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Evaluation of Malaysian Hot-Mix Asphalt Properties at Different Aggregate Gradations

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Abstract: The properties of coarse and fine aggregates used in hot-mix asphalt (HMA) mixtures significantly affect the performance of the highway pavements in which they are used. The selection of aggregate gradation for use in HMA pavement is important to pavement performance. This study was conducted to evaluate the effectiveness of aggregate gradation on HMA according to JKR specification/1988 and JKR specification/rev. 2005. The laboratory tests carried out to determine the properties of aggregates included sieve analysis, the Los Angeles Abrasion Test, Aggregate Impact Value and Aggregate Crushing Value. A Resilient Modulus Test and Static Creep Test were also carried out to determine the performance of HMA by using Materials Testing Apparatus. In general, the aggregate gradation of Mixture 2, which follows JKR specification/rev. 2005, is better than the aggregate gradation of Mixture 1, which follows JKR specification/1988.

Key words: hot-mix asphalt, aggregates, creep, Marshall Stability and Flow.

INTRODUCTION

Hot-mix asphalt (HMA) is defined as a complex mixture composed of bituminous binders and mineral aggregate. The bitumen, black or dark brown in colour, acts as an adhesive, gluing the aggregate into a dense mass and waterproofing the aggregate particles. The mineral aggregate, when bound together, acts as a stone framework to give strength and toughness to the composite system. HMA performance is affected by the individual properties of both aggregate and bitumen and the interaction between them (Reubush, 1999).

HMA contains a significant amount of mineral aggregate, approximately 95% by weight and 85% by volume (Liu and You, 2011). The American Society for Testing and Materials (ASTM) defines aggregate as a granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone, with a cementing medium to form mortar or concrete, or alone as in base course or railroad ballast. Aggregates for HMA are usually classified by size as coarse aggregates, fine aggregates, or mineral fillers. ASTM also defines coarse aggregates as particles retained on a No. 4 (4.75 mm) sieve, fine aggregate as that passing through a No. 4 sieve (4.75 mm) and mineral filler as material with at least 70 per cent passing through a No. 200 (75 µm) sieve (ASTM, 2003).

Aggregate gradation is the most important property of HMA, as well as stiffness, stability, durability, workability, fatigue resistance and resistance to moisture damage. Aggregate grading is the distribution of particle size expressed as a percentage of the total weight. Grading is determined by passing the aggregate through a series of sieves stacked with progressively smaller holes from top to bottom, and weighing the material retained on each sieve. The gradation of an aggregate is normally expressed as the percentage passing through various sieve sizes (Robert et al., 1996).

The large increase in the number of vehicles and the volume of heavy traffic on the roads has consequently increased the tire pressure and axle loads imposed on the pavement structure. Hence, there is a need to enhance asphalt pavement mixtures that may prone to rutting and cracking to withstand the increase in loading, mitigate the adverse effects on pavement performance and reduce the occurrence of premature rutting. Therefore, the selection of aggregate gradation for use in HMA pavement is important to pavement performance (White et al., 2006). The proper gradation of aggregates is strongly affected by the mix properties such as air voids, stability and resistance to permanent deformation.

This study was conducted to evaluate the effectiveness of aggregate gradation on HMA according to Malaysian Public Works Department specification; namely JKR specification (ACW14, 1988) and JKR specification (ACW14, 2005). This study also aims to vary aggregate gradation in the HMA mixtures to determine the effects on HMA criteria such as stability, density and strength. The laboratory tests carried out to determine the properties of the aggregates included sieve analysis, the Los Angeles Abrasion Test (LAAT), Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV). A Resilient Modulus Test and Static Creep Test were also carried out to determine the performance of HMA by using Materials Testing Apparatus

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(MATTA). Samples were prepared by means of the Marshall Design method, in accordance with Malaysian Public Work Department Specifications.

2. Experimental Design:

2.1 Bitumen:

Penetration grade 80/100 bitumen was used in this study, supplied from one source in order to ensure the consistency of the original bitumen properties. Basically, this pen-grade bitumen has been used extensively for bituminous pavement in Malaysia.

2.2 Aggregates:

In this study, two commonly used aggregates were prepared; namely fine and coarse aggregates. All testing was conducted based on the "JKR Standard Specification for Road Works". A sieve analysis was made of each range, and then a quantity of aggregate of the selected blend was prepared into several sizes by the sieve method. Other aggregate properties measured included the Los Angeles Abrasion Test (LAAT), Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV). Details of the results are discussed in the following section.

RESULTS AND DISCUSSION

3.1 Aggregate Mechanical Property Test:

Four different tests were conducted to determine the mechanical properties of the aggregates. All results must be within the range of the JKR specifications.

3.1.1 Specific Gravity and Absorption of Aggregate:

This test is done to determine the aggregate absorption of the asphalt. Water absorption by the aggregate can define the ability of the aggregate to absorb asphalt. Table 1 shows the results of the specific gravity and absorption of the aggregates. The testing results show that the average value of specific gravity is 2.634 for both mixtures.

Table 1: The Specify Gravity and Absorption of the Aggregates

	A	B	C		
Sample Number	Weight of sample in air (gm.)	Weight of sample in water (gm.)	Saturated Surface-Dry, SSD (gm.)	Absorption (C-A)/A	S.G. A/(C-B)
1	1000	624.3	1005.1	0.51	2.63
2	1000	625.7	1004.2	0.42	2.64
Average				0.46	2.634

3.1.2 ***Sieve Analysis:***

The gradation of an aggregate is normally expressed as the total percentage passing through various sieve sizes. Tables 2 and 3 show the gradation of the aggregates for both mixtures. From the result, Mixture 1, mixed according to JKR/1988, has 55% fine aggregate and 38% coarse aggregate of the total weight, while Mixture 2, mixed according to the JKR/rev. 2005 specification, has 44% coarse aggregate and 55% fine aggregate. In addition, Mixture 1 has a higher percentage of mineral filler than Mixture 2.

Table 2: The Gradation of the Aggregate for JKR/1988

Sieve No.	Minimum	Maximum	Passing	Retaining
20	100	100	100	0
14	80	95	87.5	12.5
10	68	90	79	8.5
5	52	72	62	17
3.35	45	62	53.5	8.5
1.18	30	45	37.5	16
0.425	17	30	23.5	14
0.15	7	16	11.5	12
0.075	4	10	7	4.5
Pan	0	0	0	7

Table 3: The Gradation of the Aggregate for JKR/rev. 2005

Sieve No.	Minimum	Maximum	Passing	Retaining
20	100	100	100	0
14	90	100	95	5
10	76	86	81	14
5	50	62	56	25
3.35	40	54	47	9
1.18	18	34	26	21
0.425	12	24	18	8
0.15	6	14	10	8
0.075	4	8	6	4
Pan	0	0	0	6

3.1.3 *Los Angeles Abrasion Test:*

The Los Angeles Abrasion Test is primarily a measure of the resistance of aggregate to degradation by abrasion and impact. The average value obtained from this test is 21.4%, as shown in Table 4.

Table 4: Values from the Los Angeles Abrasion Test

Specimen	1	2
Weight of aggregate before test, A (gm.)	5000	5000
Weight of aggregate after test, B (gm.)	3933	3927
Loss, X = A-B	1067	1073
% Loss = (X/A)*100%	21.34	21.46
Average Loss (%)	21.4	

3.1.4 *Aggregate Crushing Value Test:*

The crushing value is the ability of the aggregate to withstand crushing due to loading. The higher the crushing value, the greater the crushability of the aggregate. The average crushing value of the aggregates for both mixtures is 25.56%. Table 5 shows the results of the aggregate crushing value.

Table 5: Aggregate Crushing Value

Specimen	Initial Mass (A)	Final Mass (B)	ACV = (B/A)*100
1	2730	725	26.56
2	2728	670	24.56
Average (%)			25.56

3.1.5 Aggregate Impact Value Test:

The aggregate impact value test measures the resistance of aggregate subjected to sudden loading, such as that inflicted by heavy vehicles. Table 6 shows that the average aggregate impact value for both mixtures is 10.18%, which is within the JKR specification.

Table 6: Impact Test Values

Sample No.	Weight of Aggregate, A	Weight of Aggregate Passing 2.36mm, B	AIV = (B/A)*100%	Average AIV (%)
1	650	65.7	10.12	10.12
2	645	66	10.23	

3.1.6 Comparison with JKR Specifications:

The results obtained from the aggregate mechanical property test show that the aggregate is of good quality according to the specified requirements used in this research. Also, the results show that all the physical properties of the aggregate are suitable for the mix design. Table 7 shows a comparison between the JKR specifications and the results obtained from the tests.

Table 7: Comparison between JKR Specifications and Obtained Results

Properties	JKR Specification, 1988	JKR Specification, 2005	Result Obtained
Bulk Specific Gravity	-	-	2.634
Absorption, %	2 Max.	2 Max.	0.46
LA Abrasion, %	30 Max.	25 Max.	21.4
Aggregate Crushing Value, %	30 Max.	30 Max.	25.56
Aggregate Impact Value, %	30 Max.	30 Max.	10.18

3.2 Optimum Asphalt Content:

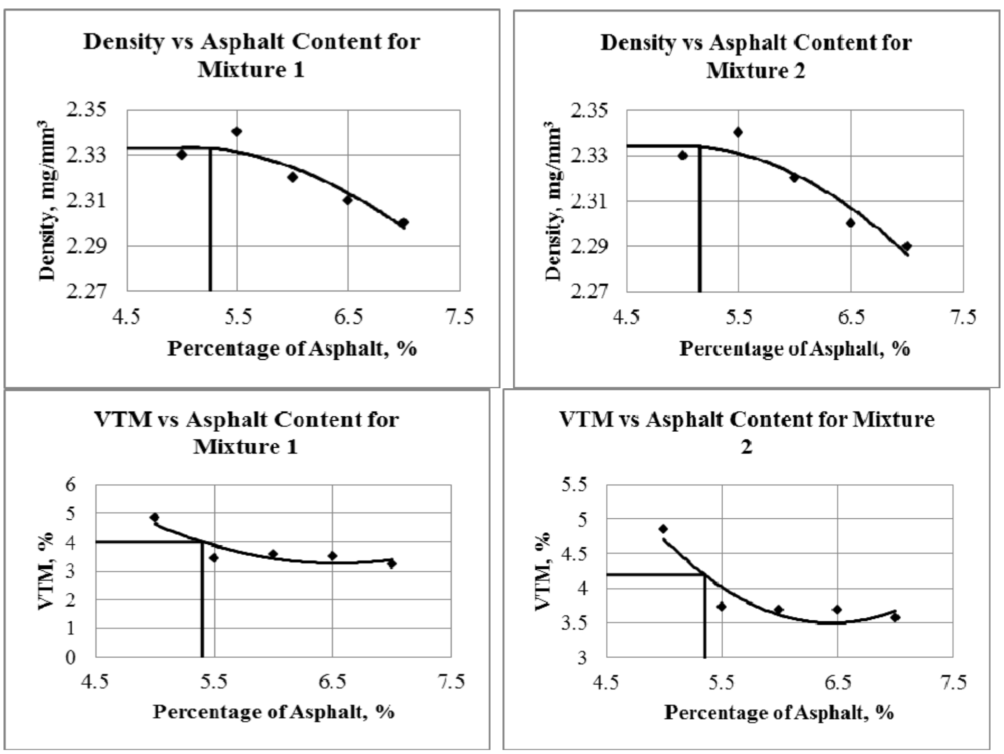
This stage was conducted by using MATTA apparatus and the Marshall Design method. The results of the Marshall Design method are used to plot the required graphs to determine the optimum asphalt content in the mix. The required graphs to determine the optimum asphalt content percentage are: 1) Bulk density vs asphalt content; 2) Air voids (VTM) vs asphalt content; and 3) Resilient modulus vs asphalt content. The graphs for bulk density, resilient modulus and voids in total mix (VTM) for Mixture 1 and Mixture 2 are given in Figure 1. In these figures it can be seen that bulk density and voids decrease with an increasing percentage of asphalt. The resilient modulus value of Mixture 1 is higher than the resilient modulus value of Mixture 2, at 580 MPa and 374 MPa respectively. This could be attributed to the higher asphalt content, mineral filler and coarse structure of Mixture 1 compared to Mixture 2. The optimum asphalt content of Mixture 1 is 5.5% and for Mixture 2 is 5.4%.

3.3 Mix Performance Analysis:

A comparison of the two types of mixture was conducted in this stage. The static creep test and Marshall Stability test were carried out to evaluate both types of mixture.

3.3.1Static Creep Test:

This test involves the application of a static load to the sample for a specified time and temperature, and the subsequent deformation of the sample is then measured. The results of this test are shown in Table 8. For Mixture 1, the value of the creep modulus is 29 MPa and the permanent strain is 7601 µ€, and the corresponding values for Mixture 2 are 38.1 MPa and 6856 µ€. This shows that Mixture 2, permanent deformation occurred at a lower strain. This also means that Mixture 2, which follows the JKR/rev. 2005 specification, would have the best resistance to rutting in a road pavement. However, Mixture 1, which follows the JKR/1988 specification, requires a higher strain for permanent deformation to occur compared to Mixture 2. This could be attributed to the greater amount of mineral filler, the percentage of particular sizes of aggregate and the low mechanical interaction between the asphalt and aggregate.



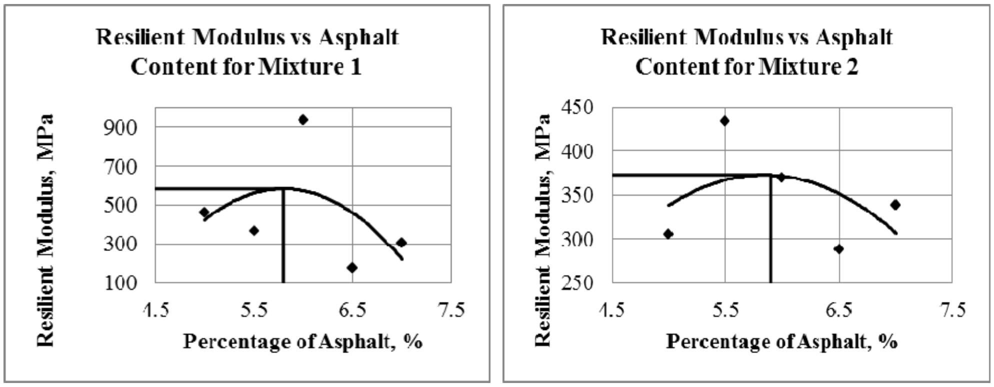


Fig. 1: Selection of optimum asphalt binder contents for Mixture 1 and Mixture 2

Table 8: Results of Static Creep Test for Both Mixtures

Sample No.	Creep Modulus Value (MPa)	
	Mixture 1	Mixture 2
1	39.68	44.9
2	18.36	31.3
Average	29.02	38.1

3.3.2 Marshall Stability Test:

Stability is the ability of the asphalt pavement mixture to resist deformation from imposed loads. Stability is dependent upon both internal friction and cohesion. Frictional resistance increases with the gradation and surface toughness of the aggregate particles. The results of the Marshall Stability test are showed in Table 9. The Marshall Stability values for Mixture 1 and Mixture 2 are 14.15 kN and 15.32 kN respectively. This shows that Mixture 2 has a higher value of Marshall Stability than Mixture 1, and the flow for Mixture 2 is also higher than for Mixture 1.

Table 9: Marshall Stability Results for Both Mixtures

Sample No.	Marshall Stability Value			
	Mixture 1		Mixture 2	
	Marshall Stability	Flow Value	Marshall Stability	Flow Value
1	14.8	2.2	16.8	3.19
2	13.5	2.81	13.8	4.13
Average	14.15	2.5	15.32	3.66

Conclusions:

Based on the analysis presented, the following conclusions can be made:

- The indirect tensile strength of Mixture 1 is higher than Mixture 2. This indicates that Mixture 1 has higher values of resilient modulus at failure indirect tensile strength under a static load. This would further imply that Mixture 1 appears to be capable of withstanding larger tensile strains prior to cracking (internal resistance).
- The Marshall Stability value of Mixture 2 is higher than Mixture 1. The reasons behind these results are that the asphalt and dust content is higher in Mixture 1 than Mixture 2.
- For the static creep test, the results indicate that the value of permanent strain of Mixture 1 is higher than Mixture 2. This could be attributed to the higher mineral filler content, the percentage of particle sizes of the aggregate and the low mechanical interaction between the asphalt and the aggregate.
- In general, the aggregate gradation of Mixture 2, which follows JKR specification/rev. 2005, is better than the aggregate gradation of Mixture 1, which follows JKR specification/1988. This could be due to the mineral filler and particle size of the aggregate. In addition, the higher asphalt content of Mixture 1 provides a higher resilient modulus and lower values of the Marshall Stability and creep modulus. Another reason could be that there is too much asphalt cement in the mixture, causing a loss of internal friction between the aggregate particles and the asphalt cement. This may lead to high permanent deformation.

REFERENCES

American Society for Testing and Materials, 2003. *Annual Book of ASTM Standards. Volume 04.03, Road and Paving Materials; Vehicle-Pavement Systems. ASTM International, West Conshohocken*, Pennsylvania.

Liu, Y., and Z. You. 2011. Discrete-Element Modeling: Impacts of Aggregate Sphericity, Orientation, and Angularity on Creep Stiffness of Idealized Asphalt Mixtures. J. Eng. Mech., 137(4): 294-303.

Public Works Department Malaysia, 1988. Specification for Road Works. Kuala Lumpur.

Public Works Department Malaysia. Rev., 2005. Specification for Road Works. Kuala Lumpur.

Reubush, S.D., 1999. Effects of Storage on the Linear Viscoelastic Response of Polymer-Modified Asphalt at Intermediate to High Temperature. MSc Dissertation, the Virginia Polytechnic Institute and State University.

Roberts, F.L., P.S. Kandhal, E.R. Brown, D.Y. Lee, and T.W. Kennedy, 1996. Hot-Mix Asphalt Materials, Mixture Design and Construction, 2nd Edition. NAPA Education Foundation, Lanham, Maryland.

White, T.D., J.E. Haddock and E. Rismantojo, 2006. Aggregate Tests for Hot-Mix Asphalt Mixtures Used in Pavements. NCHRP Report 557. Transportation Research Board, Washington D.C.