Investigation of Superpave Mixtures in Malaysia

J. Ahmad
Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

M.Y. Abdul Rahman
Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

M.R. Hainin
Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia

ABSTRACT: During the last decade, the hot-mix asphalt (HMA) mixture design has undergone major changes with respect to mix design method and mix characterisation. Currently in Malaysia, the Marshall mix design method is still used to construct HMA pavements. This study was initiated to evaluate and compare the performance of Superpave-designed and Marshall method-designed HMA mixtures in Malaysia. Laboratory tests were done to evaluate permanent deformation (rutting) and resilient modulus of 14 different Superpave and Marshall mixtures. Dynamic modulus tests using the Simple Performance Test (SPT) were also conducted. Results obtained from the dynamic modulus tests were analysed to determine any possible correlation between rutting and modulus. Correlation to rutting was established at 40°C, 45°C and 50°C and loading rate of 0.5 Hz, 1 Hz, 2 Hz and 5 Hz from then SPT dynamic modulus test. Results showed good correlation between dynamic modulus rut factor and rutting at 40°C and 50°C at 5 Hz loading frequency. Results also showed good correlation between dynamic modulus and resilient modulus with the coefficient of determination, R^2 values ranging from 0.66 to 0.71 at 40°C. Since the dynamic modulus test provides full characterization of the mix over a broad range of temperature and loading frequencies, this test is highly recommended for Superpave mixture characterization in Malaysia.

KEY WORDS: Marshall mix design, rutting, Simple Performance Test, Superpave mix design, resilient modulus

1 INTRODUCTION

Tremendous development in the national infrastructure network over the last decade has led to increase in road construction throughout Malaysia. Asphaltic road dominates the overall surfacing types at 87,626 km. Conventional Marshall design method for HMA mix has been used for decades by the Public Works Department (PWD) to construct pavements following JKR/SPJ/2008 standard specification. Although these pavements are still in service, large amount of money is allocated for maintenance work annually due to pavement distress which sometimes occurred prematurely due to increasing traffic loads and wet tropical climatic condition.

Recently, several studies have been conducted outside United States to evaluate the feasibility and performance of Superpave-designed mixtures. A study in Taiwan compared the volumetric and mechanical performance properties of Superpave mixtures and typical Taiwan mixture (TTM) using the Marshall method (Wang et al., 2000). Results showed that the asphalt binder contents for the Superpave-designed mixtures are lower than TTM Marshall-designed mix and TTM mixtures exhibited low densification values. In Jordan, a research study proved the superiority of Superpave mixes over Marshall mixe. A study in India showed that the Superpave gyratory compactor (SGC) is capable of achieving lower air void contents than that could be achieved by the mechanical Marshall hammer compactor (Swami et al., 2004). This study also found that Superpave mixes have less asphalt binder contents than the Marshall mixes. This study was conducted to ascertain and evaluate how well Superpave designed mixtures performed compared to conventional Marshall mix with respect to permanent deformation (rutting) using local materials in Malaysia.

2 OBJECTIVES

The primary objective of this study is to evaluate the volumetric properties of both Superpave and Marshall designed mixtures using local materials. Then, a comparison between Superpave and Marshall mixtures was done for permanent deformation (rutting) using SPT dynamic modulus, resilient modulus, and wheel tracking tests.

3 VOLUMETRIC PROPERTIES OF HMA

Aggregate properties were evaluated for compliance with both mix design system. According to PWD specifications, only granite aggregates are permissible for use for asphalt wearing course. Granite aggregates from Klang Valley, denoted as QS is located in the central part of Peninsular Malaysia, were used to produce the asphaltic mixtures. Two different gradations with different nominal maximum aggregate size (NMAS) were selected as shown in Figures 1 and 2. To enable comparison of volumetric properties and rutting performance between the mixes, the gradations for all mixtures were purposely selected to fall within the upper and lower limits complying with both Superpave and PWD Marshall grading requirements. A total of eight mixes were designed of which four were Superpave-designed mix and the rest were Marshall mixes.

Asphalt binders of penetration grade 80/100 (B1) and 60/70 (B2) were used to design the mix as per recommendation for roadwork construction in the PWD specifications. Since the weather is consistent throughout the country, the binder used was not classified according to performance grade as required in the Superpave system.

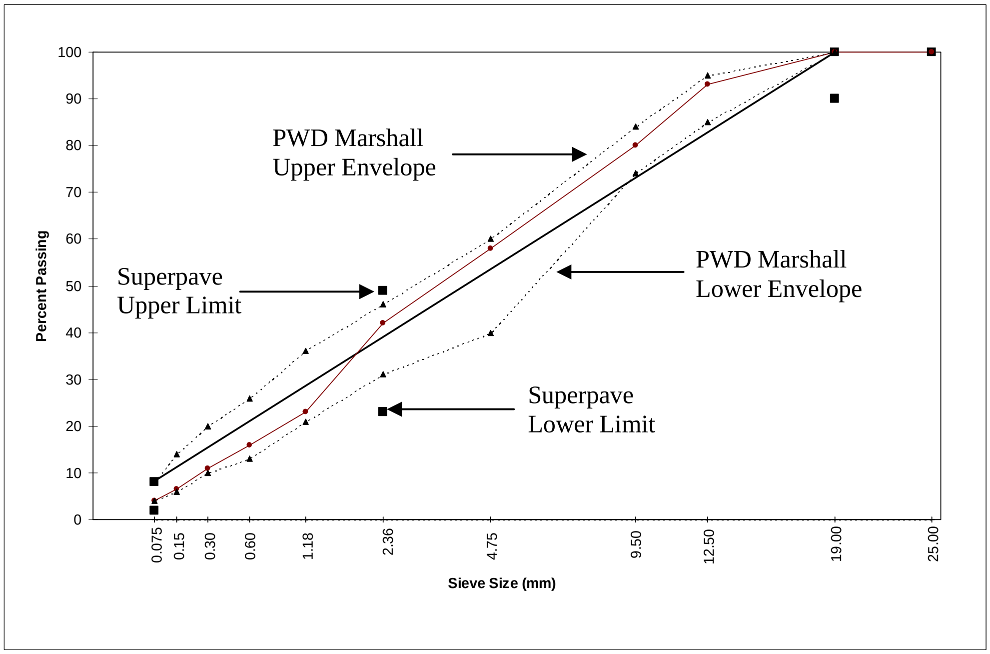


Figure 1: NMAS 12.5mm gradation

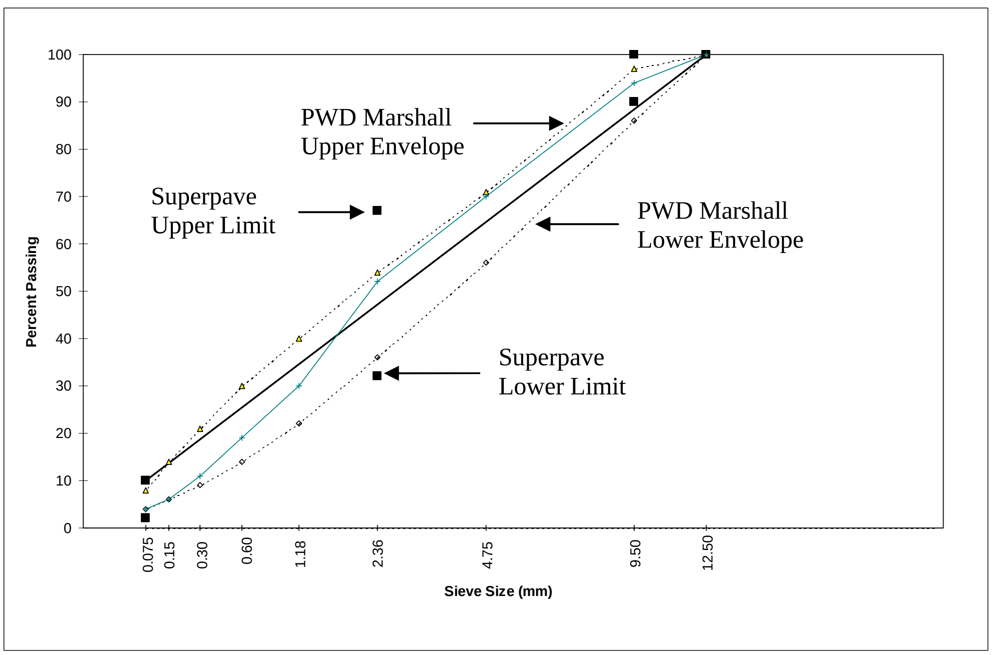


Figure 2: NMAS 9.5 mm gradation

Aggregate properties were determined and found to comply with both Superpave and PWD Marshall criteria of acceptance for use in mix design as shown in Table 1. Standard Marshall compactor is used to fabricate the specimens at 75 blows per face to achieve design density. The optimum asphalt binder content (OBC) was calculated from bulk density, voids filled with asphalt and flow values of the specimens.

The compactibility of the Superpave mixture was determined using initial compactive effort (N_{ini} = 8 gyrations) and the anticipated state of density in the mixture after an equilibrium condition is achieved (corresponded to N_{des} = 100 gyrations). The maximum compactive effort, N_{max} =160 gyrations was selected to ensure the material does not over compact under traffic. For the Superpave-designed specimens, when blended at OBC, should yield acceptable volumetric properties based on the established Superpave criteria corresponding to 4% air voids. The volumetric properties are voids in mineral aggregates (VMA), voids filled with asphalt (VFA), air voids and dust proportion (DP). The properties of the design mixtures in this study are tabulated in Table 2.

Table 1: QS aggregate properties

Aggregate Tests	Results	Criteria
Consensus properties		
Coarse Aggregate Angularity	75 %	55-100 %
Fine Aggregate Angularity	52 %	>45
Flat & Elongated	6.75 %	10 (Max)
Sand Equivalent	47.9 %	>45 %
Source properties		
Soundness	6 %	>10-20 %
Toughness	10 %	<45 %
Deleterious Material	0.3 %	0.2-10 %
PWD requirements		
Aggregate Impact Value	19 %	<30 %
Aggregate Crushing Value	21 %	<30 %
Ten Percent Fines	270 kN	>100 kN
Water Absorption	0.3 %	<2 %

From the results obtained, OBC of Marshall mix is approximately 0.5 % higher than Superpave mix. This shows that with the same design aggregate structure, Superpave designed mixtures need less asphalt binder compared to the Marshall-designed mixes. In addition, it is also noted that NMAS 9.5 mm mixtures use more asphalt binder than NMAS 12.5 mm mixes because of higher surface area.

Table 2: Volumetric properties

Mix Design Properties	12.5-B1	12.5-B2	9.5-B1	9.5-B2	Criteria
Marshall designed mixtures (PWD)					
OBC (%)	5.6	5.9	6.1	6.2	-
Stability (kN)	10.2	10.1	10.2	11.0	>8 kN
Flow (mm)	3.5	3.5	3.2	3.3	2-4 mm
VFA (%)	75	75	75	77	70-80
Superpave designed mixtures					
OBC(%)	5.1	5.3	5.4	5.7	-
Air voids (%)	4.0	4.0	4.0	4.0	4%
VMA (%)	14.9	15.8	15.7	16.5	14min#
VFA (%)	73.1	74.4	74.6	75.7	65-76*
DP	0.8	0.8	0.8	0.7	0.6-1.2

Note: B1-asphalt binder refers to PEN 80/100 and B2 refers to PEN 60/70;
(*) For NMAS 9.5, VMA is specified as 15 (min);
(#) For NMAS 9.5, VFA range shall be 65-76 percent and NMAS 12.5 VFA range shall be 65-75 percent

4 LABORATORY EXPERIMENTS

This study also evaluated and compared the permanent deformation of Superpave and Marshall mixes using three different test techniques; SPT dynamic modulus, rutting from wheel tracking, and resilient modulus test. The rutting test is an empirical test conducted to determine the rut depth of the mixtures at an elevated temperature. The SPT dynamic modulus and resilient modulus test were conducted to characterize and evaluate permanent deformation at high temperatures.

4.1 Wheel tracking test

The dry wheel tracking test was conducted using Wessex wheel tracking device (Fig. 3(a)). A mold was fabricated to hold the SGC rut specimens in the wheel tracking device (Fig. 3(b)). The height of the SGC rut mould follows exactly the original slab mould of the Wessex wheel tracking device. This is to avoid any inaccuracy during the rutting test. Approximately 3,700 g of Superpave or Marshall mix was compacted to 7 ± 0.5% air voids to make a cylindrical specimen with a diameter of 150 mm, and final height of 65 mm. This was accomplished by putting a given amount of mixture in the SGC mould and compacting to the specified height. The specimens were left to cool in room temperature for 24 hours after compaction. The air voids content was also determined before conducting the test to meet test requirements. The specimens were then trimmed and paired to fit in the wheel tracking mould. Care was taken to make sure the specimens fit exactly in the mold. The rut test was conducted at 60^{o}C since initial tests at 40^{o}C showed negligible rut depths. Prior to testing, the specimens were conditioned for at least four hours at test temperature. The specimens were subjected to a simulated trafficking with a simple harmonic motion by applying 525 N load for one hour. The LVDT transducer monitors the rut depth at the centre of the slab and setup of the equipment is as shown in Figure 3.

Figure 3: (a) Wheel tracking test setup; (b) SGC fabricated specimen

In general, Superpave mixtures exhibited rutting resistance compared to Marshall-designed mixtures. Figure 4 shows that the Superpave mixtures rutting values varies from 0.8 mm to 3.0 mm compared to Marshall mixtures with high rut values ranging from 4.1 mm to 6.5 mm. This obviously indicates the high resistance of Superpave mixtures compared to the Marshall mix. In addition, results also showed that NMAS 9.5 mm grading for a particular mixture showed lower rut values compared to NMAS 12.5 mm mixtures. Asphalt binder type was also contributed to the rutting resistance. In this study, HMA with asphalt binder type 60/70 (B2) exhibited better good rutting resistance than asphalt binder type 80/100 (B1).

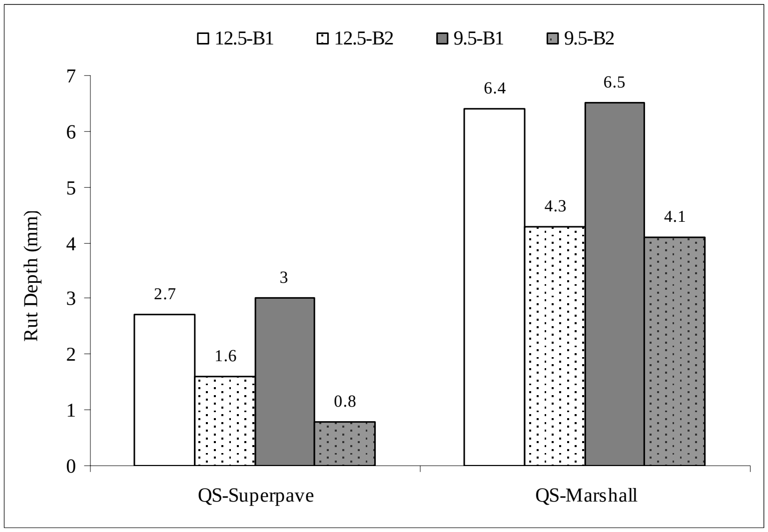


Figure 4: Comparison between Superpave and Marshall Mix

4.2 Resilient modulus test

The specimens were fabricated at OBC and resilient modulus test was conducted to evaluate rutting at 40^{o}C using IPC UTM-5 machine, according to ASTM 4123. Figure 5 shows the schematic of the test setup. These specimens were subjected to cyclic load with sinusoidal wave shape and the test sequence consisted of five count of conditioning pulses followed by five loading pulses when data acquisition took place. The load was applied for a period of 0.1 seconds and has a rest period of 0.9 seconds. The horizontal and vertical deformations were measured by the extensometers and LVDTs, respectively.

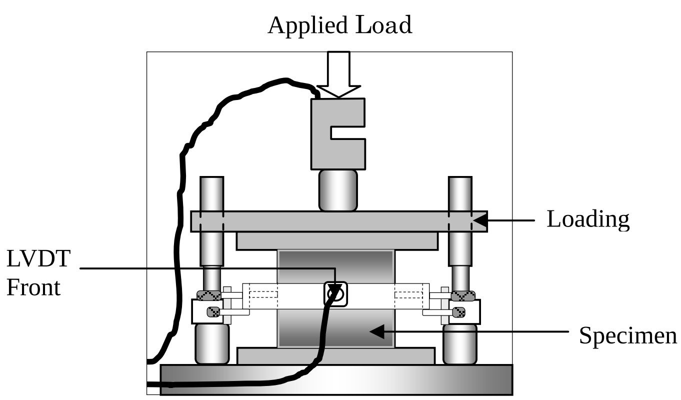


Figure 5: Schematic Diagram of Resilient Modulus Test Setup

Results in Figure 6 shows that resilient modulus values of the Superpave mixtures are higher compared to the Marshall mixes. Again, finer gradation mixture, NMAS 9.5 mm, with asphalt binder of PEN 60/70 resulted in highest resilient modulus values. At pulse repetition period of 0.1s of the resilient modulus test, results showed that the most rutting resistant mixture is 9.5-B2-SP (resilient modulus of 728 MPa), followed by 12.5-B2-SP (707 MPa), 9.5-B1-SP (649 MPa), 12.5-B1-SP (525 MPa), 12.5-B2-Marshall (521 MPa), 9.5-B2-Marshall (448 MPa), 9.5-B1-Marshall (424 MPa) and 12.5-B1-Marshall (371 MPa).

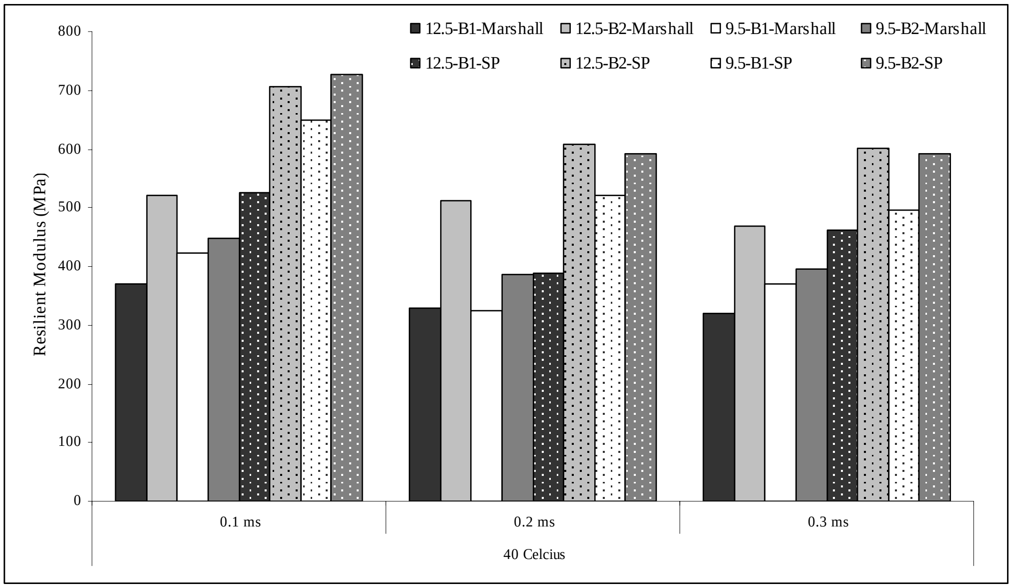


Figure 6: Resilient modulus of QS Superpave and Marshall mixes

4.3 Simple Performance Test

For SPT dynamic modulus test, the specimens were fabricated at OBC at an initial height of 165 mm and 150 mm in diameter. The specimen was then cored to achieve 100-mm diameter and trimmed to 150 mm height to obtain the final dimensions for testing. This ideal geometry was derived from the specimen size and aggregate size effect studies conducted by previous researchers (Witzcak et al., 1999). The SPT test procedure followed the test protocols of NCHRP Project 9-19, Superpave Support and Performance Models Management (Witczak et al., 2002). A schematic diagram of the test setup is as shown in Figure 7. A continuous sinusoidal load was applied on the specimen at 100 kPa inducing between 75 to 150 microstrains in the specimen. Evaluation of rutting distress was determined from dynamic modulus test conducted on each specimen at 25^{o}C to 50^{o}C with loading rate of 0.5 Hz, 1 Hz, 2 Hz and 5 Hz.

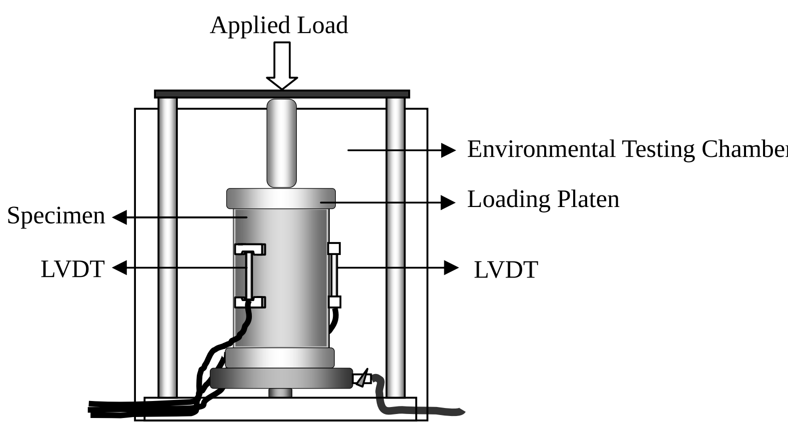


Figure 7: Schematic diagram of SPT dynamic modulus test setup

Figure 8 shows the dynamic modulus isotherms for both Superpave and Marshall mixes. The effect of test temperatures on dynamic modulus shows that the stiffness of asphaltic mixtures responds to variations in temperature. In general, the trend of this effect is the same for all mixtures tested. Dynamic modulus decreased sharply with increasing test temperature. Unlike test temperature, increasing test frequency increases the dynamic modulus. The variations in dynamic modulus results are also observed to be less at higher temperature compared to lower temperature. It is noticeable that the Superpave mixtures are stiffer and hence, have higher dynamic modulus values compared to the Marshall-designed HMA mixtures.

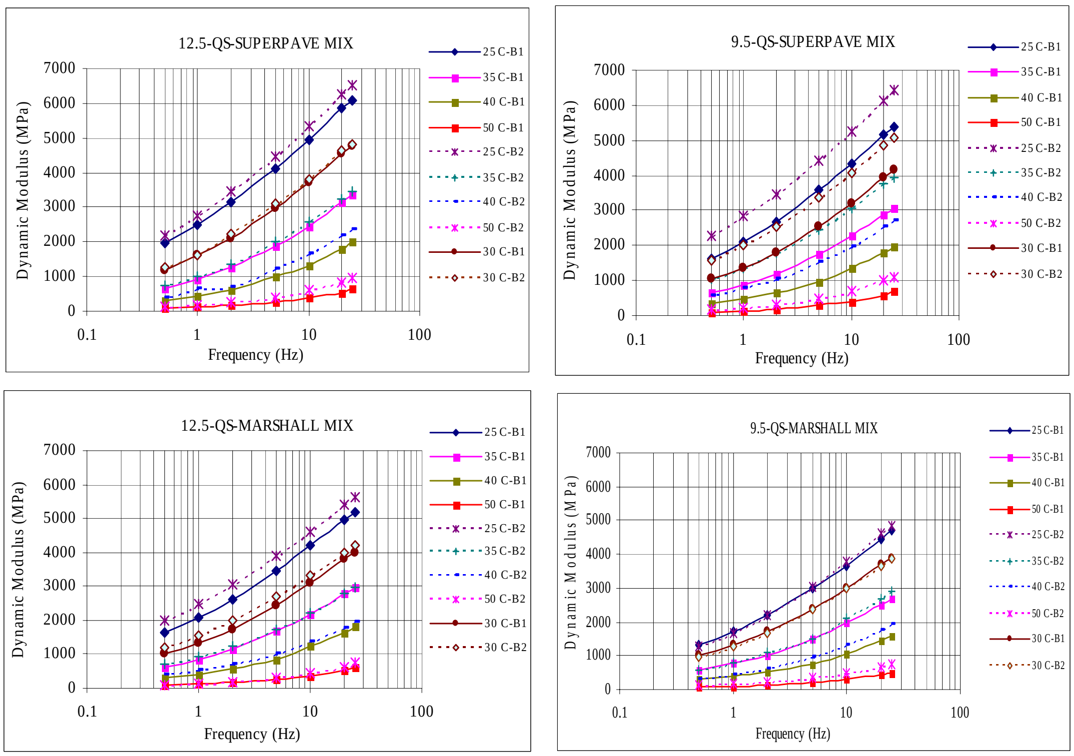
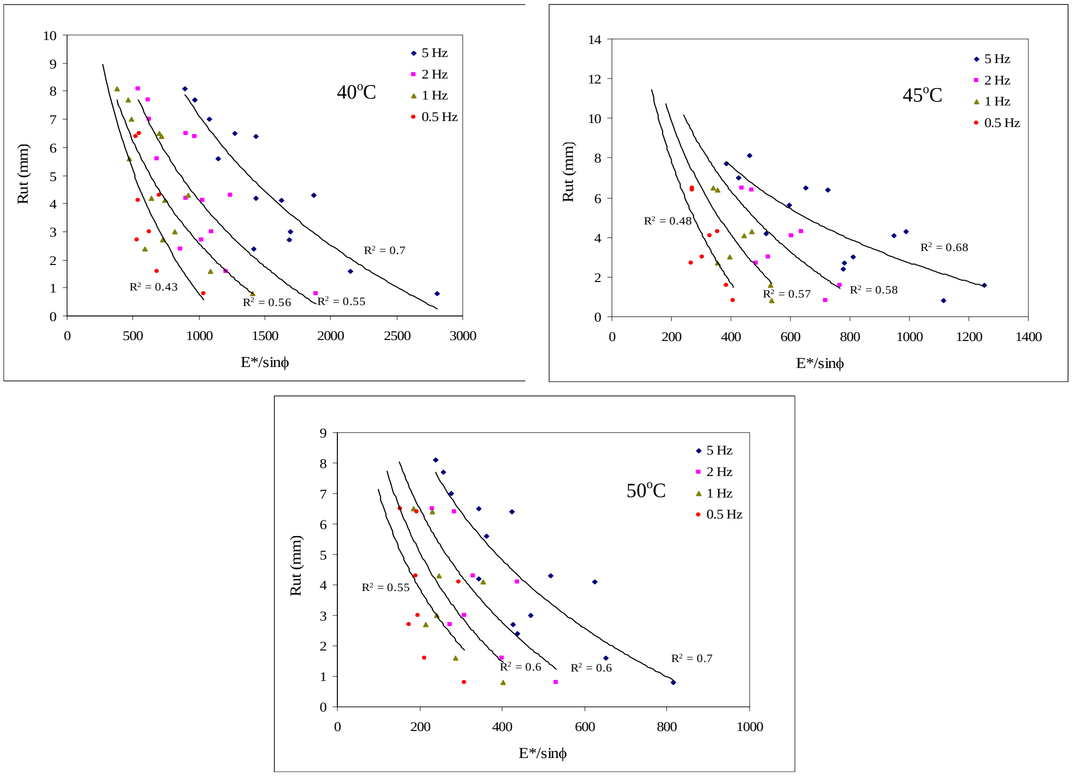


Figure 8: Dynamic modulus isotherms for Superpave and Marshall mixtures

5 EVALUATION OF PERMANENT DEFORMATION OF HMA

Results obtained from SPT dynamic modulus, wheel tracking and resilient modulus tests were analysed to determine any correlations between these tests. The performance of dynamic modulus, E* was evaluated as rut indicator at different loading frequencies. The relationship was established with a hypothesis that stiffness of asphalt mixture from dynamic modulus test could be used to evaluate rutting at high temperatures. The rut stiffness factor, E*/sinϕ values were plotted against rutting for the mixes to determine the best correlations with laboratory rutting at 40^{o}C, 45^{o}C and 50^{o}C and at 5 Hz, 2 Hz, 1 Hz and 0.5 Hz loading time. The choice of temperature and loading time must be appropriate because rutting is expected to occur at higher temperatures and lower loading times. Figure 8 shows the correlation plots for rut stiffness factor at different temperatures and frequencies versus rut depth for all the mixtures. Results from the graphs plotted above show that correlation exists between rut stiffness ratio and rutting from laboratory wheel tracking test. A strong correlation was found between rut depth and rut stiffness factor at 5 Hz loading frequency, moderate correlation at 2 Hz and 1 Hz loading frequency, and low correlation was found as loading frequency decreases to 0.5 Hz when tested at 40^{o}C and 45^{o}C. However, relationship between rut depth and rut stiffness factor at 50^{o}C showed that strong correlations exists at 5 Hz, 2 Hz and 1 Hz loading frequency. The correlation is moderate at 0.5 Hz.



5°C

Figure 8: Rut Depth vs Rut Stiffness Factor at 40°C, 45°C and 50°C

For resilient modulus test, the loading time used to perform the test is 100 ms, which is equivalent to 1.6 Hz. Hence, for comparison purposes, 2 Hz was selected from the dynamic modulus test. Figure 7 shows the correlation results between dynamic modulus test and resilient modulus test. Good correlation exists between these two tests with the coefficient of determination, R^2 values ranging from 0.66 to 0.71 at three pulse repetition periods of 0.1 s, 0.2 s and 0.3 s.

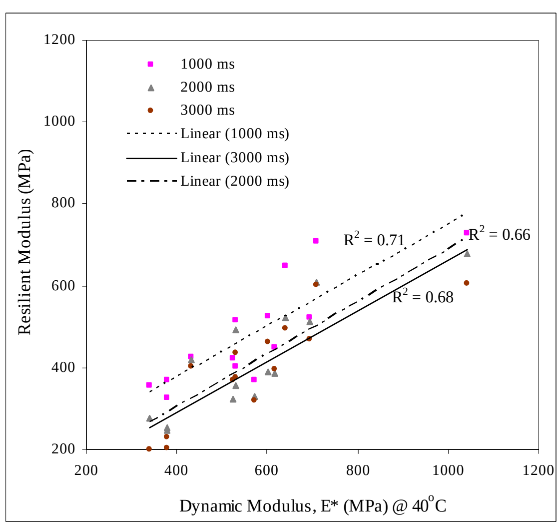


Figure 7: Resilient Modulus vs. Dynamic Modulus @ 40°C

6 CONCLUSION

This research was carried out to evaluate Superpave mixture design using local materials in Malaysia. These mixes were also compared with the conventional existing mix design practice using Marshall mix design method. In addition, permanent deformation (rutting) were evaluated from both mix types using different test methods. Based on the experimental results obtained, the following conclusions were drawn:

1. Local aggregate used in this study conformed to the Superpave consensus and source aggregate properties criteria.
2. Superpave designed mixtures utilized less asphalt binder compared to Marshall designed mix.
3. The resilient modulus values for Superpave mixtures are higher than Marshall mixes especially for fine gradation mix using PEN 60/70 asphalt binder type.
4. Superpave mixtures are least susceptible to permanent deformation (rutting) compared to the Marshall mixtures from the wheel tracking test.
5. Superpave mixtures are stiffer and hence have higher dynamic modulus values compared to Marshall designed mixtures.
6. Good correlation exists between dynamic modulus rut factor and rutting at 40^oC and 50^oC at 5 Hz loading frequency.
7. Good correlation exists between dynamic modulus and resilient modulus with the coefficient of determination, R^2 values ranging from 0.66 to 0.71 at 40^oC.

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