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ABSTRACT

Rutting of hot mix asphalt (HMA) pavement at or near intersections is very common both in cold and hot climates. Obviously, the problem is more acute in hot climates compared to cold climates because the stiffness of HMA decreases with increase in pavement temperature. In most cases, there is no significant rutting in the same asphalt pavement structure away from the intersections under fast moving traffic. This indicates a need for a different asphalt mix at or near intersections, which can sustain slow or standing traffic loads without any permanent deformation.

A field investigation of rutting near five signalized intersections in Pittsburgh, Pennsylvania indicated the following causes related to in-place HMA: (a) low voids in the mineral aggregate (VMA), (b) low air voids, and (c) use of subrounded to subangular sand. Although the mixes were designed in the laboratory with high VMA and air void content, the asphalt pavements densified significantly in the field to yield very low VMA and air voids. It was felt that the HMA at the intersections should have the following attributes: (a) should maintain adequate VMA to ensure durability, (b) should not densify below 4 percent air voids under slow and standing traffic during hot summer days, and (c) should contain stiff asphalt binder to resist creep behavior.

Based on the documented experience in the United States with the performance of stone matrix asphalt (SMA) and Superpave HMA mixes, the following recommendations have been made for asphalt pavements at intersections.

- **Wearing Course**. Use 50 mm thick SMA wearing course with a maximum nominal aggregate size of 12.5 mm.
- **Binder Course**. Use 50 mm thick SMA binder course with a maximum nominal aggregate size of 19.0 mm.
- **Base Course**. Use 150 mm thick dense-graded large stone mix with a maximum nominal aggregate size of 25 mm. This mix should be designed either by Superpave mix design method or by Marshall method modified for 6-inch (151.8-m) diameter specimens.

Various rutting studies have shown that rutting is usually confined in the top 100 mm of asphalt pavements. Therefore, the use of SMA has been recommended in the top 100 mm. The SMA has a stone-on-stone contact and, therefore, it has a very high stability and it does not densify to unacceptably low air voids under traffic.

Specifications and mix designs for the recommended three asphalt pavement courses are included in the paper.

KEY WORDS: rutting, intersection, hot climate, asphalt pavement, HMA

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INTRODUCTION

Rutting of hot mix asphalt (HMA) pavements at intersections is a common problem. Although the problem exists in both cold and hot climates, it is more common and serious in hot climates. Rutting takes place at intersections because the HMA exhibits low stiffness under slow moving or standing loads. The problem is aggravated in hot climates since the stiffness of HMA is further decreased at high temperatures. In many instances it is found that even though there is significant rutting at the intersection, there is no significant rutting in the same pavement away from the intersection. Because of the difference in the rate of loading at intersections, it seems logical that there is a need to use a different type of HMA at intersections compared to the HMA that should be used away from the intersections.

The objectives of this paper are to discuss the various causes of rutting as obtained from literature review, present a case study involving rutting at intersections, and recommend asphalt mixes for intersections in hot climates.

REVIEW OF LITERATURE

A review of literature conducted on rutting revealed the following different forms of permanent deformation and possible causes:

	Example of Distress	Possible Cause of Distress
(a)	Creep (time dependent) deformation or plastic flow (shoving)	Standing or stationary (long term or static) loading
(b)	Rutting (resulting from accumulation of the small permanent deformations associated with the passage of wheel loads)	Repetitive traffic loading (a large number of repetitions)
(c)	Rutting, sometimes associated with wash-board type distortion (especially if the bond between the pavement layers is lost)	Acceleration and deceleration loading (combined effect of horizontal and vertical stresses)

Field observations have shown that these three factors cause the rutting and shoving problems near the signalized intersections on the roads carrying very heavy and channelized traffic. Case histories of rutting and shoving near the intersections have been reported in the literature. Abson and Burton[(1)] reported, “This highway in question carried an unusually large volume of heavy truck traffic. One year after the pavement was laid, severe shoving was evident, being particularly bad at the stop light intersections. The rest of the pavement where there was no appreciable amount of stopping appeared to be in a satisfactory condition.” They concluded that this condition developed from high asphalt content for the aggregate gradation used, and low air void content.

Campen et al[(2)] investigated 18 resurfacing projects in the city of Omaha, Nebraska. The rutting and shoving occurred where traffic was channelized and in turns or the bus stops. They reported that the voids in the mineral aggregate (VMA) were low in their mixes because of a very dense gradation, and this made the performance of asphalt wearing surfaces on the border line. They stated, "either we might get a little shoving and rutting or else the rate of wear might be higher than desired."

Foster[3] has indicated that rutting and shoving would occur first in the stopping areas of the heavy traffic, because that is where compaction is greatest and the air voids are lower than where the traffic is not stopping.

Goetz et al[4] investigated several overlays over portland cement concrete in Indiana which exhibited rutting problems. The condition was found to be most severe at signalized intersections where the pavement and the overlay were subjected to stresses from braking traffic and to static loads. Density measurements made on cores taken in the rutted wheel track area indicated that the air voids had been reduced to values in the neighborhood of two percent. From this they deduced that the stability of the mixture in service could be increased by decreasing asphalt content.

Monismith and Vallerga[5] conducted a study which showed that densification of some asphalt mixtures by traffic over a period of time actually resulted in a decrease of stability (resistance to deformation). This is contrary to the concept in wide use today that an increase in density of an asphalt paving mixture results in an increase in stability. Lingle[6] analyzed their data in light of the voids in the mineral aggregate (VMA) and asphalt contents. He observed that at higher asphalt contents the most thoroughly compacted mix will show the greatest loss in stability. When the density of the pavement approaches the theoretical maximum density and when the mix could no longer consolidate, it rapidly lost stability and began to rut and shove.

Based on the laboratory studies, many theoretical models have been developed to predict the permanent deformation (resulting in rutting and shoving) in asphalt pavements. These have been discussed in the state-of-the-art report on "Rutting Prediction in Asphalt Concrete Pavements" prepared by Monismith.[7] These theoretical models have been developed by Brown and Bell,[8] Ullidtz,[9] Barksdale,[10] Mayer et al,[11] Van de Loo,[12] Morris et al,[13] Brown and Snaith,[14] Monismith and Salam,[15] Mack,[16] Haas and Meyer,[17] Rauhut,[18] Saraf et al,[19] Kenis and Sharma,[20] and Lai and Hufferd.[21] These methods require sophisticated testing equipment to simulate the repetitive and stationary traffic loading. Tests, such as repeated load triaxial compression test, creep test, etc. have been used to obtain data to plug in the models. Usually the predictions are approximate because the models are based on certain assumptions related to the behavior of the pavement materials, such as viscoelastic, elastoplastic, linear elastic, etc.

To minimize rutting under uniformly moving traffic, the triaxial compression test at temperatures and rates of loading associated with specific field conditions appears to be most appropriate. It measures the shear strength of the mixture which controls the distortion (rutting and shoving):

$$\tau = c + \sigma \tan \phi$$

Where:
τ = Shear strength
c = Cohesion
σ = Normal stress
ϕ = Angle of internal friction

The angle of internal friction ϕ is obtained from the aggregate interlocking. Higher values of ϕ are developed if the aggregate (especially the fine aggregate) is rough textured, angular, and well graded. According to Lees[22] the asphalt content affects ϕ because it changes the degree of mechanical interlock between the particles. In other words, the aggregate particles are spread further apart with a higher proportion of asphalt binder present in the mix. The cohesion, c, is obtained from the viscosity of the asphalt-fines binder. This can be increased by the use of harder asphalt binder and/or more fines in the mix. However, this would tend to make the mix brittle, especially at low temperatures, and thus prone to cracking. The c value will also decrease with increasing asphalt content due to thicker asphalt film around the aggregates.

To estimate the response of mixtures to standing and/or slow moving loads, the mixture stiffness as a function of time of loading and temperature is considered to be the most useful parameter. This can be obtained in a creep test.

Further review of literature concerning the asphaltic mix design was also conducted. The work done by Lees,(23) Khalifa and Herrin,(24) Hudson and Davis,(25) Campen et al,(26) Highway Research Board,(27) McLeod,(28) Finn,(29) and Marker (30) was also reviewed.

The following summary is based on the report by Marker,(30) and the general conclusions are based on the review of the literature:

Rutting

Rutting may be described as a longitudinal deformation developing in an asphalt pavement under the action of repeated channelized loadings. There are three mechanisms that might be involved in a rut developing, that is, plastic movement, mechanical deformation, and consolidation.(30)

Plastic movement can occur either in the subgrade on which the pavement is placed, or in the asphalt concrete mixture itself. Plastic movement is normally identified by a depression near the center of the applied load with slight humps on either side of the load. The distance of the humps from the center of the rut will be an indication of the depth at which the plastic movement is occurring.

Mechanical deformation can occur when an element under the pavement surface loses its integrity for one reason or another, and is displaced under the load. A rut resulting from this type of action will generally be accompanied by substantial pattern cracking provided the distress is allowed to progress sufficiently.

A rut caused by consolidation will normally be identified by a depression in the channelized path of the applied load without an accompanying hump on either side of the depression. It occurs because the layer in which the consolidation is occurring was not sufficiently compacted during construction, and receives further densification under repeated traffic loads. It can occur either in the subgrade, in the untreated base, or in the asphalt mix itself.

Shoving

Shoving is defined as the horizontal displacement of an asphalt mixture. There are two principal mechanisms by which shoving can occur. The first is due to instability of the asphalt mixture which results in plastic flow of the mix under horizontal thrust. The instability, and the resultant shoving under load, most frequently is because of an excess amount of asphalt binder (low air voids) which is acting as a lubricant in the mix rather than as the binder.

The second mechanism that can cause shoving is slippage in the mix under horizontal thrust. In this case, the adhesion between two layers of mix is insufficient to provide the proper shear strength along the plane between the two layers. Locations at which severe horizontal thrust occurs are braking areas (traffic coming to a stop sign), and uphill lanes on highways, particularly with large volumes of truck traffic.

The principal contributing factor to instability in an asphalt mixture is an excess asphalt content. The most common cause of a mix with insufficient shear strength is an oversanded mix, with insufficient filler, and with a low viscosity asphalt binder.

Asphalt pavements have a higher resistance to rapidly applied loads compared to slowly applied loads. The following considerations in the asphalt mix design would generally minimize the rutting and shoving (permanent deformation) problems:

1. Lower Asphalt Content: Higher asphalt content is needed for improved fatigue life and durability of the asphalt mix, but it tends to enhance the rutting and shoving problems. The mix needs to be maximized for fatigue and permanent deformation through a compromise.
2. Coarser Gradation: Finer gradations or oversanded mixes are more susceptible to permanent deformation.
3. Angular and Rough Textured Aggregate: This is especially applicable to the fine aggregate fraction. It has been demonstrated by Kalcheff and Tunicliff[31] and Brown and Cross[32] that mixtures utilizing angular manufactured sand are more resistant to permanent deformation than mixes produced with rounded or subrounded natural sand.
4. Increased Air Void Content: Mixtures with low voids in the mineral aggregate (VMA) and higher asphalt contents have a tendency to have very low air void contents after densification by traffic. Such mixtures lose stability after reaching a critical compaction level and start to rut and shove.
5. Higher Viscosity Asphalt Binder: An asphalt binder with a high viscosity at 60°C will be more resistant to horizontal thrust as far as plastic flow in a mix is concerned compared to a low viscosity asphalt binder.
6. Higher Fines Content: Increase in the minus 75 microns fraction of the mix will tend to stiffen (increase the viscosity) the binder.
7. Larger-Size Aggregate: At proper asphalt content larger-size aggregate (such as 19.5 mm) mix in the wearing course tends to be more resistant to permanent deformation.
8. Reduced Overlay Thickness: If the existing pavement is structurally sound (for example, portland cement concrete), thicker asphalt mix overlays are unnecessary in the critical areas like intersections. Thinner overlays (for example, binder course can be eliminated) in these areas will minimize the problem.
9. Improved Bond Between Pavement Layers: A lack of good bond between the pavement layers (especially in top 150 mm of the pavement) can cause slippage due to horizontal thrust.

FIELD INVESTIGATIONS

A field investigation conducted to ascertain the cause(s) of rutting at several intersections in Pittsburgh, Pennsylvania is presented below. Table 1 shows project details and mix type, average daily traffic, range and average of measured rut depths. To obtain representative samples and minimize the number of samples, ten 150-mm diameter cores were obtained from each of five projects: five in the rutted wheel track near the intersection and five in the same wheel track, about 40 to 130 m away from the intersection where there was no significant rutting. The cores were tested for bulk specific gravity, asphalt content, and gradation. The maximum theoretical specific gravity of the different mixes were determined. The air voids (voids in total mix) and VMA (Voids in Mineral Aggregate) for the different mixes were also determined and are shown in Table 2. Rut depths and mixture properties are discussed below.

Rut Depth

According to Barksdale,[10] a rut depth of 10 mm is considered a safe allowable rut depth for design use in the United States. On the main line away from the intersections, this limit is exceeded only on LR 120 (67)—Lincoln Highway, with an average rut depth of 13 mm (Table 1). Evidently, the rut depths at the intersections are excessive, ranging from 17 mm (Banksville Rd.) to 38 mm (Lincoln Highway).

Table 1. Project Details and Rut Depths

Legislative Route or LR	ADT	Mix Type	Rut Depth (mm)* At Intersection Range	At Intersection $\bar{x}$	Away from Intersection Range	Away from Intersection $\bar{x}$
120 (67) (Lincoln Hwy)	29,988	ID-2	29-46	38	11-13	13
392 (13M) (Fifth Ave)	17,238	ID-2	22-33	27	3-5	4
02060 (Gilkeson Rd)	18,144	ID-2	19-25	22	6	6
02269 (Banksville Rd)	39,564	ID-2	13-22	17	5-6	6
246 (Marshall Ave)	---	FJ-1 (Coarse)	14-32	24	5-6	5

* Measured with a 3 m straight edge in the right lane.

Density, Percent Air Voids and VMA

Table 2 gives the average air voids and VMA values at and away from the intersections. If no excessive deformation (shoving) has taken place, the air voids and VMA values are expected to be lower at the intersections due to extra compactive effort by the traffic. Except LR 120 (67) and LR 02269 where the rutting is probably associated with decompaction (slight increase in volume), this is the case.

An ideal ID-2 wearing course mixture (a dense-graded mix used in Pennsylvania) should have at least 16 percent VMA to have sufficient space for asphalt binder and air voids.[33,34] Also, an ideal ID-2 wearing course mix should have air void content in the vicinity of 3 or 4 percent after traffic densification (during the first 1½-2 years) so that the mix does not lose its stability[1,4] after being subjected to traffic. The data in Table 3 on the minimum percentages of VMA and air voids achieved on these projects indicate that the first four ID-2 wearing course mixtures are very critical and are prone to become plastic and unstable under the conditions near the intersections (the mix on LR 246 is a coarse sand mix called FJ-1).

Table 2. Summary of Average Test Data

	% Asphalt Content		% Passing 75 µm		% Air Voids		% VMA	
Project	Design	Extracted	Design	Extracted	Design	Measured	Design	Measured
LR 120 (67)								
At intersection	6.7	6.6	5.0	7.0	2.3	1.4	14.2	13.2
130 m away	6.7	6.5	5.0	6.8	2.3	1.0	14.2	12.7
LR 392 (13M)								
At intersection	7.2	6.9	4.0	5.2	2.3	0.9	15.5	13.6
70 m away	7.2	6.9	4.0	4.0	2.3	1.8	15.5	14.4
LR 02060								
At intersection	6.2	5.8	5.0	7.6	3.0	1.6	13.9	13.0
70 m away	6.2	6.0	5.0	6.4	3.0	2.2	13.9	14.0
LR 02269								
At intersection	6.7	6.6	5.0	6.2	2.0	2.3	14.0	14.0
120 m away	6.7	6.7	5.0	6.4	2.0	1.8	14.0	13.8
LR 246*								
At intersection	10.5	10.4	8.0	8.6	2.7	1.4	21.9	21.0
40 m away	10.5	10.3	8.0	7.0	2.7	5.8	21.9	24.3

*FJ-1 coarse sand mix.

Table 3. VMA and Air Voids Data

Project	% VMA		% Air Voids	
	Minimum Desirable	Actual	Minimum Desirable	Actual
LR 120 (67)	16	12.7	3	1.0
LR 392 (13M)	16	13.6	3	0.9
LR 02060	16	13.0	3	1.6
LR 02269	16	13.8	3	1.8
LR 246 (FJ-1)	18	21.0	3	1.4

The phenomenon taking place under traffic in a low VMA-low air voids mix can be described as follows. In a normal mix, the asphalt binder between the aggregate particles is squeezed out into the sufficiently available air voids space. In a low VMA-low air voids mix, there is no space available for this asphalt binder to go and it tends to remain and separate the aggregate particles acting as a lubricant and offsetting the interlocking characteristics of the aggregate frame work. Thus, the cohesion (c) and internal friction (ϕ) of the asphalt mixture decrease, making it plastic and unstable under sustained stationary and slow-moving traffic conditions.

The VMA of a mix can be increased by:

1. Deliberate deviation from the maximum density gradation line (preferably towards coarser side to improve the mix creep behavior near the intersections), and
2. Use of angular fine aggregate (manufactured sand) in the mix.

It is <u>not</u> recommended to increase the design air voids in the ID-2 mixes by decreasing the asphalt content (while keeping the same low VMA) because past experience in the Pittsburgh area has shown numerous raveling problems associated with low-asphalt, low-VMA mixes. Also, a high-VMA wearing course mix has increased fatigue life and is more resistant to low-temperature cracking and reflective cracking. However, the VMA should not be more than 2 percent higher than the minimum required VMA, otherwise the mix will experience decreased stability.

It should be noted that the FJ-1 coarse mix used on LR 246 (Marshall Ave.) has adequate VMA but low design air voids (2.7 percent) due to excessive asphalt content. This mix needs to be designed with at least 4 percent air voids which can be accomplished by reducing the asphalt content.

Shape of the Aggregate in the Mixtures

The aggregates recovered from the extraction test were examined for (a) crushed content of coarse aggregate, and (b) shape of the fine aggregate (under microscope). The results are shown in Table 4.

The gravel coarse aggregate contains adequate percentage of crushed particles. However, as mentioned earlier, the shape (angularity) of the fine aggregate (sand) is more important for improved mix creep behavior. The sand in these three mixes is subrounded to subangular. An angular sand (usually manufactured sand) would be very helpful in resisting the permanent deformation of the asphalt pavements near the intersections.

Table 4. Properties of Aggregates

Project	Coarse Aggregate (% Crushed)	Fine Aggregate Sand (Shape)
LR 120 (67)	gravel (81%)	mostly subrounded to subangular
LR 392 (13M)	gravel (97%)	mostly subrounded to subangular
LR 02060	stone (98%)	mostly subangular
LR 02269	gravel (90%)	mostly subrounded to subangular
LR 246	----	mostly angular (slag)

Based on the review of literature and test results from the case history, the following conclusions were drawn and recommendations made:

1. Higher asphalt content is needed for improved fatigue life and durability of the asphalt mix, but it tends to enhance the rutting and shoving (permanent deformation) problems near the intersections.
2. The rutting problem in Pittsburgh can be attributed to high average daily traffic (ADT), stationary and slow-moving traffic near the signalized intersections, and horizontal thrust due to deceleration and acceleration of vehicles.
3. The dense-graded ID-2 wearing course mixes in Pittsburgh were found to be very critical because of low VMA (voids in mineral aggregates) and low air voids. These mixes become plastic and unstable after densification under traffic occurs, and cannot resist the permanent deformation induced by the stationary or slow moving loads.
4. These ID-2 mixtures can be maximized for durability and resistance to permanent deformation as follows:
   (a) Increase the VMA of the mix by deliberately deviating from the maximum density line for gradation (preferably towards the coarser side), and increase the design air voids in the mix. The present asphalt content need not be decreased.
   (b) Use angular fine aggregate (manufactured sand) to improve the creep behavior of the asphalt mix.
5. The FJ-1 coarse sand mix (LR 246) has adequate VMA in the mix. It needs to be redesigned with at least 4 percent air voids by lowering the asphalt content.
6. To rectify the existing rutting and shoving situation near the intersections, cold milling to a depth of at least 100 mm is recommended. Studies have shown that rutting usually occurs in the top 100 mm of the asphalt pavement. The milled material should be replaced with a high quality asphalt mixture that contains highly crushed aggregate, proper asphalt content, and adequate binder stiffness.

RECOMMENDATIONS

In conjunction with the conclusions obtained from field investigations of rutting at several signalized junctions, the following mixes are recommended for use at intersections in hot climates. These recommendations are based on recent experience with European mixes (such as stone matrix asphalt) and Superpave mixes in the U.S.

1. 50 mm stone matrix asphalt (SMA) wearing course (nominal maximum size 12.5 mm)
2. 50 mm stone matrix asphalt (SMA) binder course (nominal maximum size 19.0 mm)
3. 50 mm dense-graded large stone mix base course (nominal maximum size 25 mm)

Stone matrix asphalt is recommended for the top 100 mm of pavement since rutting is mostly confined to top 100 mm of pavement as mentioned before.[(34)] SMA is a very strong rut resistant mix that will not generally densify below design air voids. The presence of stone-on-stone contact[(35)] in SMA will prevent significant rutting in the pavement. At the same time, the relatively high binder content will provide necessary durability to the mix.

The base course should be designed as a dense-graded 25 mm nominal size mix with the Superpave gyratory compactor. However, since there is no guidance given regarding compactive effort (N_{design}) for mixes at intersections, it is recommended to use the compactive effort for the highest traffic category in the Superpave. Alternatively, the 112-blow Marshall mix design using 6-inch diameter Marshall samples (ASTM D 5581-96) can be used. For asphalt binder it is recommended that the selected Superpave PG grade binder should be two grades stiffer than that based on design high temperature of the project location.

A brief review of SMA mix design and Marshall mix design for large stone mixes follows. For Superpave mix design the reader is referred to Reference 36.

Stone Matrix Asphalt

Important consideration in SMA mix design are aggregate toughness, flat and elongated content for aggregates, aggregate gradation, mineral filler, voids in total mix, and voids in mineral aggregate (VMA) and compactive method and effort for compaction of mix design specimens. Since SMA derives its strength primarily from stone-on-stone contact of coarse aggregates, the properties of coarse aggregate are very important for obtaining good performing SMA. Aggregate toughness as measured by the Los Angeles abrasion test (AASHTO T96) can indicate potential aggregate breakdown and hence should be considered when designing all types of mixtures, for SMA. A maximum value of 30 percent is specified in the SMA guidelines.[(37)] Current SMA guidelines specify limiting ratios of 3 to 1 and 5 to 1 for flat and elongated particles. However, recent research at NCAT has shown that the 5 to 1 ratio does not differentiate aggregates and hence specifying the 3:1 ratio may be a better approach.

Stone-on-stone contact in SMA is desired from properly graded aggregate structure. The SMA aggregate gradation guidelines[(37)] suggest a range of 20 to 28 percent passing the 4.75 mm sieve to help ensure the formation of a proper coarse aggregate skeleton and stone-on-stone contact in the SMA mixture. Previous work in NCAT[(35)] has also shown that the percent passing the 4.75 mm sieve must be lowered below approximately 30 percent to obtain stone-on-stone contact.

The function of mineral filler is essentially to stiffen the binder rich SMA. A higher percentage of very fine filler may stiffen the mixture excessively, making it difficult to work with and resulting in a crack susceptible mixture. Current SMA guidelines attempt to control the stiffening effect of the filler by regulating the amount of filler that is finer than the 0.02 mm. However, recent work done at NCAT[(38)] has shown that the percent of filler finer than 0.02 mm did not correlate well with the mortar stiffness. The dry compacted volume as obtained from the Penn State modified Rigden voids method showed a better correlation with mortar stiffness and can be utilized to characterize the filler. Generally, a more angular filler tends to produce higher Rigden voids in this test.

The SMA guidelines[(37)] also recommend a mixture design air void range of 3 to 4 percent. A field study conducted by NCAT[(39)] has shown that although setting a minimum air void level at 3 percent appears to be reasonable to prevent rutting, air voids in hot climates should be designed closer to 4 percent to minimize occurrence of fat spots (flushing of asphalt binder).

The primary purpose of the VMA requirement in SMA is to ensure a reasonably high asphalt content. Based on a number of mixture designs and a limited field study conducted by NCAT, it appears that the currently specified VMA requirement of 17 percent minimum is reasonable.[37] However, aggregates that tend to breakdown excessively during compaction may not provide a mixture that meets the VMA requirement. Hence, the mix designer needs to be careful about selecting the type of aggregates for SMA mixture.

The compactive method and effort specified by the TWG[37] is 50 blows of the mechanical Marshall hammer. Work done at NCAT[38] has shown that 100 revolutions of the Superpave gyratory compactor (SGC) result in a similar optimum asphalt content and thus similar density as produced by 50 blows Marshall compaction. Although the amount of breakdown is affected by aggregate type and compactive effort, the SGC seems to produce less aggregate breakdown than the Marshall hammer.

NCAT is conducting a national level study (NCHRP 9-9) for the development of a mix design system for SMA in the United States. Preliminary results from this study are available in Reference 38.

Modified Marshall Method for Large Stone Mixes

The important considerations for designing large stone asphalt mixes (containing aggregates with maximum size greater than 25 mm) are given in Reference 40.

Studies conducted by the Pennsylvania Department of Transportation[41] had indicated that the conventional Marshall mix design method with 4-inch specimen could not be used for binder and base course mixes with maximum size of more than 25 mm. Subsequently, PennDOT recommended the use of 6-inch diameter specimens since it is generally recognized that the diameter of the mold should be at least four times the maximum nominal size of the coarsest aggregate in the mixture to be molded.

The weight of the hammer and the number of blows were increased to provide the same compactive energy input (m-Mg/cu mm) to the specimen with 6-inch diameter as in the case of conventional 4-inch diameter specimens. The weight of the hammer was increased from 4.54 kg to 10.20 kg. The number of blows for heavy traffic mix design was increased from 75 to 112 (50% increase). Based on theoretical calculations and experimental results, it was recommended that the minimum Marshall stability requirement for 6-inch diameter specimen should be 2.25 times the requirement for 4-inch diameter specimens. Also, the range of flow values for 6-inch diameter specimens should be adjusted to 1.5 times the value required for 4-inch diameter specimens.

The same mechanical compactor can be used for compacting 4-inch and 6-inch diameter Marshall specimens.

SUMMARY

A review of literature shows that rutting of asphalt pavements occurs at intersections primarily because of slow or standing loads which result in more compaction than at the pavement sections away from the intersections. An investigation of rutting at intersections in Pittsburgh revealed that mixes with stability problems had very low air voids and VMA. The mixes became plastic and unstable under low moving and standing loads, and could not resist the permanent deformation. Even though lowering the asphalt content can cause an increase in voids and increase in stability, it is not recommended since mixes with low asphalt content can have durability problems. It is recommended to use stone matrix asphalt (SMA) wearing course (50 mm thick) and SMA binder course (50 mm thick) over a dense-graded 25 mm nominal size base course designed according to the Superpave mix design method or Marshall method modified for large stone mixes (ASTM D5581).

The SMA with stone-on-stone contact and high binder content, will be effective in preventing rutting in the top 100 mm of the pavement. Since SMA has a relatively high binder content, the mix will have adequate resistance against durability problems such as fatigue cracking. The large stone mix used in the base course will prevent any stability problems associated with the base.

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