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Aggregate Degradation Characteristics of Stone Mastic Asphalt Mixtures

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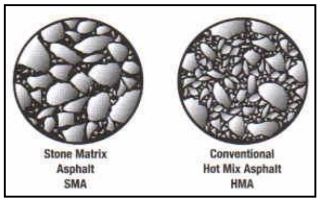
Graphical abstract



Abstract

Stone Mastic Asphalt (SMA) mixtures are designed to have a high coarse aggregate content and stone-on-stone contact, which results in more stress on the coarse aggregates during compaction and traffic loading. As a result, aggregates tend to break down more in SMA mixtures than in conventional dense graded mixtures. Aggregate degradation during compaction and traffic loading may cause changes in the original gradation and thus may also affect the volumetric parameters of SMA mixtures. Therefore, this study was conducted to determine the degree of aggregate degradation in SMA mixtures due to the compaction process. Aggregates of two Nominal Maximum Aggregates Sizes (NMAS), designated as SMA14 and SMA20, were compacted using 50 blows of the Marshall Hammer and 100 gyrations of the Superpave Gyratory Compactor (SGC). The verified samples were then prepared and extracted using the Centrifuge Method. The relationship between aggregate degradation and influencing factors, such as compaction effort and volumetric properties were investigated. Aggregate degradation by the Marshall Hammer was found to be significantly higher than degradation by the SGC. Voids in the mineral aggregate (VMA) of either compaction method decrease or are almost the same when aggregate degradation is not significant. SGC method can be selected to represent the field roller that results in a similar trend of aggregate degradation.

Keywords: Marshall; gyratory; aggregate; compaction, degradation

■1.0 INTRODUCTION

Stone Mastic Asphalt (SMA) is a gap-graded hot-mix asphalt (HMA) surfacing material[1]. SMA is designed to resist deformation, particularly rutting, and maximize durability by using stone-on-stone contact as the structural basis[2]. This mixture is characterized by its high coarse aggregate content, and the voids of the structural matrix are filled with high viscosity bituminous mastics[3]. Typically, SMA mixtures have a polymer-modified asphalt (PMA) content that ranges between 5.5 and 7.5%. The presence of PMA may be further stabilized using cellulose fibers to prevent excessive binder draindown. In addition, fibers will enhance the durability of the SMA mixture by allowing the use of a higher asphalt content[4]. Figure 1 shows a comparison between SMA and conventional HMA.

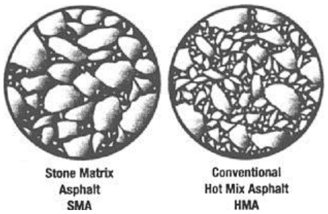


Figure 1 A comparison between SMA and HMA mixtures[5]

SMA is able to provide higher resistance to rutting due to heavy axle load and long-term durability, extending performance life by 30 to 40% compared to a conventional dense-graded HMA pavement[6]. In addition, this type of surface is environmentally friendly and safer for the motoring public, as it improves skid resistance, particularly of wet pavements, due to the high percentage of fractured aggregate[7]. The texture depth improves in the range of 0.7–1.0 mm[4].

Although water does not drain through SMA, its surface texture is similar to open-graded aggregate so that the noise generated by traffic is lower than that on dense-graded aggregate but equal to or slightly higher than open-graded aggregate[8]. Therefore, the coarser surface texture characteristics may reduce tire noise and pavement contact as well as water spray and glare. SMA can be produced and compacted with the same plant and equipment available for normal HMA using the Superpave and Marshall Procedures with modifications[9].

The Marshall Method is the most common conventional method widely used for making and evaluating trial mixes in obtaining the optimum asphalt binder content (OAC). In SMA design, the Marshall mix method is used to verify that the void content is satisfactory in SMA mixtures. Laboratory specimens were prepared using 50 blows of the Marshall Hammer per side. Seventy-five compaction blows were not used, since they would tend to break down the aggregate more and would not result in a significant increase in density over that provided by 50 blows. SMA mixtures have been more easily compacted on the roadway to the desired density than the effort required for conventional HMA mixtures[6]. The Marshall Method specified procedure of heating, mixing, and compacting the mixture of binder and aggregates is used, and the mix is then subjected to a stability-flow test and density-void analysis[10].

In recent years, the Superpave Gyratory Compactor (SGC) has become readily available for implementation in the Superpave mix design and analysis system. Gyratory compactors are gaining acceptance because of their realistic simulation of HMA compaction during construction and subsequent exposure to traffic in service. The use of SGC for HMA design and analysis is also to evaluate aggregate degradation during compaction[11]. Previous studies done by Brown and Mallick[12] and Brown *et al.*[13] indicate that 50 blows of the Marshall Hammer generate a density in SMA mixtures approximately equal to 100 gyrations of the SGC.

This mixture is recommended to be used in high stress areas such as climbing lanes or where excessive axle loads are expected[4]. For pavements with cracking or raveling it is suggested that SMA be considered for use as an overlay, because it may reduce severe reflection cracking from underlying cracked pavements due to the flexible mastic[10]. Most previous studies conducted in Malaysia focus mainly on SMA with the Marshall compactor[14-15]. However, very limited information is available on the effect of SMA with gyratory compaction. The introduction of the gyratory system is now significant for the mix designer endeavoring to design stiffer and more rut-resistant mixtures.

The application of the SMA mix is still new in Malaysia and there has been little research conducted relating to Malaysian conditions. Therefore, the objective of this study is to determine the aggregate degradation of SMA based on the Malaysian specification. This study was carried out to quantify and compare the amount of aggregate degradation for SMA mixtures produced by 100 gyrations of the SGC and 50 blows of the Marshall Hammer. Contractors from developing countries such as Malaysia may experience problems with the SMA mix because of a lack of experience, since this considered to be a new mix for road pavement compared to standard HMA. This type of information would be valuable to agencies who desire to construct SMA pavements.

■2.0 EXPERIMENTAL DESIGN

2.1 Materials

Crushed aggregates supplied by the Hanson Quarry in Johor were used throughout this investigation. To arrive at a final blend in mixture proportioning, the aggregates were washed, dried, and sieved into their respective size ranges. The coarse and fine aggregates each had a specific gravity of 2.64 and water absorption of 0.48 and 0.86% respectively. Gradation is one of the important factors influencing the properties of HMA such as stiffness, stability, durability, etc. Two aggregate gradations were selected for this study, namely SMA14 and SMA20, as illustrated in Figure 2. The aggregate gradation was designed based on the mean of the gradation limit according to the Malaysian Public Works Department (PWD) specification[4]. A conventional binder was used in this research (penetration grade 76-22). The physical-chemical characteristics of the binder used in this study are listed in Table 1.

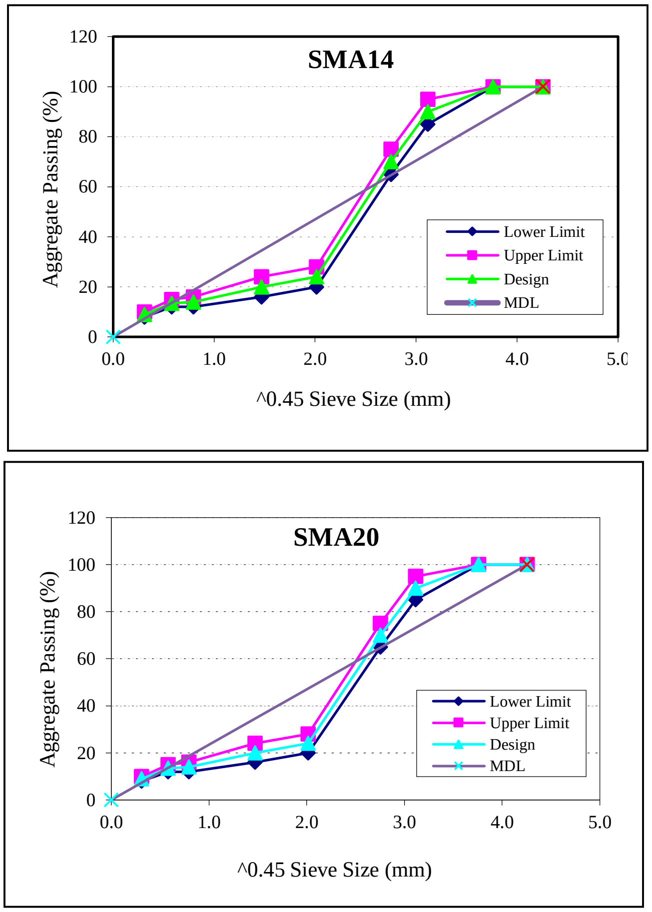


Figure 2 Aggregate gradations for SMA 14 and SMA20

Table 1 Physical-chemical characteristics of the PG 76-22 binder

Test	ASTM	Results
Penetration (dmm)	D5-97	41.5
Softening point (°C)	D36-95	62.0

2.2 Sample Preparation

The laboratory work was divided into several stages, beginning with aggregate preparation and distribution into different particles sizes through sieve analyses. The granite aggregate was dried, sieved, and blended according to the gradation limit fulfilling the PWD specification. Since aggregate properties vary significantly from source to source, it follows that their engineering properties will also differ. In this investigation, the basic aggregate tests were carried out in order to control the quality of the aggregates, and the results are summarized in Table 2. The Marshall and Superpave Mix Design of SMA14 and SMA20 for all specimens were prepared, including mixing and different compaction methods, in order to determine the OAC. A binder-drain down test was carried out with different compactors on three uncompacted specimens for both mix designs. An additional two compacted specimens for each category were also prepared for the asphalt extraction test in accordance with ASTM D 2172-11. This test was done to obtain the extracted aggregate needed for degradation analysis.

Table 2 Properties of granite aggregate

Aggregate test	Flakiness Index	Elongation Index	PSV	ACV	LAAV
Results	18.50%	28.0%	52.1	26.80%	9.30%

2.3 Compaction Methods

As stated earlier, the Marshall and gyratory compaction methods were used in this study. The Marshall test is an empirical test in which cylindrical compacted specimens of 100 mm diameter by approximately 63.5 mm high were immersed in water at 60 °C for 30 to 40 min. The test was carried out according to the D6927-06 test method. Aggregates and binder were mixed and compacted using 50 blows per face of the Marshall Hammer. After compaction, the specimens were removed from the molds and allowed to cool.

As for the gyratory compaction, the design number of gyrations (N_{design}) was 100. A total of 16 specimens were prepared, with two specimens gyrating by SGC at three asphalt contents, 6.0%, 6.5% and 7.0%, for both design mixes, SMA14 and SMA20.The compaction procedure specified by AASHTO T 312 was followed in this study:

a. After mixing, the loose mix materials were spread in a pan. The compaction molds (100 mm diameter) and base plate are placed in the oven at 135 °C for 30-45 minutes prior to use.
b. The vertical pressure of the gyratory compactor is set to 600 KPa (100 psi). The N_{max} (max. number of gyrations) is set at 100.
c. The base plate is fixed in place, with a paper disk on the top of the plate, then the mold is charged by the conditioned mix in a single shift, and a paper disk is placed on the top of the mix. The compactor ram is lowered until it contacts the mix with a resting pressure of 100 psi, then an angle of 1.25 is applied and compaction commences. When N_{max} is reached, the system stops automatically.

■3.0 RESULTS AND DISCUSSION

3.1 Marshall and Gyratory Mix Design

Table 3 shows the mixture design properties at different gradations. It can be seen that the optimum binder contents obtained from both mix designs were almost similar except the Marshall mix design of SMA14, where the optimum binder content was about 0.7–0.8% higher than the others. The greater VMA value obtained from the Marshall mixes, particularly for SMA14, may result from the aggregate degradation during the compaction process. This observation might be related to the presence of a higher percentage of 9.5 mm aggregate in SMA 14 compared to SMA 20 mixes. A study conducted by Prowell found that the density increase with a 9.5 mm SMA beyond the point where stone-on-stone contact was achieved is most likely due to aggregate breakdown[16]. When the aggregate breakdown becomes excessive, a mixture may not be able to meet minimum VMA requirements[17].

Table 3 Mix design results for Marshall and Gyratory compaction at different gradations

Properties	**SMA14**		**SMA20**	
	Marshall	Gyratory	Marshall	Gyratory
OAC (%)	8.7	8.0	8.0	7.9
G_{mb}	2.640	2.640	2.634	2.634
G_{eff}	2.641	2.641	2.644	2.644
G_{mm}	2.325	2.347	2.349	2.353
Air voids (%)	4.20	4.50	4.10	4.80
VMA (%)	23.0	21.9	21.5	21.9
Stability (N)	10490	-	9530	-
Draindown (%)	0.052			

As shown in Table 3, SMA uses a very high percentage of binder. A similar observation was made by Gite and Abjal[18], where the presence of more than 6.5 per cent of OAC is attributed to filling more air voids due to the greater coarseness of the aggregate skeleton. The higher asphalt content contributes to the longevity of the pavements[18]. The VMA for SMA14 using the Marshall compaction was found to be the highest compared to other mixtures. This may due to the excessive aggregate degradation caused by the Marshall Hammer. The additional degradation of aggregate particles obviously helps to fill some of the air voids. When VMA were examined for degradation, it was observed that it decreased or was almost the same when aggregate degradation is not severe for either compaction method.

On the other hand, when aggregate degradation is obvious, the VMA of the Marshall mixes and the gyratory mixes differ significantly. Since less degradation means better quality control, the kneading behavior of the gyratory compactor is more closely related to field rolling compaction. In this investigation, the trend of aggregate degradation experienced in the field followed the trend of the gyratory compaction method; therefore, gyratory compaction is more appropriate than the Marshall Hammer for the mix design.

3.2 Aggregate Degradation by Compaction

The gradation changes by using the Marshall and gyratory compaction methods are listed in Table 4. The difference in the sieve analysis results is shown as the difference (percentage) in gradation before and after compaction. The critical sieve size identified was 4.75 mm for both 19 mm and 12.5 mm mixtures. This is due to the high level of sieve changes between the gyratory and Marshall compactors. However, the coarser part was easier to degrade by Marshall Compaction. It can be deduced that 9.5 mm was the critical sieve.

Table 4 Aggregate degradation under different compaction methods

NMAS	Compactor type	Sieve Change (%)*						
		12.5 mm	9.5 mm	4.75 mm	2.36 mm	0.60 mm	0.30 mm	75 µm
19	Gyratory	-0.5	-1.6	-7.5	-1.2	1.3	2	1.1
	Marshall	-0.4	-2.3	-10.9	-3.2	0.9	2	1.4
	Wheel	8.0	12	-4.5	-0.2	2.5	4.9	5.8
12.5	Gyratory		-1.6	-4.4	-2.3	1.8	2.8	2.0
	Marshall		-2.4	-8.5	-3.9	2.1	3.4	3.6

*Sieve change = % before compaction – % after compaction

3.3 Statistical Analysis by T-test

In this study, the T-test was employed to compare Marshall and gyratory compaction efforts for critical sieve change. The T-test assesses whether the means of two compaction methods are statistically different from each other. This analysis is appropriate to compare the means of both methods. From Table 5 it can be seen that there was an insignificant difference between the Marshall and gyratory compaction methods, as indicated by a p-value of 0.47 and 0.15 at a 95 per cent confidence level for SMA14 and SMA20 mixes respectively. From the results of the analysis shown in Table 6, by comparing laboratory compaction methods with the field roller, the T-test results show that gyratory compaction is not significantly different to the field roller, with a p-value of 0.03, while for the Marshall compaction method there was a significant difference, with a p-value of 0.01. It can be concluded that the gyratory method can be selected to represent the field roller, resulting in a similar trend of aggregate degradation.

Table 5 T-test analysis aggregate degradation under different compaction

Designation	SMA14		SMA20	
	Gyratory	Marshall	Gyratory	Marshall
Mean	-0.29	-0.93	-0.93	-1.78
Variance	8.4	23.21	10.33	19.84
Observations	6.0	6.0	7.0	7.0
Pearson Correlation	0.99		0.99	
Hypothesized Mean Difference	0.0		0.0	
df	5.0		6.0	
t Stat	0.78		1.67	
P(T<=t) one-tail	0.23		0.07	
t Critical one-tail	2.02		1.94	
P(T<=t) two-tail	0.47		0.15	
t Critical two-tail	2.57		2.45	

4.0 CONCLUSIONS

The following conclusions can be drawn based on the results of this study:

a. Aggregate degradation was significantly affected by the compaction method.
b. Using the Marshall Hammer at 50 blows significantly crushed more aggregate than the gyratory compactor at 100 gyrations. These compaction methods critically degraded more aggregate at 4.75 mm sieve size and were not significantly different for SMA14 and SMA20 mix designs.
c. For SMA20 mix design, the field roller produced high aggregate degradation, critically at a sieve size of 9.5 mm.
d. The gyratory compactor was not significantly different from the field roller, while the Marshall compaction method was significantly different.

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