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RHD TECHNICAL SPECIFICATION FOR DENSE BITUMENOUS SURFACING: A COMPREHENSIVE REVIEW

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Abstract: **The Technical Specification represents a dynamic document, subject to continuous evolution through the ongoing inclusion or exclusion of the latest techniques and technologies over time. This study thoroughly examines the Third Edition of the Roads and Highways Department (RHD) Technical Specification (2016) pertaining to the production and placement of dense bituminous surfacing. The scope of modification is assessed based on current state-of-the-art technologies. Various elements of the existing specification, including minimum and maximum VMA requirements, VFA range, lift thickness, field density measurement system, aggregate gradation, and binder grading, appear to be inappropriate. This study identifies the inadequacies and proposes improvements such as restrictions on natural sand content, the use of hydrated lime, incorporation of the Baily method in aggregate blending, Apparent Film Thickness requirements, Gmm criteria, HMA performance tests, and statistics-based quality acceptance. These enhancements are expected to significantly enhance the assurance of bituminous surfacing performance. Furthermore, introducing a certain level of flexibility in specification requirements related to census and strength properties of aggregates, considering the design traffic environment and layer position, could optimize performance, economics, and sustainability.**

Keywords: **VMA, VFA, lift thickness, hydrated lime, Baily method and performance test.**

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1. INTRODUCTION

Presently, the bituminous paving mixes are generally produced and placed in flexible pavement under RHD road network as specified in RHD Technical Specifications (RTS), Third Edition, 2016. As Technical Specification is a live document, its evolution through inclusion or exclusion of the latest techniques and technologies is inevitable as former Chief Engineer of RHD Mr. Ibne Alam Hasan has mentioned in the Preface of 3rd Edition of the RHD Technical Specification "This Specification, I believe, will undergo further refinement based on the lessons from filed applications and technological innovations". It is a guideline for RHD Engineers, consultants and contractor to construct good performing and economic bituminous or asphaltic surfacing or hot mix asphalt (HMA). Ultimate pavement performance is related to durability, impermeability, strength, stability, stiffness, flexibility, fatigue resistance and workability (MS-2, 2014). A properly designed asphalt mixture provides a balance of engineering properties and economics. Specification provisions should have ample opportunity to explore new alternatives as well as some preference for ensuring maximum performance of the product. Considering design traffic level, environment force and position of HMA layer, the requirements of census and source (strength) properties of aggregates can be optimized. 95% by weight of the HMA mixture is aggregate which are acquired from nature which is scares. Most of the aggregate materials using in RHD road network are exported. Therefore, flexibility in specification requirement by conforming certain level of performance could create opportunity to use local marginal aggregates with or without modification. Opportunities of better performing mix production with economics and sustainability are explored in this study. General understanding is Good-performing asphalt mixtures should have high binder content and low air voids (to have high durability), and smaller nominal size (to avoid segregation). RHD pavements have been failed prematurely with cracking, rutting, ravelling and pothole even after obeying all specification requirements. Hence, there are several problems are inherent in RTS, which are evaluated in this study.

2. MATERIALS

HMA mixtures are complex materials composed of mineral aggregates and asphalt binder. 95 percent by weight of the HMA mixture is aggregate. So, the coarse and fine aggregate properties influence pavement performance significantly (White et al., 2006). HMA pavement rutting and stripping can be directly related to improper selection and use of aggregates (Kandhal and Parker, 1998).

2.1 Coarse Mineral Aggregate (CA)

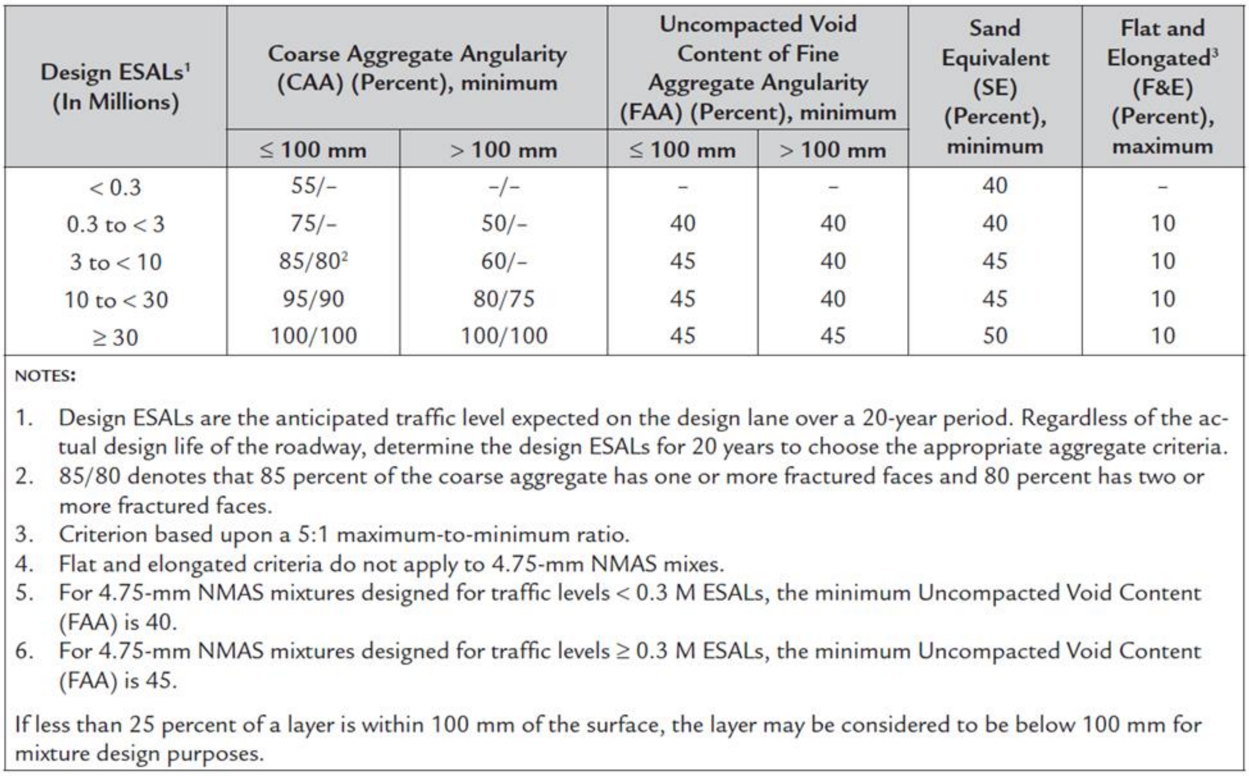
The aggregate retained on the 4.75 mm sieve is known as coarse aggregate which could be crushed stone or crushed gravel. RTS has specified two census properties of CA regardless design traffic volume and layer's position as Flakiness index (An aggregate is classified as being flaky if it has a thickness or smallest dimension of less than 0.6 of its mean sieve size) should not exceed 30% and at least two fractured faces should not less than 90% for crushed gravel. Energy efficient CA selection could be attained if it is possible to follow MS-2, 2014 recommendation for fracture faces considering design ESALs and position of bituminous course which is presented in Table 1, i.e. 85% one or more fractured faces and 80% two or more fracture faces would be required for wearing or binder course and only 60% one or more fractured faces could be enough for base course in case of 3 to 10 million ESAL. MS-2 is more conservative and has limited flat and elongated (F&E) (based upon 5:1 maximum-to-minimum ration) proportion 10%. F&E increases aggregate breakdown during handling, mixing, and placement, which most likely undesirable in HMA but some level of F&E may be desirable to meet minimum Void in Mineral Aggregate (VMA) requirements (Prowell et al., 2005). However, Kandhal and Parker, 1998 have criticized due to the extremely variability of current test for F&E (ASTM D4791) and its neither conformity of measure flat particle nor elongated particle but only ratio between thickness and length of the aggregate and preferred flat or elongated 2:1 ratio (FOE21) which is close to the cubical shape and yield more numerical value for fatigue and rutting model. Rutting and resistance to fatigue cracking increases with increasing FOE21. FOE21 value of 50 percent appears to be a reasonable upper limit for specification purposes (White et al., 2006). Uncompacted Void Content of Coarse Aggregate (CA_UVC) and FOE21 are good predictors of bituminous mixture performance. CA_UVC increases, HMA mixture resistance to fatigue cracking increases. CA_UVA seems preferable because it is typically less time consuming than the FOE21 test and can capture information related to particle shape and texture. It is recommended that CA_UVC 40% minimum for less than 1 million ESAL and CA_UVC 45% minimum for more than 1 million ESAL (White et al., 2006). RHD specification should be switched with either CA_UVC or FOE21 from flakiness index.

Though source properties (Aggregate Crushing Value-ACV, Los Angeles Abrasion-LAA and Sodium Sulfate Soundness) are different for wearing and base course in RST but traffic volume is not incorporated as MS-2 recommendation as Table 2. The Micro-Deval (AASHTO T327 or ASTM D6928) and Magnesium Sulfate tests (AASHTO T104 or ASTM C88) could be used in all climates and for all materials. These tests may be important in high moisture climates. The Micro-Deval test is more precise than the Sulfate soundness tests. Therefore, the Micro-Deval test should replace Sulfate soundness test for measuring aggregates' resistance to abrasion, wetting and drying, and slaking (Prowell et al., 2005). A maximum value of 15 and 20 percent for Micro-Deval and $MgSO_4$, respectively, are recommended for all traffic levels for Durability/ Toughness (White et al., 2006).

2.2 Fine Mineral Aggregate

The aggregate passing on the 4.75 mm sieve is known as fine aggregate which could be crushed natural sand, stone screenings, or a combination of both. Sand equivalent (%) minimum value and Sulfate soundness (%) maximum value could be modified as a function of design ESAL rather than single value 50% and 15% respectively in the RST. Though, the methylene blue (AASHTO TP57) value appears to be a better indicator of harmful clays in fine aggregate than is the sand equivalent test (Prowell et al., 2005). Fine aggregate angularity (FAA) ensures a high degree of internal friction and rutting resistance, which is defined as the percent of air voids present in loosely compacted aggregates smaller than the #8 sieve (2.36 mm). The test method is specified in AASHTO T 304, "Uncompacted Void Content of Fine Aggregate (FA_UVC)". This property is influenced by particle shape, surface texture and grading. Higher void contents typically mean more fractured faces (MS-2, 2014). FA_UVC must be incorporated in RTS for HMA as a function of design traffic. The specification restricted maximum 15% natural sand but this restriction could be modified with function of layer position from 10 to 15%. It is recommended to use maximum 10% in the BC binder and wearing courses (layers within 100 mm of the road surface) to minimize rutting problem (Kandhal et al., 2010).

Table 1: Aggregate Consensus Property Requirements (MS-2, 2014)



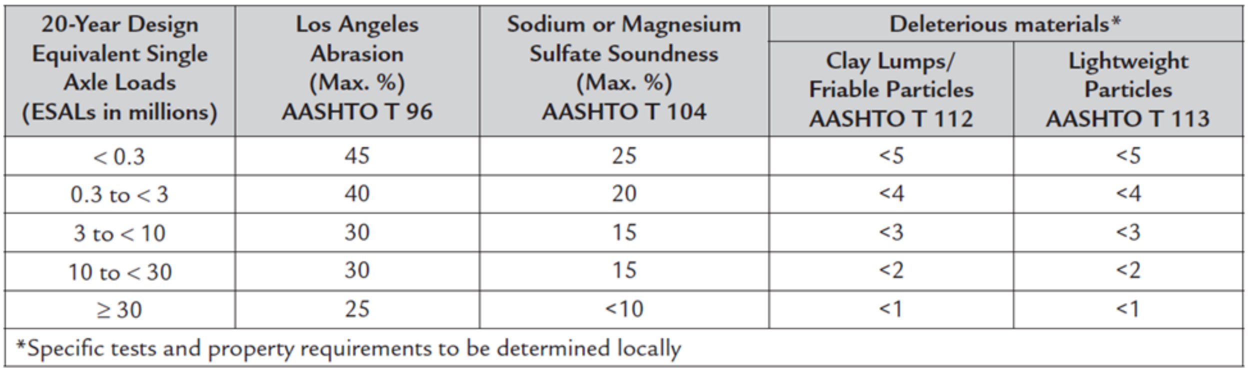
Design ESALs[1] (In Millions)	Coarse Aggregate Angularity (CAA) (Percent), minimum		Uncompacted Void Content of Fine Aggregate Angularity (FAA) (Percent), minimum		Sand Equivalent (SE) (Percent), minimum	Flat and Elongated[3] (F&E) (Percent), maximum
	≤ 100 mm	> 100 mm	≤ 100 mm	> 100 mm		
< 0.3	55/–	–/–	–	–	40	–
0.3 to < 3	75/–	50/–	40	40	40	10
3 to < 10	85/80[2]	60/–	45	40	45	10
10 to < 30	95/90	80/75	45	40	45	10
≥ 30	100/100	100/100	45	45	50	10

NOTES:

1. Design ESALs are the anticipated traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years to choose the appropriate aggregate criteria.
2. 85/80 denotes that 85 percent of the coarse aggregate has one or more fractured faces and 80 percent has two or more fractured faces.
3. Criterion based upon a 5:1 maximum-to-minimum ratio.
4. Flat and elongated criteria do not apply to 4.75-mm NMAS mixes.
5. For 4.75-mm NMAS mixtures designed for traffic levels < 0.3 M ESALs, the minimum Uncompacted Void Content (FAA) is 40.
6. For 4.75-mm NMAS mixtures designed for traffic levels ≥ 0.3 M ESALs, the minimum Uncompacted Void Content (FAA) is 45.

If less than 25 percent of a layer is within 100 mm of the surface, the layer may be considered to be below 100 mm for mixture design purposes.

Table 2: Recommended Superpave Source Property Tests and Typical Requirements (MS-2, 2014)



20-Year Design Equivalent Single Axle Loads (ESALs in millions)	Los Angeles Abrasion (Max. %) AASHTO T 96	Sodium or Magnesium Sulfate Soundness (Max. %) AASHTO T 104	Deleterious materials*	
			Clay Lumps/ Friable Particles AASHTO T 112	Lightweight Particles AASHTO T 113
< 0.3	45	25	<5	<5
0.3 to < 3	40	20	<4	<4
3 to < 10	30	15	<3	<3
10 to < 30	30	15	<2	<2
≥ 30	25	<10	<1	<1

*Specific tests and property requirements to be determined locally

2.3 Mineral Filler

Mineral filler is consisting of rock dust, Portland cement, hydrated lime, silica cement and even the baghouse dust of HMA plant which should be non-plastic and free from objectionable material. A certain amount of mineral filler is necessary for good rut resistance and durability; adding mineral filler to a mix design will normally tend to reduce VMA, decreases permeability for the same in-place air void content; subsequently binder age hardening and water infiltration are reduced in mixtures with lower permeability, leading to improved durability and greater resistance to moisture damage (NCHRP Report 673, 2012). Both lime and cement could increase Marshall stability, resilient modulus, tensile strength and resistance to moisture damage of mixtures but hydrated lime had better results than Portland cement due to its superior anti-stripping and antioxidant properties (Bihery, 2013 & Fakhri and Kheiry, 2008). Another research showed that hydrated lime as mineral filler has improved the permanent deformation characteristics and fatigue endurance of the asphaltic concrete mixtures (Mohammad et al., 2000). IRC has encouraged to use 2% hydrated lime by total weight of aggregate and percentage of fine aggregate reduction accordingly (IRC 111, 2009). MS-2, 2014 is recommended ranges from 0.5 to 1.5 percent by dry weight of aggregate. Hydrated lime replacing negative ion of aggregate surface by positive calcium ion resulting better asphalt-aggregate adhesion. Fine particles sized less than 10–20 µm in the filler is expected to act as an asphalt extender (MS-2, 2014). RHD specification has also encouraged to use hydrated lime powder or Portland cement filler limiting by 2% of dry weight of aggregate but could emphasis on using hydrated lime with need based dosage if the designed mix fails the Moisture Susceptibility test (AASHTO T 283).

2.4 Binder Material

RTS has four Penetration Grade Bitumen or asphalt cement 40/50, 60/70, 80/100 and 180/200. 60/70 penetration grade bitumen is the most common to use for bituminous surfacing. [Fig. 1] shows that 60-70 penetration grade bitumen (Type C) could have very low viscosity at 135^0 C, which may cause tender mix problems. Indian Highway Agency has been using Viscosity grading which is based on a fundamental, scientific viscosity test conducted at 60^0 C (near the maximum pavement temperature during summer) and its measurement unit is poise. Viscosity grades bitumen were suitable for a wide range of temperatures: 25^0 C for ravelling/fatigue cracking; 60^0 C for rutting; and 135^0 C for construction. Viscosity grading system, although more rational than the penetration grading system, but still based on experience (Kandhal, 2007). Superpave-performance grading (PG) system for bitumen, which is based on engineering principles to address common asphalt pavement distress problems. Polymer modified bitumen is suitable for highly-trafficked roads (Kandhal et al., 2010). Several researchers suggested that only one PG binder could cover whole Bangladesh, therefore shifting penetration grading to performance grading would be wiser rather than to Viscous Grading (VG). Binder modification option also should be introduced in RTS.

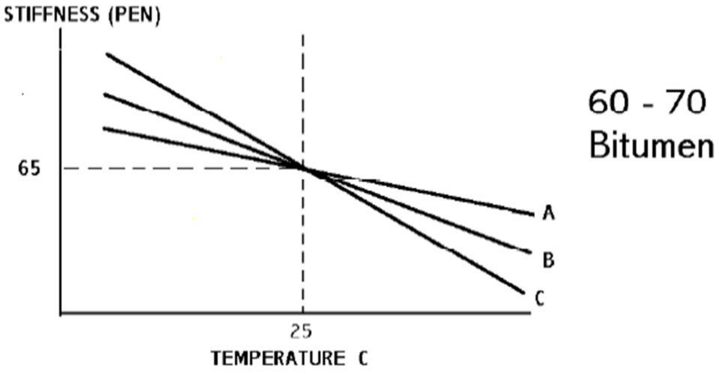


Figure 1: Three 60-70 penetration grade bitumen with different stiffness at high and low service temperatures (Kandhal, 2007)

3. HMA MIX DESIGN

According to this Specification, the surface shall consist of one or two layers; in case of two layers surfacing the top layer is denoted as wearing course and lower layer as the base course. There are three distinctive mix classifications (1, 2, 3) for wearing and base course with specific lift thickness. Apparently, the provision of intermediate course or binder course is absent in the RTS. The direction of laying bituminous mix in two courses in case of surfacing thickness exceeding 75 mm, actually limits the maximum thickness to 125 mm (maximum base and wearing course thickness 75 mm and 50 mm respectively) of bituminous layer for flexible pavement of RHD. The performance criteria of wearing, binder and base course are distinctive. Therefore, considering the design of pavement for heavy traffic with thicker bituminous layer, inclusion of binder course in RTS is necessary.

Wearing course directly exposes to traffic and environment force, therefore it requires high resistance to load-induced rutting, shoving and surface cracking; high resistance to thermally induced cracking; low permeability; high durability to resist disintegration due to combined effects of aging and traffic loading; appropriate surface texture for noise control; adequate friction for wet weather safety and smoothness for riding comfort. These properties are mostly counter-factual to each other. Since intermediate/binder courses are close to the surface of the pavement, they must be resistant to rutting, can be constructed with mixtures having lower binder contents than surface courses because the intermediate course is not directly subjected to traffic loading or the damaging effects caused by water and oxidative hardening of asphalt binder. Base course is the primary load-carrying element in deep-strength flexible pavements, do not have to be highly rut resistant. Base course mixtures should be relatively easy to compact to ensure that the base course is durable and resistant to bottom-up fatigue cracking. Pavements with higher traffic levels require surface and base courses with greater resistance to fatigue cracking. Permanent deformation (rutting) within flexible pavement is usually confined to the top 100 to 150 mm of the pavement, which means both the binder and wearing course mixes should be designed to be resistant to rutting (Kandhal et al., 2010).

Kandhal et al., 1993 observed that the bituminous pavements in the US were achieving densities under heavy truck traffic with high tyre pressures significantly higher than those obtained in the laboratory using 75- blow Marshall compactor. In other words, the pavement density after 2-3 years' traffic was greater than 75-blow Marshall laboratory design density. Increasing the number of blows above 75 and introducing Refusal density concept (300, 400 blow) could not help because it simply caused aggregate breakdown (degradation) under the impact type Marshall hammer compaction; which has no resemblance to actual degrades under roller and traffic. Moreover, the extent of degradation varies from aggregate to aggregate depending on their toughness and mix could cool fast, which are variables. It is suggested that to use 0.2 to 0.3% less binder which is determined by 75 Marshal blow with 4% air void for very heavy traffic road because Superpave volumetric mix design is generally less than that obtained by conventional Marshall design by 0.2 to 0.3 percent (Kandhal et al., 2010). In HMA design, the Maximum Specific Gravity of the bituminous mix (G_{mm}) should not be calculated by a formula from the specific gravity values of individual aggregates and bitumen; rather, it should be measured directly by using ASTM D 2041.

3.1 Nominal Maximum Aggregate Size (NMAS)

Only two nominal maximum size of Aggregates (NMAS) 20 mm and 12.5 mm are allowed in RHD Specification but different road agencies have found other NMAS aggregates as 37.5 mm, 12.5 mm, 9.5 mm and 4.75 mm are also performing well in different courses. Smaller NMAS mixtures can be placed in thinner layers, have higher binder contents when compacted to the same in-place air void content, have lower permeability (Fig. 2) than larger NMAS mixtures (NCHRP Report 673, 2012). The finer aggregate blends (4.75 to 12.5 mm) are normally used in the wearing surface for achieving a smoother surface or lower IRI value after placement, while the larger-sized mixtures are used in the lower asphalt layers either as an intermediate or base layer (Von Quintus and Hughes, 2019). The permeability of mixtures mainly depends on percent air voids, nominal maximum size of aggregate and the type of gradation. At a given air void content, the 19.0 mm NMAS mixes showed significantly higher permeability values than the 9.5 and 12.5 mm NMAS mixes. Also, the 25.0 mm NMAS mixes had about three times higher permeability value than the 19.0 mm NMAS mixes which is clearly observed in Fig. *2 (Khosla and Sadasivam, 2005).*

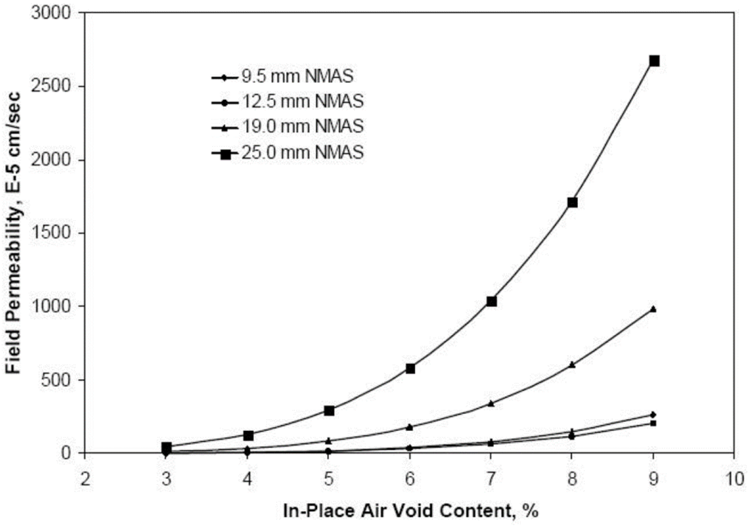


Figure 2: Effect of Nominal Maximum Size on Field Permeability (Khosla and Sadasivam, 2005)

Von Quintus and Hughes has cited that the pavements subjected to very heavy loads, high tire pressures, or combinations of punching and standing loads, stiff mixtures with an increased resistance to indentation, abrasion, and deformation can be achieved by including 37.5 mm crushed stone in the mix. In addition, the use of larger size stone reduces the aggregate surface area and increases the volume concentration of aggregate. Both factors contribute to a reduction in the design binder content and improve the economic features of the mixture (Acott, 1986). Three principal challenges may arise when using large maximum size aggregate for heavy-duty pavements: segregation, aggregate fracture and equipment wear for rolling large-stone mixtures to obtain adequate density (Button et al., 1997). Modified Marshal Method using 150 mm diameter specimen as per ASTM D 5581 should be used in case of aggregate NMAS more than 25 mm but Modified Marshal hammer and mould are not readily available in Bangladesh. A maximum of 5% aggregate particles between 25 mm and 37.5 mm may result in less of a segregation problem, which can be evaluated during pre-construction compaction trials (Overseas Road Note 19, 2002).

Considering pavement performance as durability, impermeability, strength, stability, stiffness, flexibility, fatigue resistance and workability, Kandhal, 2016 proposed four dense graded mixes which can be accommodated in RHD technical Specification of HMA:

- ✓ Base Course: DBM Grading 2 (nominal aggregate size 25 mm)
- ✓ Binder Course: BC Binder Grading (nominal aggregate size 19 mm)
- ✓ Wearing Course BC: Grading 1 (nominal aggregate size 12.5 mm) for heavy traffic road
- ✓ Wearing Course BC: Grading 2 (nominal aggregate size 9.5 mm) for light to medium traffic and urban area

3.2 Gradation

There are four types of aggregate gradation: dense-graded, fine-graded, coarse graded, and open-graded which is presented in Fig. 3. Dense-graded mixtures can be used with all traffic level (NCHRP Report 673, 2012). If the percent passing the primary control sieve is equal to or greater than the specified value in Table 3, the mixture classifies as a fine mixture; otherwise it classifies as a coarse mixture. Fine mixtures have smoother surface texture, lower permeability for the same in-place density, and can be placed in thinner lifts than coarse mixtures (NCHRP Report 673, 2012). Although in the past it was believed that relatively coarse-graded mixtures with large NMAS provide optimum rut resistance, more recent research has suggested that equal or even better rut resistance can be obtained using fine-graded mixtures with 9.5- or 12.5-mm NMAS aggregate gradations (Timm et al., 2006). Adopting of aggregate gradation procedure of Superpave method in Marshall method significantly improves rutting resistance, due to more interlock and more stiffness (Al-Humeidawi, 2016). Gradation comparison is shown in Table 4 it can be observed that in case of RHD base course gradation goes outside of superpave control point but IRC binder course seems fit within it for NMAS 19 mm aggregate size. In case of NMAS 12.5 mm aggregate both specification obeyed superpave gradation. For very heavy traffic levels, Gap Graded HMA mixtures (Stone Mastic Asphalt-SMA) will provide the best performance with the greatest assurance of a long pavement life and for intermediate to high traffic levels, carefully designed dense-graded HMA mixtures should perform well in surface course (NCHRP Report 673, 2012). Mix type can be selected by following Table 6, i.e. fine and course graded mix could be used in base and binder course in all traffic condition; conversely only course graded mix could be used in surface/wearing course in case of high traffic (more than 10 million).

The application of Bailey method of gradation analysis showed that the permeability is greatly influenced by the aggregates of 4.75mm, 2.36mm and 1.18mm sizes. The guidelines recommend a low proportion of #4 size aggregates and high proportion of #8 and # 16 size aggregates for low permeable mixtures. The higher proportions of 1/2" and 3/8" aggregates can be used to ensure the discontinuity of smaller voids. (Khosla and Sadasivam, 2005)

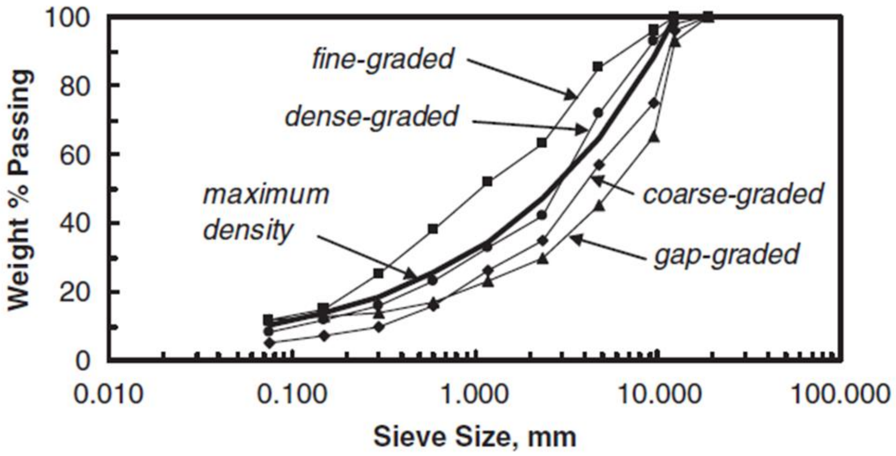
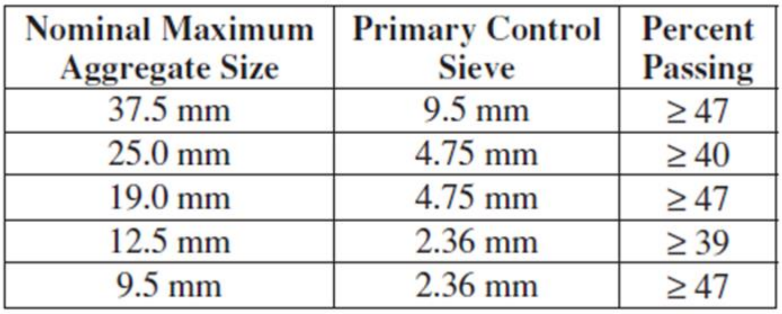


Figure 3: Types of HMA aggregate gradations; heavy black line represents maximum density gradation (NCHRP Report 673, 2012).

Table 3: Definition of fine, dense-graded HMA mixtures (AASHTO M323) (NCHRP Report 673)



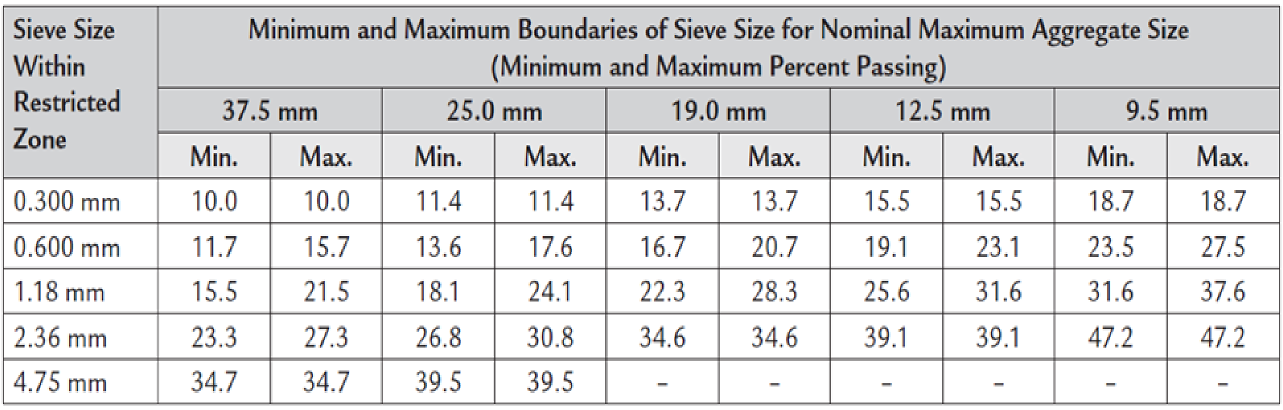
Nominal Maximum Aggregate Size	Primary Control Sieve	Percent Passing
37.5 mm	9.5 mm	≥ 47
25.0 mm	4.75 mm	≥ 40
19.0 mm	4.75 mm	≥ 47
12.5 mm	2.36 mm	≥ 39
9.5 mm	2.36 mm	≥ 47

Table 4: Four Dense mix gradation (MS-2, 2014 & Kandhal, 2016)

	NMAS=25mm				NMAS=19mm						NMAS=12.5mm						NMAS=9.5mm			
	Superpave		IRC_DBM		RHD Specification		Superpave		IRC_BC Binder		RHD Specification		Superpave		IRC_BC-1 Wearing		Superpave		IRC_BC-2 Wearing	
Seive size, mm	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
37.5	100		100																	
25	90	100	90	100	100		100		100											
19		90	71	95	90	100	90	100	90	100	100		100		100					
12.5			56	80				90	59	79	85	100	90	100	90	100	100		100	
9.5					55	82			52	72	70	90		90	70	88	90	100	90	100
4.75			38	54	35	57			35	55	52	72			53	71		90	55	75
2.36	19	45	28	42	20	40	23	49	28	44	40	58	28	58	42	58	32	67	40	55
1.18					15	33			20	34	30	48			34	48			29	44
0.6					10	26			15	27	20	38			26	38			21	33
0.3			7	21	6	20			10	20	14	28			18	28			14	25
0.15					5	13			5	13	8	20			12	20			7	15
0.075	1	7	2	8	3	7	2	8	2	8	6	10	2	10	4	10	2	10	4	7
Binder Content			min 4.5%		4-6%				min 5.2%		5-7%				min 5.4%				min 5.7%	

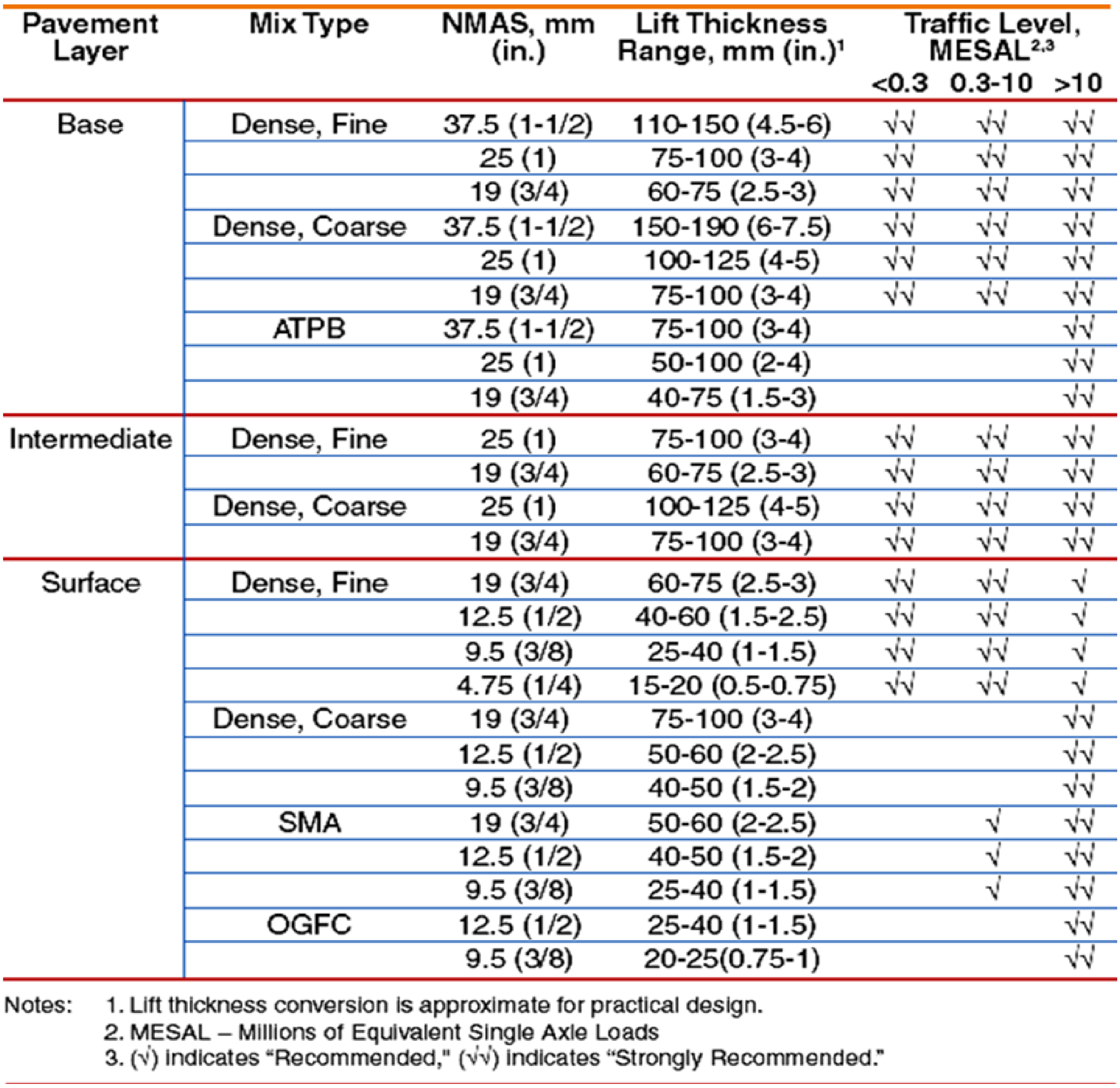
Use of the restricted zone which originally be specified to limit the amount of natural rounded sand is not compulsory. But particle size distributions which pass below the restricted zone will normally provide the most effective material for roads carrying very heavy traffic and for severe sites (Overseas Road Note 19, 2002). Restricted zone has been removed from most current Superpave specifications (MS-2, 2014 & Kandhal, 2016).

Table 5: Restricted Zone Boundaries (MS-2, 2014)



Sieve Size Within Restricted Zone	Minimum and Maximum Boundaries of Sieve Size for Nominal Maximum Aggregate Size (Minimum and Maximum Percent Passing)									
	37.5 mm		25.0 mm		19.0 mm		12.5 mm		9.5 mm	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
0.300 mm	10.0	10.0	11.4	11.4	13.7	13.7	15.5	15.5	18.7	18.7
0.600 mm	11.7	15.7	13.6	17.6	16.7	20.7	19.1	23.1	23.5	27.5
1.18 mm	15.5	21.5	18.1	24.1	22.3	28.3	25.6	31.6	31.6	37.6
2.36 mm	23.3	27.3	26.8	30.8	34.6	34.6	39.1	39.1	47.2	47.2
4.75 mm	34.7	34.7	39.5	39.5	–	–	–	–	–	–

Table 6: Mix type selection guide for long-life HMA pavements (Newcomb and Hansen, 2006)



Pavement Layer	Mix Type	NMAS, mm (in.)	Lift Thickness Range, mm (in.)¹	Traffic Level, MESAL²,³		
				<0.3	0.3-10	>10
Base	Dense, Fine	37.5 (1-1/2)	110-150 (4.5-6)	√√	√√	√√
		25 (1)	75-100 (3-4)	√√	√√	√√
		19 (3/4)	60-75 (2.5-3)	√√	√√	√√
	Dense, Coarse	37.5 (1-1/2)	150-190 (6-7.5)	√√	√√	√√
		25 (1)	100-125 (4-5)	√√	√√	√√
		19 (3/4)	75-100 (3-4)	√√	√√	√√
	ATPB	37.5 (1-1/2)	75-100 (3-4)			√√
		25 (1)	50-100 (2-4)			√√
		19 (3/4)	40-75 (1.5-3)			√√
Intermediate	Dense, Fine	25 (1)	75-100 (3-4)	√√	√√	√√
		19 (3/4)	60-75 (2.5-3)	√√	√√	√√
	Dense, Coarse	25 (1)	100-125 (4-5)	√√	√√	√√
		19 (3/4)	75-100 (3-4)	√√	√√	√√
Surface	Dense, Fine	19 (3/4)	60-75 (2.5-3)	√√	√√	√
		12.5 (1/2)	40-60 (1.5-2.5)	√√	√√	√
		9.5 (3/8)	25-40 (1-1.5)	√√	√√	√
		4.75 (1/4)	15-20 (0.5-0.75)	√√	√√	√
	Dense, Coarse	19 (3/4)	75-100 (3-4)			√√
		12.5 (1/2)	50-60 (2-2.5)			√√
		9.5 (3/8)	40-50 (1.5-2)			√√
	SMA	19 (3/4)	50-60 (2-2.5)		√	√√
		12.5 (1/2)	40-50 (1.5-2)		√	√√
		9.5 (3/8)	25-40 (1-1.5)		√	√√
	OGFC	12.5 (1/2)	25-40 (1-1.5)			√√
		9.5 (3/8)	20-25(0.75-1)			√√

Notes: 1. Lift thickness conversion is approximate for practical design.
2. MESAL – Millions of Equivalent Single Axle Loads
3. (√) indicates "Recommended," (√√) indicates "Strongly Recommended."

3.3 Volumetric Design of HMA

RHD Specification specified air void in mix 3-5% for both wearing and base course with Marshal blow in both side of 50 for light to medium traffic and 75 for heavy traffic. NCHRP Report 673 suggested 4% air void for surface course and intermediate (binder) course mixes. However, the design air void content for these mixtures is allowed to vary from 3.5% to 4.5%.

The lower design air void content of 3.5% will result in an increase in binder content of a few tenths of a percent and a mixture that is slightly easier to compact and increasing of 0.5% air void will have the opposite effect—it will slightly decrease the design binder content and produce a mix that is more difficult to compact, while increasing rut resistance. Rich bottom or base course mixes should be designed at a slightly lower air void content of 3.0 to 4.0%, as this layers are located deep within the pavement structure, the decrease in rut resistance caused by a lower design air void content is not normally a major concern. A minimum void content of 3 percent is specified because air voids below this level can result in poor mix stability and flushing/bleeding. Texas DOT recommends a design air void level of 3% to include more asphalt for asphalt base layers in its long-life pavements (Von Quintus and Hughes, 2019).

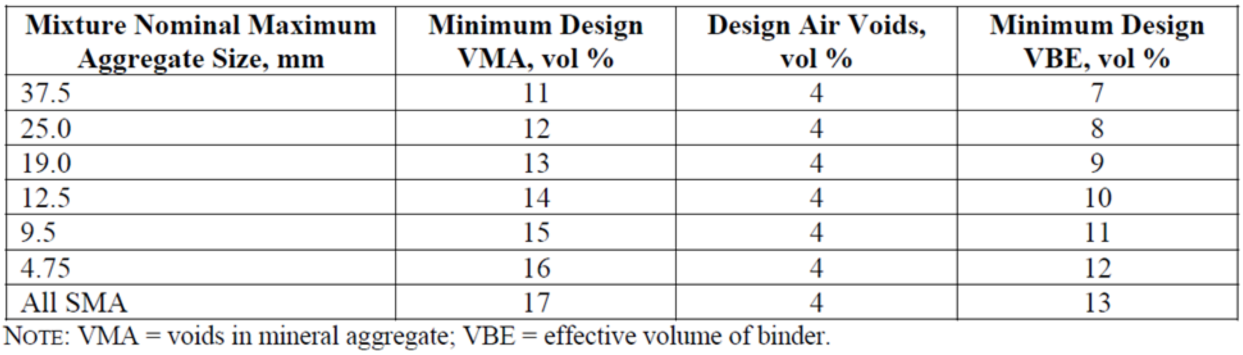
The binder content is selected at an air void content of 4%, the VMA is checked to ensure its minimum requirements (Von Quintus and Hughes, 2019). RTS has fixed the VMA 15-20% regardless NMAS but minimum VMA should be the function of NMAS which is shown in Table 7 must be incorporated in RTS. Maximum allowable VMA is 2% more of minimum value, i.e. for aggregate with NMAS 19 mm minimum VMA is 13% and maximum allowable VMA would be 15%; furthermore, agency may increase the minimum and maximum values for VMA by up to 1% to obtain mixtures with increased binder content, which can improve field compaction, fatigue resistance, and general durability (Von Quintus and Hughes, 2019). Care should be taken to ensure that the resulting HMA mixtures maintain adequate rut resistance for their intended application. Because, increasing minimum VMA requirements can also decrease rut resistance and the required dust/binder ratio of 0.8 to 1.6 (0.6 to 1.2 in RHD Specification) should not be lowered if VMA requirements are increased (NCHRP Report 673). In these regard RTS seems inadequate, i.e. if 19 mm NMAS mix follow VMA 15-20% requirement, it already passed allowable VMA limit and potentially became rutting prone mix.

Design the VMA dry side of binder content to avoid bleeding (MS-2, 2014 & Kandhal, 2016). VMA decreases with adding asphalt is called the "dry side," while the portion where VMA increases with more asphalt is called the "wet-side" they are often very sensitive to small changes in mixture proportions, aggregate gradations, aggregate characteristics, and/or asphalt content (Von Quintus and Hughes, 2019). RTS specified Void filled with Bitumen (VFA) 65-80% and 70-80% for base and wearing course respectively, but allowable range for VFA depends on traffic level (light, medium or heavy). For light traffic, allowable VFA ranges from 70 to 80%; for medium traffic, the allowable range is from 65 to 78%; for heavy traffic, the allowable range is from 65 to 75% (NCHRP Report 673, 2012). These norms could be added in RTS. The Bailey Method which is based on theoretical principles of particle packing and, although relatively complicated, for aggregate proportioning in HMA Mixture could provide many quantitative rules for modifying aggregate blends to achieve a desired change in VMA.

3.4 Binder Content

RTS specified the ranging of binder content for specific course and specific layer thickness, i.e. 4.5 to 6.5% of total weight of mixture for 40-60mm wearing/binder course. Binder content by total mix weight is a function of both asphalt content by volume and aggregate specific gravity. The most important matter is asphalt content by volume not by weight that dictates performance of bituminous layer. Theoretically, the most effective way of characterizing and specifying asphalt binder content is effective binder content by volume (VBE). VBE is the primary mixture design factor affecting both durability and fatigue cracking resistance. Durability and fatigue resistance improve with increasing VBE (Bonaquist, 2014). Therefore, engineers and technicians should either use VBE or VMA at a constant design air void content not concentrate on binder content limitations as presented in Table 7. The use of higher effective binder content dense-graded mixtures should be considered for surface and base layers when the traffic level exceeds 10,000,000 ESALs (NCHRP Report 673, 2012).

Table 7: Summary of AASHTO M323 and AASHTO M325 Design Minimum VBE (Bonaquist, 2014)



Mixture Nominal Maximum Aggregate Size, mm	Minimum Design VMA, vol %	Design Air Voids, vol %	Minimum Design VBE, vol %
37.5	11	4	7
25.0	12	4	8
19.0	13	4	9
12.5	14	4	10
9.5	15	4	11
4.75	16	4	12
All SMA	17	4	13

NOTE: VMA = voids in mineral aggregate; VBE = effective volume of binder.

3.5 Apparent Film Thickness (AFT)

Apparent film thickness refers to the average thickness of binder coating aggregate particles in the mixture which is idealized in Fig. 3. Some engineers and researchers have proposed it as an important characteristic related to several aspects of pavement performance—mixtures with low film thickness will be brittle and prone to durability problems, while mixtures with high film thickness will have too much asphalt and may be prone to rutting and shoving (NCHRP Report 673, 2012). AFT values in the range of 7 to 9 microns appear to provide the best compromise between workability and rut resistance

$$AFT\ (\mu m) = \frac{1000\,VBE}{S_s P_s G_{mb}}$$

(Christensen and Bonaquist, 2006 and ORN 19, 2002). It is suggested that special care to ensure that there are no unintended conflicts with any simultaneous requirements for VMA, design air void content, or aggregate gradation (NCHRP Report 673, 2012). AFT could be adopted in RHD Specification. Following equations can be used for estimate AFT:

$$AFT\ (\mu m) = \frac{1000\,VBE}{S_s P_s G_{mb}}$$

$$S_s = \frac{P_{0.3} + P_{0.15} + P_{0.075}}{5}$$

empirical methods for calculating aggregate specific surface through,

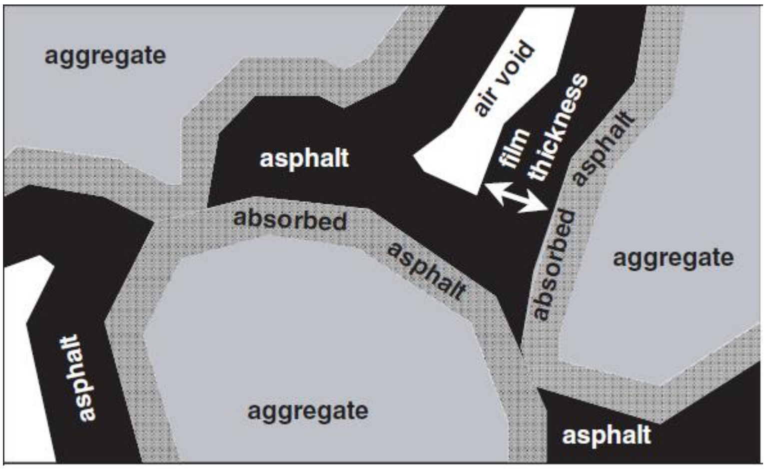


Figure 4: Concept of apparent film thickness (NCHRP Report 673, 2012)

4. CONSTRUCTION

HMA performance problems could be the result of construction problems as high in-place air void content due to poor field compaction, rather than improper mix design. Therefore, Proper compaction of HMA is critical to its long-term performance.

4.1 Lift Thickness (t)

Adequate compaction may not be possible if lift thickness is not properly considered during pavement design and mixture selection (Prowell and Brown, 2007). For improved compactibility, it is recommended that the t/NMAS be at least 3 for fine-graded mixes and at least 4 for coarse-graded mixes but should not exceed 6:1, especially when using larger-sized aggregate. Thicker lift thickness provides a secondary benefit to retains higher temperatures in mat for longer periods of time which extends the available time for compaction and helps to achieve higher and more uniform mat densities. The higher density increases the mixture's tensile strength, stiffness, fatigue strength, and rutting resistance (Brown et al., 2004). Therefore, RTS regulation of compacted layer thickness at least twice of maximum aggregate size should be amended.

4.2 Field Density

RTS has recommended the average field density should not be less than 98% of laboratory bulk density in which no any density test result should fall below 97%. But most of the agencies of the world are using G_{mm} based field density because laboratory density test is very subjective test and forensic investigation could be hampered due to missing of laboratory density data. The density of finished paving layer should not be less than the 92% and not more than 97% of the average theoretical maximum specific gravity of the loose mix (G_{mm}) obtained on the day of paving (Kandhal et al., 2010). In place density more than 8%, the surfacing will be vulnerable to premature deterioration through ageing of the bitumen and moisture damage due to high permeability (ORN 19, 2002 and Zube, 1962). However, to ensure that permeability is not a problem, the in-place air voids should be between 6 and 7 percent or lower (Brown et al., 2004). The difference in air voids near joints should not be more than 2% relative to the density of the main mat. Florida DOT has been assessed the pavement's coefficient of permeability if it is greater than or equal to 1.25×10^{-5} m/s, the Contractor may require removal and replacement at no cost or may accept the payment at 90% pay (Sholar & Page, 2006). RST should introduce permeability test on compacted HMA mat.

4.3 Application Rate of Tack Coat

RTS has suggested the tack coat as 60/70, 80/100 penetration grade, Rapid curing cutback RC-30 or RC-70 and Rapid setting emulsion with maximum application rate 0.45 L/m^2 for dry surface condition. AASHTO 2008 recommended the emulsified bitumen as tack coat 0.15 to 0.70 L/m^2 application rate. In case of penetration grade bitumen Uzan et al., 1978 suggested the optimum tack coat application rates for yielding the maximum shear strength to be 0.97 L/m^2 at 25 ºC and 0.49 L/m^2 at 55 ºC. The tack coat application rate could be revised.

4.4 Opening for Traffic

The current RHD Specifications does not allow traffic for 6 hours after compaction for cooling the HMA to approximately ambient air temperature. Technically, it may forfeit the purpose of using hot bituminous mix, which lends itself to fast opening to traffic, and practically become unreasonable (Kandhal et al., 2010). If there is a fear that the traffic will rut the pavement, it means that the mat has not been rolled enough. But it should be ensured that traffic is not allowed on the surface until the paved mat has cooled below a temperature of 60ºC in its entire depth. Under hot climatic conditions during summer, it is estimated that a 50 mm thick bituminous layer should cool to 60ºC in about one hour and a 75 mm thick bituminous layer should cool to this temperature in about one and half hour (Kandhal et al., 2010). Therefore, it is reasonable to open for traffic on compacted mat after 2 hours.

5. PERFORMANCE TEST

HMA design involves evaluating the performance of the mixture according to three failure modes: (1) rutting; (2) moisture susceptibility (ravelling, pop-outs or potholing); and (3) fatigue (White et al., 2006). Due to the high variability of fatigue testing, it is rarely performed in practice. Therefore, MS-2 recommended performance test of moisture resistance for all mixtures and rut resistance for traffic levels of 3 million ESALs and higher. Rut resistance can be evaluated by dynamic modulus and flow number from the Asphalt Mixture Performance Tester (AMPT) or Asphalt Pavement Analyser which measures maximum rutting depth and Hamburg Wheel-Track Test (HWT) which can check rutting or moisture resistance of HMA mixtures simultaneously.

6. QUALITY CONTROL & ASSURANCE

Quality control is the responsibility of the contractor to keep a control on the process. Quality assurance or acceptance is the responsibility of the specifying agency. For quality control, the agency specifies the types and minimum frequency of the tests to be conducted by the contractor during construction. The quality acceptance should be based on statistical principles. Pay factor should be determined by using three main systems: Percent Within Limits (PWL) of the Specification; difference between average sample test value and target Job - Mix Formula (JMF); and probability based (Kandhal et al., 2010). In these regard, RHD Specifications have addressed the quality control aspect only, it needs to be specific about quality acceptance.

7. CONCLUSIONS & RECOMMENDATION

After reviewing the RHD Standard Specification 2016, there are several problematic issues are identified, single or combine effect of these problems could be the cause of premature failure of bituminous surfacing of RHD pavement. Based on latest state of art, specification modification and incorporation of new techniques and technologies are recommended below:

- Uncompacted Void Content for course and fine aggregate should be introduced
- Natural sand content should be restricted to 10% for binder and wearing course for heavy trafficked road
- Encourage to use 1-2% of hydrated lime by dry weight of aggregate and subsequent reduction of fine aggregate
- Shifting from penetration grade to Superpave Performance Grade (PG) and binder modification option should be introduced
- Reduction of 0.2-0.3% binder from Marshall design binder with 75 blows could equivalent to Superpave binder content
- Four dense graded mixes can be accommodated in RHD technical Specification of HMA: Base Course: DBM Grading 2 (nominal aggregate size 25 mm); Binder Course: BC Binder Grading (nominal aggregate size 19 mm); Wearing Course

BC: Grading 1 (nominal aggregate size 12.5 mm) for heavy traffic road and Wearing Course BC: Grading 2 (nominal aggregate size 9.5 mm) for light to medium traffic and urban area

- Course dense graded HMA is preferable for wearing course but fine or course both graded mix can be used in binder and base course
- Wearing and binder course can be design for 4% (±0.5%) air void but for base course, it is 3-4%.
- Minimum VMA requirement should be function of NMAS and maximum allowable VMA is 2% more of minimum value. Binder content should be selected from dry side of VMA curve
- Allowable VFA ranges from 70 to 80% for light traffic, 65 to 78% for medium traffic and 65 to 75% for heavy traffic
- Aggregate proportioning can be done with the Baily Method
- Apparent Film Thickness values in the range of 7 to 9 microns appear to provide the best compromise between workability and rut resistance
- Lift thickness/NMAS be at least 3 for fine-graded mixes and at least 4 for coarse-graded mixes but should not exceed 6:1, especially when using larger-sized aggregate
- The field density of finished paving layer should not be less than the 92% and not more than 97% of the theoretical maximum specific gravity of the loose mix (G_{mm})
- Tack coat application rate could be revised
- 2 hours after compaction of HMA mat could be optimum for opening for traffic
- Moisture susceptibility test for all mix with AASHTO T283 and rutting performance for traffic levels of 3 million ESALs and higher should be introduced
- Statistics based quality acceptance can be introduced

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