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Evaluating the Impact of Aggregate Gradations on Permanent Deformation of SMA Mixture

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ABSTRACT

Since Stone Mastic Asphalt (SMA) is a gap graded special mix consists of up to 80% by weight of coarse aggregate, therefore, the study of permanent deformation properties of SMA mixtures has become the focus of many studies, which aims to minimize or reduce rutting potential and provide sustainable pavements to protect our environment, thus decreasing the maintenance and rehabilitation cost. This paper presents an evaluation of the effects of aggregate nominal maximum size on the permanent deformation properties of SMA mixtures incorporating granite aggregates. The selected fraction of granite aggregate nominal maximum size (14 mm) was blended in four proportions with 80/100 penetration grade asphalt to determine the permanent deformation characteristics of bituminous mixtures by Repeated Axial Load Test (RLAT) using the Universal Testing Machine (UTM) in accordance with procedures outlined in BS-EN 12697-25:2005. The results and the analysis of the fundamental parameters of permanent deformation has indicated that SMA mixtures specimens containing a higher percentage of coarse aggregate compared to the other specimens gave the lowest permanent deformation. On the other hand, rutting decreases with an increase in aggregate size.

INTRODUCTION

Stone matrix asphalt (SMA) was developed in Germany in the 1960s as a deformation resistant material for use on highways. SMA design provides a stable stone-to-stone skeleton, bonded together by a rich mixture of asphalt cement, filler, and stabilizing agent such as fibre or asphalt modifiers. Thus, SMA was known by its great potential to resist rutting and to decrease wear due to the studded tires (Asi, 2006; Richardson, 1999). Furthermore, SMA is being considered a best alternative in terms of longer life bituminous material, low noise and smooth riding quality mixes, and better return on investment (Muniandy, 2004).

Permanent deformation (rutting) is one of the most significant failure experienced on flexible pavements in the Malaysia. This is attributed by the tremendous increase of volume of traffic and the raises of axle load and truck tire pressure. Environmental factors such as moisture and temperature also have significant influence on rutting. In recent years, the potential for rutting on the Malaysia's highways has increased due to increasing of traffic volume, truck traffic and higher tire pressure. Due to that the service lives of the road pavement are greatly decreased. It is known that the rutting resistance of conventional asphalt mixtures depends on a number

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of factors related to constituents of the asphalt mixtures, such as aggregate type and gradation, sand angularity and asphalt content. In order to eliminate the rutting problem and improve the performance of pavements mixes, the nation's highway agencies are trying to utilize the SMA mixtures in the flexible pavement.

The amount of aggregate in Stone Mastic asphalt (SMA) consists over 90% of the total volume. Hence, such properties of aggregate as gradation and size definitely affect the quality of asphalt mixtures for pavement. Aggregate gradation, which is one of the most important factors to resist pavement distress, is the distribution of particle sizes which is normally expressed in percentage of the total weight (Shen, Kuo, & Du, 2005). El-Basyouny & Mamlouk (1999) concluded that both the aggregate gradation and aggregate nominal size affected the rut depth for Superpave mixes by using creep test, and analyzed the results using the VESYS-3AM (a viscoelastic multilayer program). However, their study was subject to limitations of the model.

Cross, Adu-Osei *et al*. (1999) evaluated permanent deformation of two mixtures with different aggregate gradations using Asphalt Pavement Analyzer (Georgia rut tester) and concluded the finer gradation had better resistance to rutting. Carpenter and Enockson (1987) studied 32 overlay projects in Illinois, USA, and concluded that majority of the rutting problem can be attributed to aggregate gradation. Oliver *et al*. (1997) carried out both field and laboratory study on several mixtures in Australia and concluded that, among other factors, aggregate gradation has a significant influence on rutting resistance. Dukatz (1989) argued that gradation is a key factor in permanent deformation resistance and specifically he argued that bumps on the 0.45 power curve tend to give mixes that are tender, i.e., mixes that rut easily under traffic. However, Cross and Brown (1992) argued that aggregate properties have little effect on rutting when voids are less than 2.5% based on their study, which involved laboratory tests on samples collected from field. Even when percentage of voids is greater than 2.5, Brown and Cross argued that, it is the fine aggregate angularity and not the gradation that has a significant influence on rutting resistance. Also Barksdale Ramsamooj, Ramadan *et al*. (1998) studied rutting of paving materials and found that permanent deformation in dense graded asphalt concrete was not sensitive to gradation of aggregates. Goh *et al*. (2011), analyzed the effects of voids in coarse aggregates to determine SMA mixtures rut potential in the field by used dynamic modulus testing. Hafeez *et al*. (2012) investigated effects of nominal size of four aggregate on rutting potential of SMA using Wheel Tracker at three different temperatures. They concluded that rutting increases with an increase in temperature and decreases with an increase in aggregate size. Besides, Ahmed & Attia (2013) evaluated effect of aggregate gradation and type on HMA rutting in Egypt rutting. They found that rutting resistance is affected by the mix gradation and type of aggregate.

Researchers have come to different conclusions with regard to the effect of aggregate gradation on resistance to rutting of asphalt mixtures. However, most of the authors seem to agree that aggregate gradation has an influence on the rutting resistance of asphalt mixtures. Nevertheless, since the studies were conducted with different methodology and experimental set up, conclusions and results cannot be directly comparable. This study aims to evaluate and determine the permanent deformation characteristics of bituminous mixtures by Repeated Axial Load Test (RLAT) using the Universal Testing Machine (UTM) in accordance with procedures outlined in BS-EN 12697-25:2005 . Binder types, binder content and air voids were kept almost at the same level.

MATERIALS AND METHODS

To study the effect of aggregate gradation on permanent deformation of the mixture, five typical aggregates gradation with nominal maximum size of 14 were employed according to Malaysian Standard Specification for Road Work (JKR) (2005) as tabulated in Tables 1. Single source of aggregates were used to avoid the influence of change in the properties of aggregate to mixture's performance. Figure1 illustrate the semi-log graph their typical percentages used in the mixtures.

Table 1: Typical and Selected Aggregate Grading.

Sieve size	Percent Passing %					
(mm)	G1	G2	G3	G4	G5	Specification
14	80	87.5	95	92	83	80 - 95
9.5	68	79	90	87	71	68 - 90
5	52	62	72	66	58	52 - 72
3.35	45	55	65	55	55	45 - 65
1.18	30	37	45	35	40	30 - 45
0.5	17	23	30	21	26	17 - 30
0.15	7	11.5	16	8	15	7 - 16
0.075	4	7	10	4	10	4 - 10

The mix design was performed using Marshall design method and the optimum asphalt content is defined following University Putra Malaysia (UPM) method as the average of 4 values (asphalt content at 4% air voids, asphalt content at maximum stability, asphalt content at maximum density, and asphalt content at maximum resilient modules).

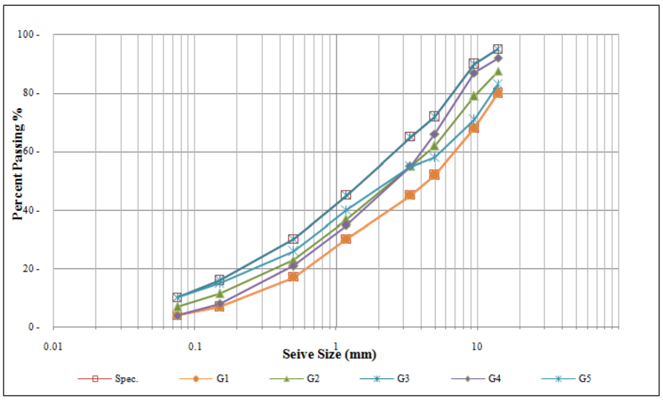

Fig. 1: Aggregate Gradations Limits.

The repeated load test has been used to characterize permanent deformation responses of the designed mixes under more realistic conditions than those of the creep test. Test loading stress of 500 kPa has been applied to measure the response of asphalt concrete mixes to repeated loading with 2000 ms pulses period at temperature of 40ºc. The load was applied until sample failure.

The creep behaviour of asphalt concrete can be analyzed with respect to both mix parameters and test condition parameters. As mentioned before objective of this study is to investigate the effect of gradation on permanent deformation properties of asphalt concrete.

RESULTS AND DISCUSSIONS

In this study the Bailey Methods used to identified coarse and fine base on the nominal maximum size of aggregate (Zafar, n.d.). In this method the sieve that separates the coarse and fine aggregates is known as Primary Control Sieve (PCS) where for Nominal Maximum Particle Size (NMPS) of 14mm the coarse aggregate considered material retained on sieve #6 (3.35 mm) and fine aggregate as material passing sieve #6 (3.35mm).

In Table 2 below shows the Coarse Aggregate Ratio (CA Ratio), Fine Aggregate Coarse Ratio (FA_c Ratio), and Fine Aggregate Fine Ratio (FA_f). The CA Ratio below the corresponding range suggested in the above mentioned table could indicate a blend that may be prone to segregation. An increase in CA Ratio will cause a corresponding increase in air voids and VMA, hence CA Ratio increases towards 1.0, VMA increase. As the ratios FA_c and FA_f increase, the packing of fine aggregates becomes denser and the and at the same time voids in the mixture decrease. With a balanced aggregate structure the mixture should be easy to compact in the field and should perform optimally under load.

Table 2: Control sieves for asphalt mix.

	NMPS (14mm)								NMPS (14mm)
	G1	G2	G3	G4	G5	Specification		Half Sieve	9.5
CA Ratio	0.72	1.14	2.50	2.46	0.55	0.72- 2.5		PCS	3.35
FA_c Ratio	0.67	0.67	0.69	0.64	0.73	0.67- 0.69		SCS	1.18
FA_f	0.23	0.31	0.36	0.23	0.38	0.23- 0.36		TCS	0.15

The results of optimum asphalt content (OAC) and resilient modulus at OAC are presented in Figure 2. Results indicate that there is a difference in optimum asphalt content due to aggregate gradation from 4.3 to 5.13 percent by weight of total mix. A lower OAC was achieved by gradation 4 and higher resilient modulus was achieved by gradation1.

Samples at OAC for all mixes were tested in Repeated Axial Load Test (RLAT) to study the effects of aggregate gradations on the rutting characteristics of asphalt mixes. The results of RLAT are presented in Figures 3.

Permanent Strain was taken as a good indicator for rutting resistance (RR) in the specimens. This parameter has been used to evaluate asphalt mixtures for their susceptibility to rutting based on the cyclic load triaxial test. Figure 3(a) plotted the mean creep curves for analysis in regard to gradation type for SMA 14 with respect to applied stress. Besides, Figure 3(b) illustrated that the 1%, 3%, failure of permanent strain with respect to the number of cycles for each gradation. Results show that the gradation 1 had the highest RR and gradation 2 had the lowest RR. Results are presented in graphical form followed by an evaluation of the conventional permanent deformation parameters for their sensitivity to changes in proportion of aggregate.

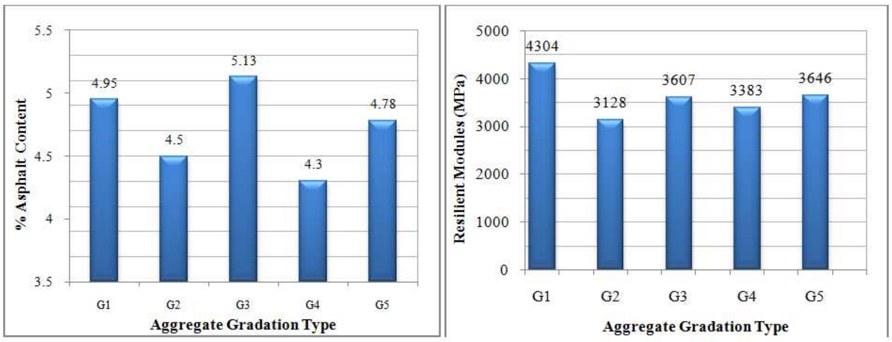

Fig. 2: Effect of aggregate gradation on mix properties.

The creep rate is often calculated in the secondary creep range (the straight-line portion) of the creep curve. However, this has proved to be difficult in many cases because generally there is no part in the creep curve with really constant slope. In addition, some specimens can fail (enter the tertiary creep range) without showing any distinct secondary creep range and others undergo large deformation apparent in the primary creep range. The creep rate can be calculated by a least square linear fit of the linear part of the creep curve, if any linear part is present, but the result depends highly on the selected interval used for curve fitting. In this study, the creep rate was calculated by assuming the curve within each interval as straight lines and taking the slope of the line. Hence, for each mix in experiment in phase II, the average mixtures creep slope (log psi/log Sec) was calculated. The average deformation rates are given in Table 3 with various granite proportions.

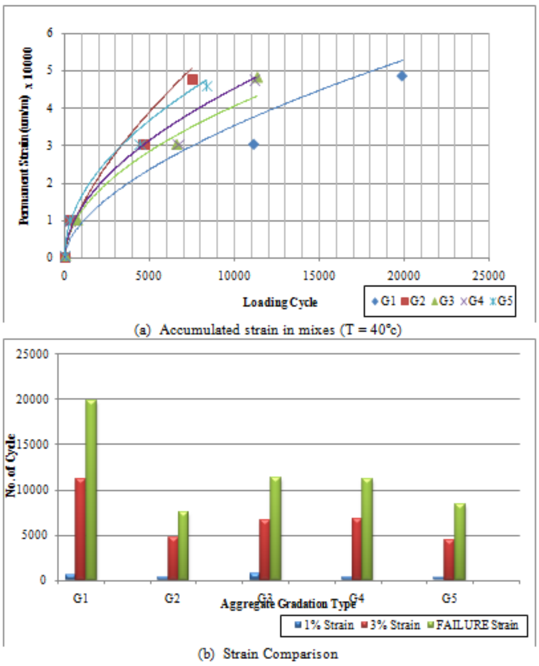

Fig. 3: Effect of aggregate gradation on rutting resistance.

Table 3: Average creep slope (SMA14).

Sample	Slope (Log psi/logs Sec)	Granite Aggregate Proportion (%)		
		Coarse	Fine	Filler
G1	1.098	55	41	4
G2	1.214	45	48	7
G3	1.143	35	55	10
G4	1.156	45	51	4
G5	1.191	45	45	10

The unit strain per cycle plotted according to the percentage of fines aggregate is as shown in Figure 4. To find a mathematical model that fits these data with a straight-line function, found out as the fines increase, unit per cycle increases at the rate of (0.0018X + 1.0735). In addition, it showed that the creep slope decreased while the percentage of coarse aggregate is increased. The creep slope changed at the rate of (-0.0022X + 1.2616).

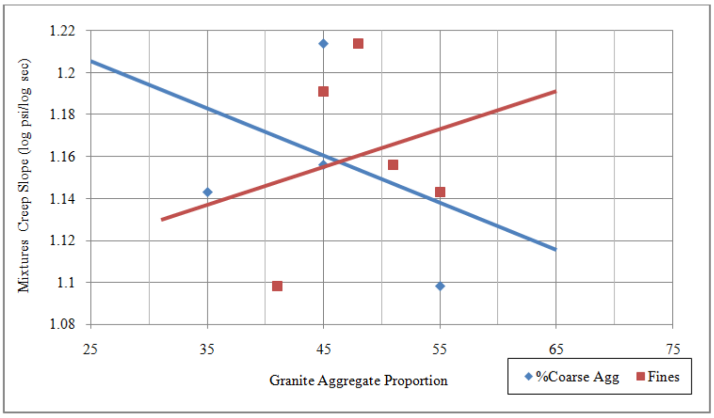

Fig. 4: Creep rate with regards to granite proportion.

Conclusions And Recommendation:

The evaluation of the creep test result for SMA14 indicated that the mixture will have superior deformation resistance (that means lower creep slope) when the mixture have more coarse aggregate and a less amount of fines. Furthermore, the equilibrium point shows the fines and coarse aggregates have appropriate proportion which had almost identical percentage (54/46) with the creep slope rate of 1.56. The predicted gradation is almost near to gradation1, as discussed earlier.

It was observed that the gradation characteristics have a strong effect on the strength and stability properties of SMA mixtures. These characteristics include the proportioning required to achieve a well-balanced continuous gradation, otherwise known as well-graded gradation. On the other hand, it can be reported that the creep or permanent deformation is affected by coarse and fine aggregate proportion of mixture. This agrees with the findings of Ahmed & Attia(2013) and El-Basyouny & Mamlouk, (1999) who recommended the use of continuously coarse graded mix to reduce rutting susceptibility of asphalt concrete.

Consequently, it is extremely important that a suitable gradation be selected to minimize potential problems with the rutting or cracking of flexible pavements. In the future study it is recommended that the effect of temperature, on SMA is also investigated.

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