so constructed that uniform applications may be made at the specified rate per m^2 with a tolerance of ± 0.2 kg/m^2.

Aggregate Spreader

The aggregate spreader shall be hydrostatically driven and self-propelled. It shall be equipped with a hydraulically controlled variable adjustable head that is capable of spreading aggregate in widths from 1.5 to 5.5 m. The spreader shall be mounted on pneumatic tyres, and shall spread the aggregate on the road surface in a manner that ensures that the tyres do not contact the road surface until after the aggregate has been applied. The unit shall be equipped with an electronic radar type sensor used to measure ground speed and will automatically adjust the aggregate application rate depending on width of application and the speed of chip spreader. It shall have the ability to apply aggregate on any gradient from 0 - 6%. The spreader shall be equipped with an integral hopper with a minimum capacity of 5 tons of aggregate which shall be filled by trucks in a manner which ensures that the truck tyres never come in contact with the road surface until the aggregate has been properly applied. To maintain constant aggregate application, a self-locking truck hitch will permit towing of aggregate trucks without stopping the chip spreader. It shall be capable of maintaining positive engagement over irregular terrain.

Pneumatic-Tyred Roller

A minimum of 2 self-propelled, multiple wheel, pneumatic-tyred rollers shall be used, both shall weigh a minimum of 15 tons, and shall have a total compacting width of at least 1.5 m.

b) Construction Method

Surface Preparation

Defects on the existing pavement surface such as potholes and depressions shall be patched or regulated accordingly. The surface shall then be thoroughly cleaned by sweeping with power broom and/or air blower prior to application of CRMB and aggregate chipping.

Seasonal and Weather Limitations

Construction shall proceed only when the atmospheric temperature is at least 20 °C. No water shall be present on the road surface.

Application of CRMB

The CRMB shall be applied at a temperature in the range between 180 to 200 ^{o}C and at a rate of 2.0 to 2.6 kg/m^2.

Longitudinal joints shall be parallel to centrelines. Where any construction joint occurs, the edges shall be broomed back and blended so there are no gaps and the elevations are the same, and free from ridges and depressions. Longitudinal joints shall be overlapped by 100 mm.

During application, adequate provision shall be made to prevent marring and discoloration of adjacent pavements, structures, vehicles, foliage or personal properties.

The CRMB distributor shall be operated at constant speed to ensure the homogeneity during the spraying process. Over-spray shall be avoided and partial-miss shall be made good manually.

Construction equipment or other vehicles shall not drive on the CRMB layer before aggregates are applied.

Application of Aggregate

The application of aggregate shall follow as close as possible behind the application of the CRMB which shall not be spread further in advance of the aggregate spread than can be immediately covered. The aggregate shall be spread uniformly by a self-propelled spreader at a rate ranging from 12 to 16 kg/m^2 which shall be determined from a trial section. During construction, the aggregate shall fully cover the CRMB area and no loose aggregate shall be allowed. Any deficient areas shall be covered with additional aggregate manually.

Compaction

A minimum of 2 pneumatic-tyred rollers, each with operating weight of at least 15 tons, shall be used for aggregate embedment into the CRMB. Rolling shall commence immediately after spreading the aggregate. There shall be at least 3 passes (a pass being 1 movement of a roller in either direction) by the roller to embed the aggregate particles firmly into the CRMB. Each pass shall overlap at least 1/3 of the wheel width.

Compaction sequence shall be from the lower side to the crown.

Sweeping

When all the aggregate has been firmly embedded into the CRMB and the pavement has cooled, all loose aggregate shall be swept or removed manually. This shall be done at a time in a manner, which will not displace any embedded aggregate or damage the CRMB. The aggregate removed shall be disposed from the site.

Preparation for Overlay

Tack coat, using RS-1K bituminous emulsion, shall be applied at 0.25 to 0.5 l/m^2 before overlay is carried out.

Opening to Traffic

CR-SAMI layer construction shall be immediately followed by overlay. No traffic is allowed between these processes. Where it is necessary to allow earlier use of the finished CR-SAMI to facilitate the movement of traffic, vehicles shall only be allowed at least 3 hours after the CR-SAMI construction, provided that speeds are restricted to 25 km/h or less and sharp turning movements are prohibited.

Appendix A - Binder Drain-Down Test

1.0 Scope

This test method covers the determination of the amount of binder drain-down in an un-compacted asphalt mixture sample when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport and placement of the mixture.

2.0 Reference Documents

AASHTO Standards T 245 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus and M 92 Standard Specification for Wire Cloth Sieve for Testing Purposes.

3.0 Binder Drain-Down

For the purpose of this test method, binder drain-down is considered to be that portion of the bituminous mixture which separates itself from the sample as a whole and is deposited outside the wire basket during the test.[10]

4.0 Summary of Method

A sample of the asphalt mixture of mass 1.1 kg is prepared in the laboratory or obtained from field production. The sample is placed in a wire basket that is positioned on a pre-weighed paper plate. The sample, basket and plate are placed in a forced air oven for one hour at a pre-selected temperature. At the end of 3 hours, the basket containing the sample is removed from the oven along with the paper plate and the paper plate is weighed to determine the amount of binder drain-down that occurred.

5.0 Significance and Use

Test method can be used to determine whether the amount of binder drain-down measured for a given asphalt mixture is within acceptable levels. It also provides an evaluation of the binder drain-down potential of asphalt mixture produced in the field.

[10] *Any noticeable aggregate particles that are deposited outside the basket shall be added back into the mixture and not counted as binder drain-down. Alternatively the test shall be repeated.*

6.0 Apparatus

i. Oven capable of maintaining the temperature in a range from 1200 – 1750 °C. The oven shall maintain the set temperature to within ± 2 °C.
ii. Paper plates of appropriate size. The paper plates shall be of appropriate durability to withstand the oven temperatures.
iii. Standard cylindrical shaped basket meeting the dimensions shown in Figure 1. The basket shall be constructed using standard 6.3 mm sieve cloth as specified AASHTO M 92.
iv. Spatulas, trowels, mixer and bowls as needed.
v. Balance accurate to 0.1 g.

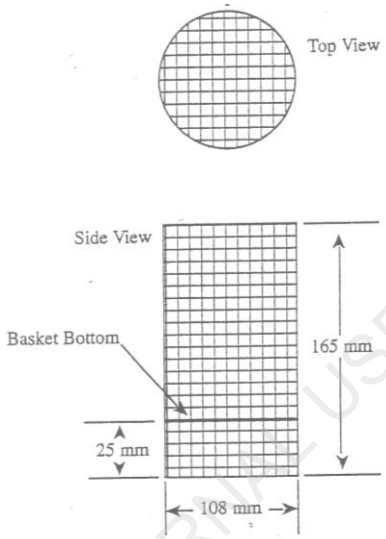


FIGURE 1 – Wire basket assembly

7.0 Prepared Samples

7.1 Laboratory Prepared Samples

i. For each mixture, the binder drain-down characteristics shall be determined at the anticipated plant production temperature. Duplicate samples shall be tested.

ii. Dry the aggregate to constant mass and sieve it into appropriate size fractions as indicated in AASHTO T 245, Section 3.2.

iii. Determine the anticipated plant production temperature or select a mixing temperature in accordance with AASHTO T 245, Section 7.3.1. The supplier's recommendations shall be sought when using modified bitumen.

iv. Weigh into separate pans for each test sample the amount of each size fraction required to produce complete bituminous mixture samples having a mass of 1,200 g. The aggregate fractions shall be combined such that the resulting aggregate blend has the same gradations as the job mix formula. Place the aggregate samples in an oven and heat to a temperature not to exceed the mixing temperature established in (iii) by more than approximately 28 °C.

v. Heat the asphalt mixture to the temperature established in item (iii).

vi. Place the heated aggregate in the mixing bowl. Form a crater in the aggregate blend and add the required amount of asphalt. The amount of asphalt shall be such that the final sample has the same binder content as the job mix formula. At this point,

the temperature of the aggregate and asphalt mixture shall be within the limits of the mixing temperature established in (iii). Using a spatula (if mixing by hand) or a mixer, mix the aggregate and binder quickly, until the aggregate is thoroughly coated.

7.2 Plant Produced Samples

For plant produced samples, duplicate samples shall be tested at the plant production temperature.

Samples shall be obtained during plant production by sampling asphalt mixtures from tipper lorries prior to the mixtures leaving the plant. Samples obtained during actual production shall be reduced to the proper test sample size by the quartering method.

8.0 Procedure

i. Transfer the laboratory produced or plant produced un-compacted open graded friction course mixture sample to a tarred wire basket described in 6.0 (iii). Place the entire sample in the wire basket. Do not consolidate or otherwise disturb the sample after transfer to the basket. Determine the mass of the sample to the nearest 0.1 g.

ii. Determine and record the mass of a paper plate to the nearest 0.1 g. Place the basket on the paper and place the assembly into the oven at the temperature as determined in 7.1 (iii) for 3 hours ± 1 minute.

iii. After the sample has been in the oven for 3 hours, remove the basket and paper plate. Determine and record the mass of the paper plate to the nearest 0.1 g.

9.0 Calculations

Calculate the percent of mixture which drained by subtracting the initial paper plate mass from the final paper plate mass and divide this by the initial total sample mass. Multiply the result by 100 to obtain a percentage.

10.0 Report

Report the average percent binder drain-down at the test temperature.

Appendix B - Schellenberg Binder Drainage Test

1.0 Scope

This method is to determine the free asphalt quantity of asphalt binder separated from asphalt mixtures at the condition of high temperature and used to inspection of maximum binder content of crumb rubber - stone mastic asphalt (CR-SMA), crumb rubber - gap graded asphalt (CR-GGA) and crumb rubber - open graded friction course (CR-OGFC).

2.0 Apparatus and Materials

i. 800 ml beaker
ii. Oven
iii. Small-size asphalt mixtures mixer
iv. Glass plate
v. Balance: with a sensibility not greater than 0.1 g
vi. Others: hand shovel, cotton yarn, etc.

3.0 Test Procedure

i. Prepare 3 duplicate asphalt samples which comply with the job mix formula. Each sample shall be 1 kg.
ii. Clean the 800 ml beaker, dry it and weigh the beaker mass m_0 to an accuracy of 0.1 g.
iii. Pour 1 kg of the mixture into the beaker, and weigh the total mass of the beaker and the mixture to an accuracy of 0.1 g.
iv. Cover the beaker with a glass plate, put the beaker into a 170 ± 2 ºC oven, if it is the CR-SMA, the temperature shall be 185 ºC for 60 ± 1 minutes.
v. Take the beaker out without any impact or vibration, put the mixture downwards on the glass plate, weigh the total mass m_2 of the beaker, binder attached on the beaker, fine aggregate and mastic to an accuracy of 0.1 g.

For construction quality inspection, samples shall be obtained during plant production by sampling asphalt mixtures from tipper lorries prior to the mixtures leaving the plant. Samples obtained during actual production shall be reduced to the proper test sample size by the quartering method.

4.0 Calculation

The drainage mass loss of the asphalt shall be calculated according to *Equation 1*.

$$\Delta m = \frac{m_2 - m_0}{m_1 - m_0} \times 100 \qquad \textit{(Equation 1)}$$

where:

m_0 = The beaker mass (g);

m_1 = The total mass of beaker and asphalt mixtures for test use (g);

m_2 = The total mass of beaker, asphalt binder attached on the beaker, fine aggregate, and mastic (g);

Δm = The drainage mass loss of the asphalt (%).

5.0 Report

The test shall be carried out on at least 3 samples and the average value shall be taken as the test result.

Appendix C - Cantabro Test

1.0 Scope

Cantabro test shall be done on the proposed mix to measure its resistance to stone loss at high frequency. The test procedures and apparatus are described below;

2.0 Apparatus

i. Marshall Compactor - see description in ASTM D 1559.
ii. Loss Angeles Drum - see description in ASTM C 131.
iii. Thermometers: to measure the temperatures of the aggregate, binder and bituminous mix, metal thermometers with a scale up to 200 ^{o}C and accuracy of 3 ^{o}C are used. To measure the temperature at which the test is carried out, a thermometer with a scale from 0 to 50 ^{o}C and an accuracy of 0.5 ^{o}C is used.
iv. Balances: a balance with a capacity of 2 kg to an accuracy of 0.1 g to weight the samples and another with a capacity of 5 kg to an accuracy of 1 g to prepare the mixes.
v. General materials: tray, pots, spatulas, asbestos gloves, curved scoops, filter paper rings etc.

3.0 Procedure

The different aggregate fractions which make up the mix are dried in a stove at 105 – 110 ^{o}C until constant weight is reached. At the proposed optimum binder content, 4 Marshall specimens are manufactured with 50 blows on each side at adequate temperature[11]. The relative density and void percentage shall be determined as soon as they have cooled to ambient temperature. The procedure to determine the density and void percentage shall be based on geometric procedures.

The specimens shall be dried at ambient temperature for 2 days. Before testing the specimens, they shall be kept at test temperature, 25 ^{o}C, for at least six hours. After the specimens have been kept for the required time, weigh it (M_0), then place immediately into the Los Angeles drum without abrasion loads (balls). The drum shall be turned at a velocity between 188 and 208 rad/s and submitted to 300 revolutions. This shall be repeated for the 4 specimens.

Weigh the specimen after test (M_1). For each specimen, the stone loss or attrition resistance is computed;

$$L = \frac{M_0 - M_1}{M_0} x\ 100\% \qquad \textit{(Equation 2)}$$

The average stone loss (L) is reported and shall be not more than 15%.

[11] *Mixing temperatures are usually 130 ^{o}C for conventional binder and 170 ^{o}C for CRMB.*

Appendix D - Semi-Circular Bend (SCB) Test

1.0 Scope

This test method covers the procedures for preparation, testing, and measurement of asphalt mixture cracking resistance at Long Term Pavement Performance (LTPP) database intermediate temperatures using semi-circular bend (SCB) geometry laboratory prepared or pavement core asphalt mix samples tested monotonically. The SCB sample is a half-disk with a notch cut parallel to the loading and vertical axis. The test method describes the determination of the critical strain energy release rate, J_c, and other parameters determined from the load-displacement curve. These parameters can be used to rank the resistance of asphalt mixtures to cracking.

2.0 Summary of Test Method

A semi-circular specimen is loaded monotonically until fracture failure occurs under at constant rate of deformation in a three-point bending load configuration. The load and deformation are continuously recorded and are used to compute the critical strain energy release rate, J_c. High J_c values are desirable for fracture-resistant mixtures. A J_c value ranging from 0.5 to 0.60 kJ/m^2 is typically recommended to ensure adequate fracture resistance of the mixture.

This test procedure considers the elasto-plastic/viscoelastic relationship of asphalt mixtures and fracture mechanics (Mull, et al., 2006, Anderson 2005 and suggested by Wu et al., 2005).

3.0 Apparatus

i. Load Test System:
A load test system consisting of an axial loading device, environmental chamber, and control and data acquisition system. The test system shall meet the minimum requirements specified in Table 9.
   - Axial Loading Device – The load apparatus shall be capable of maintaining a constant cross-head deformation rate of 0.5 mm/min.
   - Environmental Chamber – A chamber capable of maintaining 60.3 ºC of the climatic intermediate temperature calculated in Equation 3.
   - Control and Data Acquisition System – The system shall include a data acquisition system comprising analog to digital conversion or digital input, or both, for storage and analysis on a computer. The system shall be capable of measuring and recording 3 signals during the test including load, displacement, and chamber temperature 10 Hz. The minimum resolution of the measurements is provided in Table 9.

Table 9 *SCB Test System Minimum Requirements*

Measurement	Range	Accuracy
Load Measurement and Control	0 to 10 kN	± 1%
Displacement Measurement and Control	0 to 30 mm	± 0.5%
Temperature Measurement and Control Range	5 to 35 ºC	± 0.3 ºC

ii. Measurement Devices:
- Load Measuring Device – The load measuring device shall consist of an electronic load cell, designed for placement between the load platen and piston, with the minimum capacity and sensitivity stated in Table 9. The load cell shall be calibrated in accordance with ASTM Standards E4.
- Axial Deformations – Axial deformations shall be measured with linear variable differential transformers (LVDT) or other devices capable of measuring displacement within the range and tolerance provided in Table 9. The LVDT shall be calibrated in accordance with Practice ASTM Standards E3029, Class B.
- Temperature – Chamber temperature shall be measured with Resistance Temperature Detectors (RTD) or other suitable devices accurate to within ± 0.3 ^{o}C.

iii. Gyratory Compactor – A gyratory compactor and associated equipment for preparing laboratory specimens in accordance with ASTM Test Method D6925 shall be used.

iv. Saw – The saw shall be capable of producing three different notch sizes ranging from 0 to 50 mm. The width of the saw blade shall be < 3.5 mm.

v. Test Fixture—The loading frame shall consist of a loading rod and 2 sample support rods. The schematic of the test apparatus is shown in Figure 2. The diameters of the loading and supports rods shall be 25 mm and the anvil span shall be 127 mm.

vi. Reaction Surface Treatment—Polytetrafluoroethylene (PTFE) strips are used to reduce friction between the specimen and the lower two support rollers.

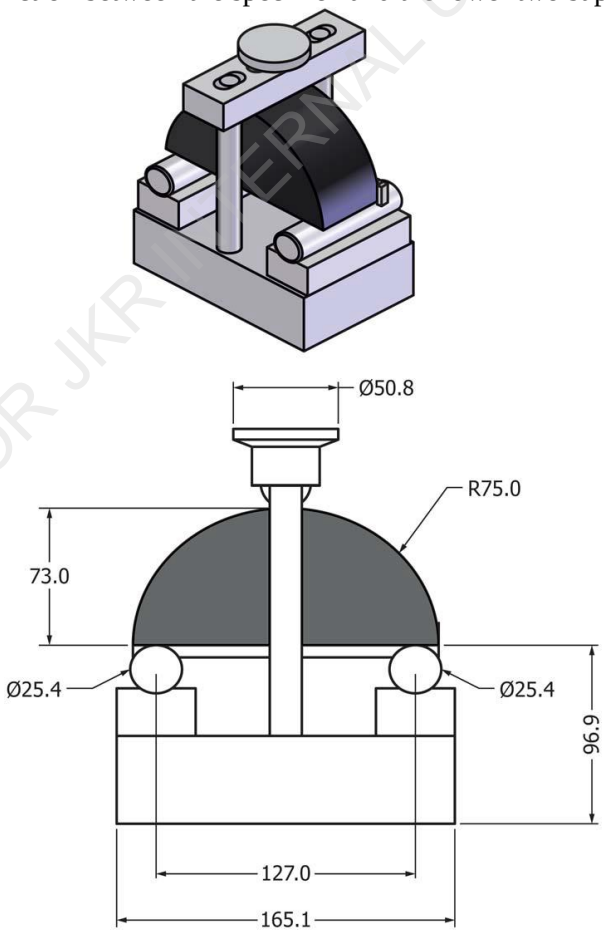


Figure 2 *Shop Drawing of SCB Test Fixture*

4.0 Sampling, Test Specimens, and Test Units

Semi-circular bend testing may be performed on field cores or laboratory prepared test specimens.

4.1 Laboratory-compacted asphalt mixture samples:

i. Specimen Size – The test specimens shall be 150 mm in diameter by 120 mm thick.

ii. Air Void Content – Prepare a minimum of 3 gyratory test specimens at the target air void content using the Superpave Gyratory Compactor (SGC) according to ASTM Test Method D6925 at the target air void content ± 0.5%. The typical air void target for the test specimens is 7.0 %.

iii. The semi-circular shaped specimens are prepared by first cutting a 150 mm diameter by 120 mm thick specimen into 2 equal circular samples 57 mm thick. These samples are cut along its central axis into 2 equal circular samples. The height (radius) of the 2 halves shall be within 1 mm of each other.[12]

4.2 Samples Cored from Asphalt Pavement:

i. Roadway cores can be used if pavement thickness is between 38 to 60 mm. Cores shall be taken full depth so that no prying action is needed to extract the cores from the pavement.

ii. Care shall be taken to avoid stress or damage to the interface during coring, handling, and transportation. The cores shall be trimmed such that only a single layer is tested.

iii. Roadway core specimens shall be approximately 150 mm diameter with all surface of the perimeter perpendicular to the surface of the core within 6 mm. If the thickness of the core being tested is greater than 57 mm, it shall be trimmed with a wet masonry saw to a height of 57 mm.

iv. The semi-circular shaped specimens are prepared by slicing the 150 mm diameter specimen prepared in 7.2.3 along its central axis into 2 equal circular samples. The height (radius) of the 2 halves shall be within 1 mm of each other.

Notching – A straight vertical notch is cut along the symmetrical axis of each semi-circular specimen. The location of the notch shall be in the center of the specimen within 0.3 mm. The three nominal notch depths are 25 mm, 32 mm, and 38 mm. The notch depth tolerance is ± 1.0 mm. The width of the notch shall be <3.5 mm.[13]

Aging – Laboratory-prepared test specimens shall be long term temperature-conditioned in according to AASHTO R30. Roadway cores need not be aged prior to testing.[14]

A minimum of 4 specimens shall be tested at each of the following notch depths: 25 mm, 32 mm, and 38 mm.

[12] *Some practitioners believe that the test should be conducted on specimens with 2 cut faces. If this approach is used, increase the compacted sample height by approximately 15 ± 5 mm such that the semi-circular shaped specimens with 2 cut faces have a final thickness of 57 ± 1 mm.*

[13] *Ruggedness testing between 4 laboratories has shown the J_c for split samples to have a within laboratory COV of 9.9 % for specimens with notch widths between 1.3 mm and 3.4 mm. The specimens should be symmetrical about the cut notch.*

[14] *A loose mix aging method is under development that may be able to achieve the AASHTO R30 level of aging in 12 to 24 h, NCHRP 9-54 Long Term Aging of Asphalt Mixtures for Performance Testing and Prediction. The long term temperature aging is needed to account for binder source, RAP, RAS and rejuvenators on mix performance (Reinke, et al., 2009, 2015, Cooper, et al. 2014, 2015).*

5.0 Procedure

i. Inspect the fixture to ensure all contact surfaces are clean and free of debris. Place the PTFE tape or pads to reduce friction caused by interactions between the specimen and testing fixture during loading. Depending on fixture geometry the PTFE pads can be placed either:
   - between the specimen and the bottom support rollers or,
   - with the specimen resting on the support rollers between the rollers and the base of the text fixture.

ii. Load the specimen in the fixture, ensuring the specimen is centered and making uniform contact (level) on the support rollers (as shown in Figure 3).

iii. Set the environmental chamber temperature and allow it to stabilize to the test temperature 60.3 ºC. A dummy specimen with a temperature sensor mounted to its center can be monitored to determine when the specimen reaches the test temperature 60.3 ºC. In the absence of a dummy specimen, the specimens should be placed in the environmental chamber set at the test temperature for a minimum of 2 ± 0.5 h to reach the required temperature equilibrium.

iv. Select test temperature based on the climatic intermediate temperature performance grade temperature as defined in AASHTO M320 or M332 and provided below in *Equation 3*:

$$PG\ IT = \frac{PG\ HT + PG\ LT}{2} + 4 \qquad \textit{(Equation 3)}$$

where:

$PG\ IT$ = Intermediate performance grade temperature (ºC),
$PG\ HT$ = Climatic high performance grade temperature, and
$PG\ LT$ = Climatic low performance grade temperature.

v. After temperature equilibrium is reached, apply a preload of 45 ± 10 N for a maximum duration of 30 s to specimen to ensure the sample is seated properly. After ensuring the sample is level, release the load.

vi. Begin to apply load to specimen in displacement control at a rate of 0.5 mm/min ensuring that time, force, and displacement are measured and recorded at a sampling rate of 10 Hz. Test may be terminated when the applied load decreases to 25% of the peak load.

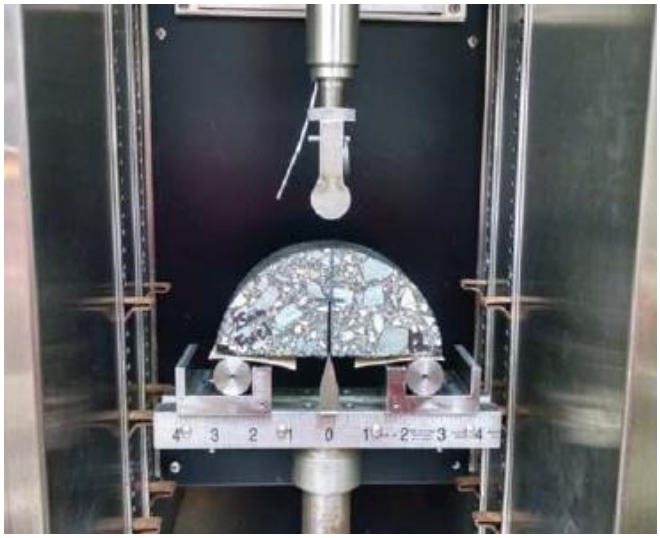
6.0 Calculation or Interpretation of Results

The critical value of *J*-integral (J_c) is determined using Equation 4:

$$J_c = \frac{-1}{b}\left(\frac{dU}{da}\right) \qquad \textit{(Equation 4)}$$

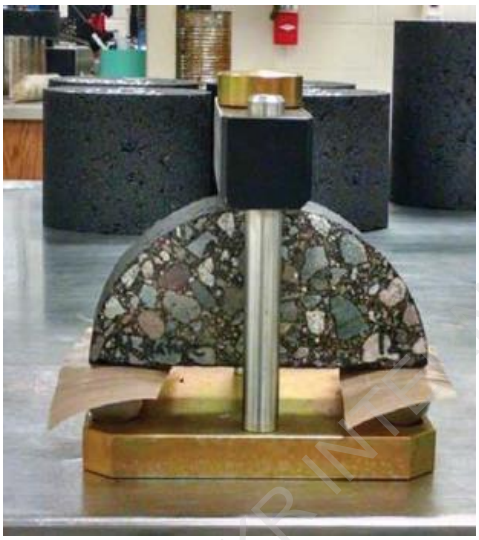
where:

J_c = critical strain energy release rate (kJ/m^2),
b = sample thickness (m),
a = notch depth (m),
U = strain energy to failure (kJ), and
dU/da = change of strain energy with notch depth (kJ/m).

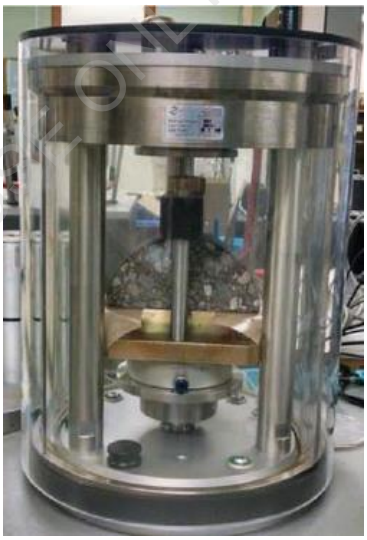


(a)

(b)



(c) Sample placed in Marshall fixture



(d) Fixture in AMPT

Figure 3 *Examples of SCB Test Fixtures for a Universal Testing Machine (a and b) and a Marshall Press (c) or AMPT (d)*

Appendix E - Hamburg Wheel-Tracking Test

1.0 Scope

This test method describes a procedure for testing the rutting and moisture-susceptibility of asphalt mixture pavement samples in the Hamburg Wheel-Tracking Device.

The method describes the testing of submerged, compacted asphalt mixture in a reciprocating rolling-wheel device. This test provides information about the rate of permanent deformation from a moving, concentrated load. A laboratory compactor has been designed to prepare slab specimens. Also, the Superpave Gyratory Compactor (SGC) has been designed to compact specimens in the laboratory. Alternatively, field cores having a diameter of 150 mm, 250 mm, or 300 mm, or saw-cut slab specimens may be tested.

The test method is used to determine the premature failure susceptibility of asphalt mixture due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage. This test method measures the rut depth and number of passes to failure.

The potential for moisture damage effects are evaluated since the specimens are submerged in temperature-controlled water during loading.

2.0 Referenced Documents

AASHTO Standards:

i. R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
ii. T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
iii. T 168, Sampling Bituminous Paving Mixtures
iv. T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
v. T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
vi. T 312, Preparing and Determining the Density of Asphalt Mixture (HMA) Specimens by Means of the Superpave Gyratory Compactor

3.0 Summary of Method

A laboratory-compacted specimen of asphalt mixture, a saw-cut slab specimen, or a core taken from a compacted pavement is repetitively loaded using a reciprocating steel wheel. The specimen is submerged in a temperature-controlled water bath of 40 to 50 ºC or a temperature specified for the binder being used. The deformation of the specimen, caused by the wheel loading, is measured.

The impression is plotted as a function of the number of wheel passes. An abrupt increase in the rate of deformation may coincide with stripping of the asphalt binder from the aggregate in the asphalt mixture specimen.

4.0 Apparatus

i. *Hamburg Wheel-Tracking Device* – An electrically powered machine capable of moving a 203.2 diameter, 47 mm wide steel wheel over a test specimen. The load on the wheel is 705 ± 4.5 N. The wheel reciprocates over the specimen, with the position varying sinusoidally over time. The wheel shall make 52 ± 2 passes across the specimen per minute. The maximum speed of the wheel shall be approximately 0.305 m/s and will be reached at the midpoint of the specimen.

ii. *Temperature Control System* – A water bath capable of controlling the temperature within ± 1.0 ºC over a range of 25 to 70 ºC. This bath shall have a mechanical circulating system to stabilize the temperature within the specimen tank.

iii. *Impression Measurement System* – A linear variable differential transducer (LVDT) device capable of measuring the depth of the impression of the wheel within 0.15 mm, over a minimum range of 0 to 20 mm. The system shall be mounted and capable of measuring the depth of the impression at different intervals across the width of the wheel's path on the test specimen. The impression shall be measured at least every 400 passes of the wheel. This system must be capable of measuring rut depth without stopping the wheel. This measurement must be referenced to the number of wheel passes.

iv. *Wheel Pass Counter* – A non-contacting solenoid that counts each wheel pass over the specimen. The signal from this counter shall be coupled to the wheel impression measurement, allowing for the rut depth to be expressed as a function of the wheel passes.

v. *Slab Specimen Mounting System* – A stainless steel tray that can be mounted rigidly to the machine. This mounting system must restrict shifting of the specimen to within 0.5 mm during testing. The mounting system shall suspend the specimen, allowing for free circulation of the water bath on all sides. The mounting system shall be designed to provide a minimum of 20 mm of free circulating water on all sides of the specimen.

vi. *Cylindrical Specimen Mounting System* – A stainless steel tray that can be mounted rigidly to the machine. This mounting system must restrict shifting of the specimen to within 0.5 mm during testing. The mounting system shall include 2 high-density polyethylene molds (as shown in Figures 4 and 5) placed in a stainless steel tray to secure the specimen. The stainless steel tray is suspended in the machine, allowing for free circulation of the water bath on all sides. The mounting system shall be designed to provide a minimum of 20 mm of free circulating water on all sides of the specimen.

vii. *Linear Kneading Compactor* – A hydraulic powered unit used to compact asphalt mixtures into rectangular slabs. The mixture is placed in a mold and compacted through a series of vertically aligned steel plates that compress the asphalt mixture into a flat slab of predetermined thickness and density.

viii. Balance of 12000 g capacity, accurate to 0.1 g.

ix. Ovens for heating aggregate and asphalt binders.

x. Superpave Gyratory Compactor (SGC) and molds conforming to T 312.

xi. Bowls, spoon, spatula, etc.

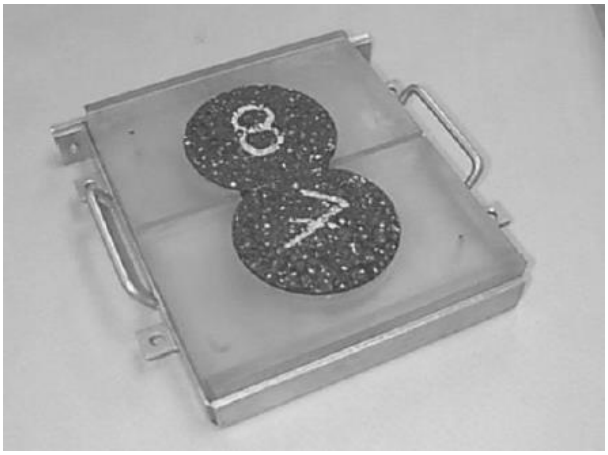
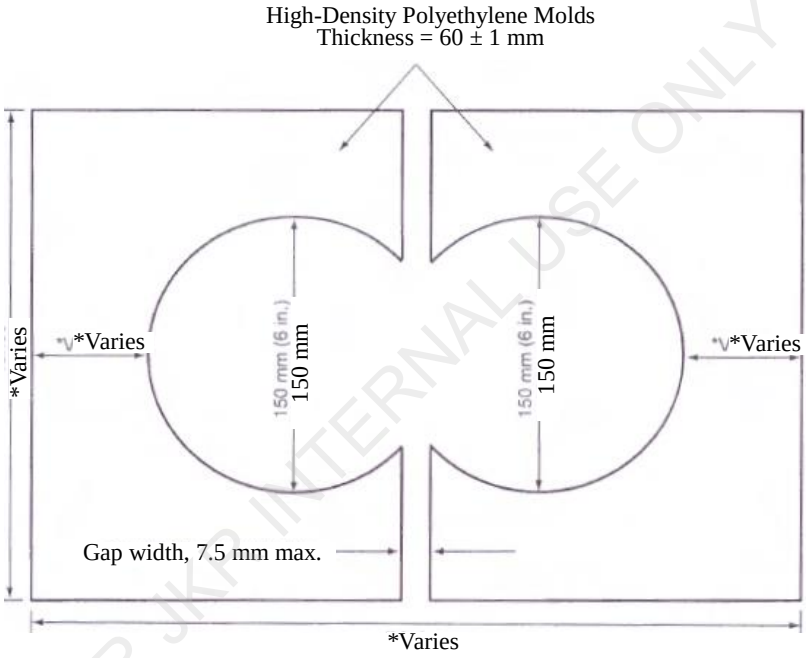


Figure 4 *Cylindrical specimen mounting system*



**Dimension may vary depends on manufacturer.*

Figure 5 *Schematic of Cylindrical Specimen Mounting System*

3.0 Specimen Preparation

2 test specimens shall be prepared for each test. Specimens may either be slab specimens or cylinders.

3.1 Laboratory-Produced Asphalt Mixture:

i. Mixture proportions are batched in accordance with the desired job mix formula.

ii. The temperature to which the asphalt binder must be heated to achieve a viscosity of 170 ± 20 cSt shall be the mixing temperature. For modified asphalt binders, use the mixing temperature recommended by the binder manufacturer.

iii. Dry-mix the aggregates and mineral admixture (if used) first; then add the correct percentage of asphalt binder. Mix the materials until all aggregates thoroughly coated. (Wet-mix the aggregates if a lime slurry or other wet material are used).

iv. Test samples shall be conditioned at the appropriate compaction temperature in accordance with the short-term conditioning procedure for mechanical properties in R 30.

v. The temperature to which the asphalt binder must be heated to achieve a viscosity of 280 ± 30 cSt shall be the compaction temperature. For modified asphalt binders, use the compaction temperature recommended by the binder manufacturer.

vi. Specimens compacted in the laboratory shall be either compacted slab specimens or SGC cylindrical specimens.

- Compacted Slab Specimens:
  Material shall be compacted into slab specimens using a Linear Kneading Compactor (or equivalent) and shall be 320 mm long and 260 mm wide. A slab specimen thickness of 38 mm to 100 mm can be used. The slab specimen thickness shall be at least twice the nominal maximum aggregate size. Compacted slab specimen shall be cooled at room temperature on a clean, flat surface until the specimen is cool to the touch.

- SGC Cylindrical Specimens:
  Material shall be compacted into specimens using an SGC according to T 312. A specimen thickness shall be at least twice the nominal maximum aggregate size. Two 150 mm diameter specimens are needed. Compacted specimens shall be cooled at room temperature on a clean, flat surface until the specimen is cool to the touch.

3.2 Field-Produced Asphalt Mixture – Loose Mix:

i. Obtain a sample of asphalt mixture in accordance with T 168.

ii. Specimens compacted in the laboratory shall be either compacted slab specimens or SGC cylindrical specimens as specify in 3.1 (vi).

3.3 Field-Produced Asphalt Mixture – Field Compacted (Core/Slab Specimen):

i. Cutting Field Cores or Field Slab Specimens – Field cores or field slab specimens shall consist of wet saw-cut compacted specimens taken from asphalt mixture pavements. Field cores shall be 300 mm, 250 mm, or 150 mm in diameter. Field slab specimens shall be wet saw-cut to approximately 260 mm wide by 320 mm long. A slab specimen thickness is typically 38, but may be adjusted to fit the specimen mounting system by wet saw-cutting. Field cores shall also be cut according to 3.4 (ii).[15]

ii. Cutting SGC Cylindrical Specimens and Field Cores – Cut specimens using a wet saw after a minimum of 24 hr from the time of compaction. Saw the specimens along a secant line (or chord) such that when joined together in the molds, there is no space between the cut edges. The amount of material sawed from the SGC cylindrical specimens may vary to achieve a gap width no greater than 7.5 mm between the molds.

[15] *Care should be taken to load the sample so it is level to the surface of the mold. The sample must be trimmed if it is too tall or shimmed up if it is too short (supporting with plaster if needed). The down pressure from the wheel is calibrated to be 705 N (158 lb) at the center, level to the top of the mold position. Even a small change in elevation will change the down pressure significantly.*

4.0 Determining Air Void Content

i. Determine the bulk specific gravity of the specimens in accordance with T 166.
ii. Determine the maximum specific gravity of the mixture in accordance with T 209.
iii. Determine the air void content of the specimens in accordance with T 269. It is recommended for laboratory-compacted specimens, that the target air void content be 7.0 ± 1.0%. Field specimens may be tested at the air void content at which they are obtained.

5.0 Procedure

i. Slab and Large Field Core Specimen Mounting:
Use Plaster-of-Paris to rigidly mount the 300 mm, 250 mm, or slab specimens in the mounting trays. Mix the plaster at approximately a 1:1 ratio of plaster to water. Pour the plaster to a height equal to that of the specimen so that the air space between the specimen and the sides of the mounting tray is filled. The slab specimen shall be in direct contact with the mounting tray; however, plaster may flow underneath the specimen. The plaster underneath the specimen shall not exceed 2 mm. Allow the plaster at least 1 h to set. If using other mounting material is used, it should be able to withstand 890 N of load without cracking.
ii. SGC Cylindrical and Field Core Specimen Mounting:
Place the high-density polyethylene molds in the mounting tray. Insert the cut specimens in the molds. Shim the molds in the mounting tray as necessary. Secure the molds into the mounting tray by thightening the bolts of the edge plate 'hand tight'.
iii. Place the mounting tray(s) with the test specimens into the device and secure by tightening the bolts 'hand tight'.
iv. Turn the testing device and computer on.
v. Start the software used to communicate with the testing device.
vi. Enter the pertinent project information and testing configuration requirements.
    a) Select the test temperature based on the applicable specifications.
    b) Select the maximum allowable rut depth based on the applicable specifications.
    c) Select the maximum number of passes based on the applicable specifications.
    d) Enter a start delay of 30 min to precondition the test specimens. The temperature of the specimens in the mounting tray shall be the test temperature selected in 5.0 (vi)(a) upon completion of this preconditioning period.
vii. Proceed to 5.0 (viii) to operate the testing device in "Auto" mode. Proceed to 5.0 (ix) to operate the testing device in "Manual" mode.[16]
viii. Performing the Test in Auto Mode:
    - Adjust the height of the LVDT to a location as per manufacturer's recommendations.[17]
    - Lower the wheels onto the edge of the test specimens such that a majority of the wheel is in contact with high-density polyethylene molds in the mounting tray.

[16] *Perform the test in "Auto" mode for testing devices manufactured in the United States later than 1998, where software will automatically open and close the valves to fill and drain the water bath. Devices made available to the United States prior to 1998 do not have this option and must be operated manually.*

[17] *The LVDT for each steel wheel is automatically zeroed at the start of the test. The software will display a zero at the start of the test.*

- Start the test by selecting the "Start" button of the testing device software.[18]
- The wheel-tracking device shall shut off when 20,000 passes have occurred or when the test has achieved the maximum impression depth established in 5.0 (vi)(b). The testing device software automatically saves the test data file.
- Raise the wheel(s) and remove the specimen mounting tray(s) and rutted specimens.
- Proceed to 5.0 (x).

ix. Performing the Test in Manual Mode:

- Close the drain valve(s) and fill the water bath of the wheel-tracking device with water until the float device(s) raises to a horizontal position.[19]
- Precondition the test specimens in the water bath for 30 min after the water has reached the selected test temperature.
- Lower the wheels onto the specimens after the test specimens have preconditioned at the selected test temperature for 30 min. For machines that start automatically after the selected preconditioning time, it is allowable to lower the wheels before the preconditioning cycle. The wheel shall not be in contact with the specimen for more than 5 min prior to starting the wheel.
- Ensure the micro-control unit's LVDT reads between 10 mm and 18 mm. Adjust the LVDT height to obtain this reading. Loosen the 2 screws on the LVDT mount and slide the LVDT up or down to the desired height. Tighten the screws.
- Start the test.
- The wheel-tracking device will disengage when 20,000 passes have occurred. The devise will also disengage if the average LVDT displacement (read from the micro-control unit, not the screen) is 40.90 mm or greater for an individual specimen. Note that the screen readout subtracts the initial LVDT reading from the total displacement.
- Open the valve(s) beneath the tanks and drain the water bath. Raise the wheel(s) and remove the specimen mounting tray(s) and rutted specimens.

x. Clean the water bath, heating coils, wheels, and temperature probe with water and scouring pads or per the manufacturer's recommendations. Use a wet-dry vacuum to remove particles that have settled to the bottom of the baths. Clean the filter element and spacers after every test or as per the manufacturer's recommendations. Do not use solvents to clean the water bath.

xi. Turn the wheels after each test, so the same section of the wheel surface is not in contact with the test specimen from test to test. This rotation will provide for even wear over the entire wheel. The test should operate with a smooth movement across the test specimen.

[18] *The start delay time or preconditioning time will start after the water heats to the test temperature selected in 5.0 (vi)(a).*

[19] *Adjust the amount of hot and cold water if necessary, as the water temperature may vary.*

6.0 Calculation

Plot the rut depth versus number of passes for each test. A typical plot of the output produced by the Hamburg Wheel-Tracking Device is shown in Figure 6. From this plot, obtain the following values:

- slope and intercept of the first steady-state portion of the curve, and
- slope and intercept of the second steady-state portion of the curve.

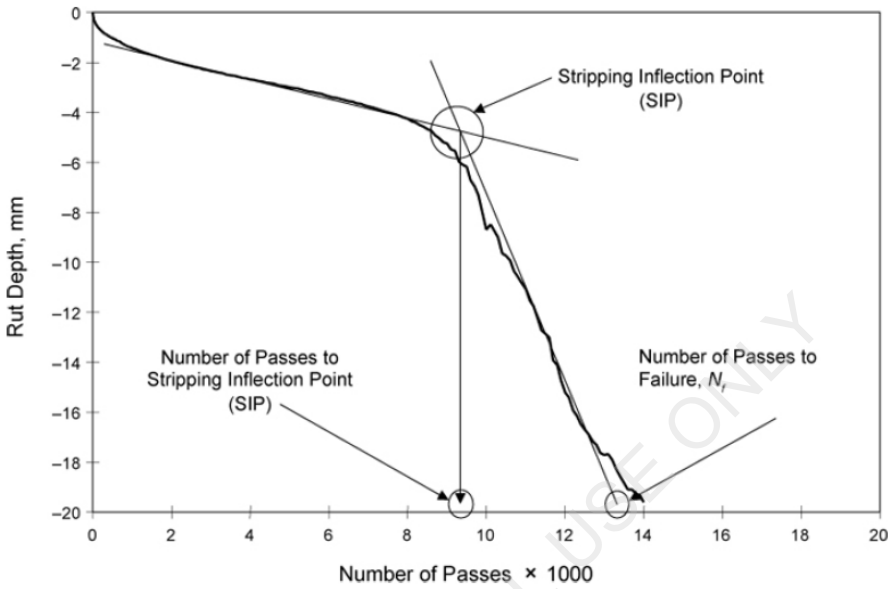


***Figure 6** Hamburg Curve with Test Parameters*

Calculate the following test parameters, all expressed in "Passes."

$$Stripping\ inflection\ point\ (SIP) = \frac{intercept\ (second\ portion) - intercept(first\ portion)}{slope\ (first\ portion) - slope\ (second\ portion)} \qquad \textit{(Equation 5)}$$

where:

Failure rut depth is the specified maximum allowable rut depth for the test.

7.0 Report

The report shall include the following parameters:

i. Asphalt mixture production (field or lab);
ii. Compaction method (slab or SGC cylindrical specimen);
iii. Number of passes at maximum impression;
iv. Maximum impression;
v. Test temperature;
vi. Specimen(s) air voids;
vii. Type and amount of anti-stripping additive used;
viii. Creep slope;
ix. Strip slope; and
x. Stripping inflection point.

Appendix F – Water Permeability Test of Asphalt Mixtures

1 Scope

This method is applicable to determinate the permeability coefficient of asphalt mixtures specimen prepared by rolling and to inspect asphalt pavement in field.

2.0 Apparatus and Materials

i. Pavement water permeameter: It's shape and dimension are shown as Figure 7; the measuring cylinder filled with water at the upper part is made of clear organic glass with a volume of 600 ml with graduation; at 100 ml and 500 ml, there are thick mark lines; the base is connected with the lower part through a ø 10 mm tubule with a valve in the middle. The measuring cylinder is coupled through the support and for the opening below the base, inside diameter is 150 mm and outside diameter is 220 mm. The apparatus is attached by 2 stainless steel rings, 5 kg for each and the inside diameter is 160 mm.
ii. Measuring cylinder and large funnel.
iii. Stopwatch.
iv. Sealing material: water-proof putty, putty or plasticine.
v. Others: water, chalk, plastic ring, scraper, broom, etc.

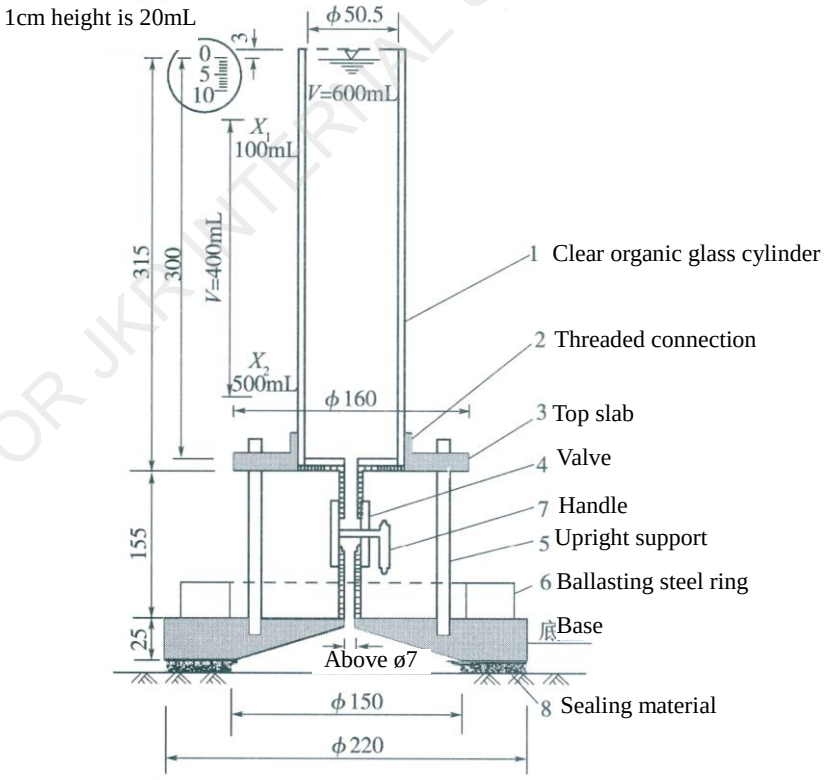


Figure 7 *Water Permeameter (Dimension Unit: mm)*

3.0 Procedure

i. Assemble and install pavement water permeameter.

ii. Prepare asphalt mixtures specimen according to preparation method of asphalt mixtures specimen (rolling method) of this specification, extracted from mold after being cooled down to the specified time and remove the paper on the surface at preparation of the specimen.

ii. Place specimen on a stable plane and plastic ring at the measuring points at the center of the specimen, draw 2 circles with a chalk along the inner side and outer side of the plastic ring and the part between the outer ring and the inner ring is the sealing area required to be sealed with sealing material.

iii. Make a sealing treatment to the annular seal area with sealing material and notice not to make the sealing material into the inner circle; if the sealing material enters by accident, tear it away with scraper. Pile the strip sealing material which is twisted into thumb shape at the center of the annular seal area and pile it into a circle.

iv. Erect the specimen at left and right sides with suitable cushion block or wood block. Place a water receptor below the specimen. Place the water permeameter on the measuring points of the specimen and superpose the water permeameter center to the ring center as much as possible, then press the water permeameter slightly on the surface of the strip sealing material and add the counterweight in case of pressure water outflowing from the part between the base and the specimen.

v. Close the valve, fill the measuring cylinder with water, then open the valve to make the water in the measuring cylinder flow downwards to remove the air in the bottom of the water permeameter; when the water surface in the measuring cylinder falls down slowly, press the water permeameter slightly with both hands to discharge all the bubbles at the bottom of the water permeameter. Close the valve and fill the measuring cylinder with water again.

vi. Open the valve and start the stopwatch immediately when the water surface falls to 100 ml and read and record the graduation of mesuring cylinder at an interval of 60 s until the water surface falls to 500 ml. In the test, if the water permeates from the parts between the base and the sealing material, it means the sealing between the base and pavement is poor and resealing is required. When the water surface falls at a slow rate, stop after the seepage amount is determined for 3 min; when the water surface falls at a fast rate and reaches 500 ml within 3 min, record the time when the water surface reaches 500 ml; if the water surface remains unchanged after falling at a certain height, it means to be basically watertight or watertight ultimately which shall be indicated in the report.

vii. 3 specimens made of the same materials shall be used to determine the permeability coefficient in accordance with the procedure above and take the average value as the test result.

4.0 Calculation

Permeability coefficient of asphalt mixtures specimen shall be calculated according to Formula (*Equation 6*), subject to the time required by the water surface from 100 ml to 500 ml; if the water penetration time is overlong, the water amount passed in 3 min may be adopted for calculation.

$$C_w = \frac{V_2 - V_1}{t_2 - t_1} \times 60 \qquad \textit{(Equation 6)}$$

Where:

C_w = The pavement permeability coefficient (ml/min);

V_1 = The water amount at the first timing (ml), 100 ml usually;

V_2 = The water amount at the second timing (ml), 500 ml usually;

t_1 = The time at the first timing (s);

t_2 = The time at the second timing (s).

5.0 Report

Report the permeability coefficient of each specimen point by point and the average value of 3 specimens. If the specimen is watertight, it shall be indicated in the report.