Rutting Evaluation of Dense Graded Hot Mix Asphalt Mixture

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Abstract— **Rutting is one of the common pavement distresses which led to lower riding comfort for road users and high maintenance costs. One of the widely used tests is the simulation test using the wheel tracking device. In this study, efforts have been made to evaluate rutting of dense graded hot mix asphalt (HMA) using the dynamic modulus Simple Performance test (SPT). Granite aggregates from Klang Valley located in the central region of Peninsular Malaysia were used to produce the HMA mixtures with two different types of aggregate gradation designed using Superpave and Marshall mix design method. The rut evaluation was selected from SPT dynamic modulus test conducted at 40°C, 45°C and 50°C and 5 Hz, 2 Hz, 1 Hz and 0.5 Hz loading frequencies. Results from the study indicated that a correlation was found between the rut stiffness factor from SPT dynamic modulus test when tested at 5 Hz loading frequencies with temperature of 40°C, 45°C and 50°C and the rut depth from Wessex wheel tracking test.**

Index Term-- **hot mix asphalt; rutting; simple performance test; wheel tracking test**

I. Introduction

Rutting has been a major concern for flexible asphalt pavement. It is also one of the most common pavement permanent deformations due to repetitive traffic loads which accumulate small deformations of pavement materials appearing as longitudinal depressions in the wheel paths of the roadways. The primary problem of rutting arise from excessive traffic consolidation in the upper layer of the pavement, plastic deformation due to insufficient mixture stability and also instability caused by stripping of asphalt binder below the riding surface of the pavement. Numerous test procedures have been conducted to evaluate and predict rutting in the laboratory. The most common test is the use of wheel tracking test which simulates traffic loading on pavements by tracking to and fro on a specimen. The test conditions are similar to pavement conditions in service to obtain rut depth under a specified load cycle. A study has shown that there is a correlation between Vacuum Repeated Load Axial test (VRLAT) and Wessex Wheel Tracking (WTT) test [1]. The wheel tracking test has proven to be feasible alternative in evaluating rutting and test results can be used as predictive measures to analyze the performance of HMA mixture in road conditions [2]. However, the data obtained cannot be used in a mechanistic pavement analysis and the fundamental property of the HMA material was not measured. Further investigations to assess rutting potential using the repeated creep test was investigated [3]. The findings were favorable and correlation between the creep and loaded wheel tests was found to be good. Despite the extensive research conducted on permanent deformation of HMA mixtures, the basic mechanism for the mode of failure were further investigated to find the relationship between rutting of the HMA mix and asphalt binder. The asphalt mixture is time dependent and stress-dependent material, hence exhibits elastic, plastic, viscoelastic and viscoplastic responses when subjected to repeated loading. Permanent strains build up from repeated loadings and considered essential in assessing rutting. In the National Cooperative Highway Research Project (NCHRP) Report 465, study showed that the Simple Performance Test (SPT) accurately and reliably measures a mixture response or characteristic that is highly correlated with the occurrence of pavement distress over a diverse range of traffic and climatic conditions [4]. Hence, the objective of this study was to investigate rutting potential using SPT dynamic modulus test and how well this test correlates with the Wessex wheel tracking test to evaluate rutting potential of local HMA mixture.

II. Laboratory Experiment

The rutting tests were performed on hot mix asphalt of two aggregate gradations with nominal maximum size of 12.5 mm and 9.5 mm. The mixes incorporate conventional asphalt binder of penetration 80-100 and 60-70. The gradation of the blended aggregates is shown in Figures 1 and 2. The Superpave and Marshall mix design method were employed to prepare the test specimens.

All specimens were designed at 4 percent air voids to determine the optimum binder content and then prepared to achieve 7±0.5 percent target air voids for the rut test. The volumetric results obtained from both mix showed that the optimum binder content (OBC) achieved for the Marshall designed mixes range from 5.6 to 6.2 percent and 5.1 to 5.7 percent for Superpave designed mixes [5].

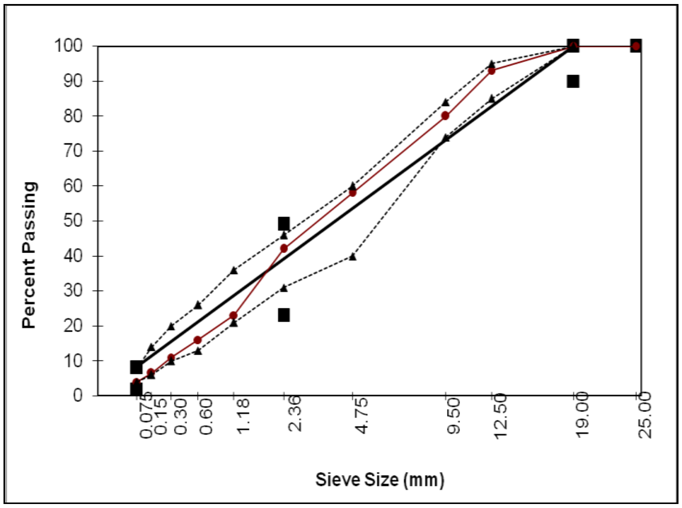

Fig. 1. 12.5mm mix gradation

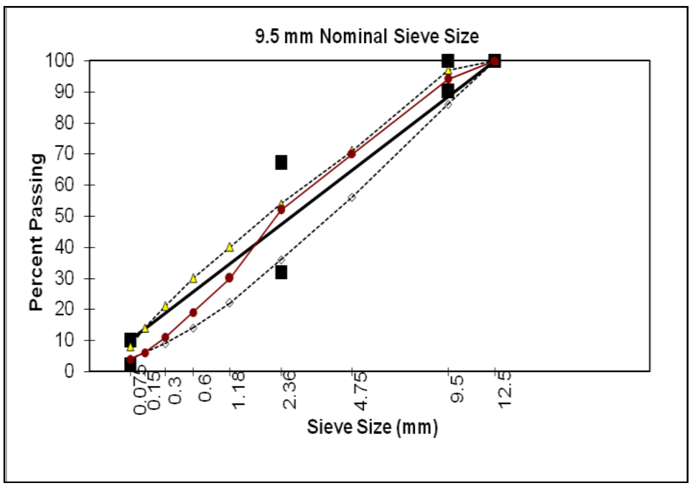

Fig. 2. 9.5mm mix gradation

Dynamic Modulus Simple Performance Test

For the SPT dynamic modulus test, cylindrical specimens of 150 mm in diameter and 170 mm in height were compacted using the Superpave Gyratory Compactor (SGC). The specimens were cored to achieve 100 mm diameter and trimmed to 150 mm height. This ideal geometry was recommended based on the specimen size and aggregate effect study [6]. The SPT is a fully integrated device which comprises of an environmental chamber, hydraulic actuator and pump, refrigeration and heating unit with heat exchanger and a control and data acquisition system. The test setup for the SPT dynamic modulus test is shown in Figure 3.

The testing procedure for the SPT dynamic modulus test was derived from NCHRP 9-29, Simple Performance Tester for Superpave mix design. Initially, three Linear Variable Displacement Transducers (LVDT) were glued at 120^{o} on the specimen surface to capture full range accumulation of the compressive permanent deformation before running the test. A continuous uniaxial sinusoidal (haversine) compressive stress at specified test frequency is applied to the unconfined cylindrical test specimen in a cyclic manner. The dynamic stress applied was 100 kPa and the strain level was kept between 75 to 125 microstrains. Prior to testing, the specimens were conditioned in the chamber for at least four hours to achieve the target temperature. The behaviour of asphaltic concrete mixtures were analysed from the dynamic modulus test which allows the dynamic modulus the ability to distinguish between QS Superpave and QS PWD Marshall mixtures.

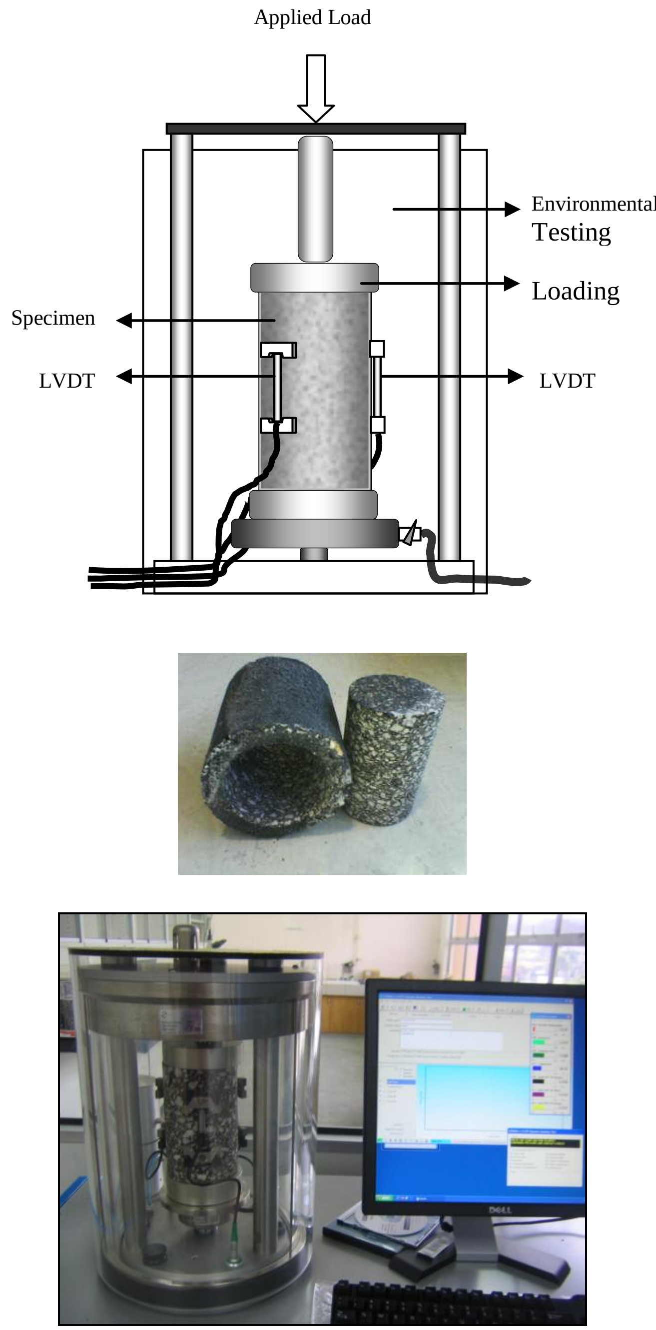

Fig. 3. SPT dynamic modulus test setup

Wheel Tracking Test

The Wessex wheel tracking test specimens were prepared with a diameter of 150 mm and 63 mm height using the SGC. The specimens were trimmed and paired to fit in the wheel tracking mould. Care must be taken to ensure the specimens fit exactly without any allowance for any movement in the mould. All the specimens were conditioned at the testing temperature at least four hours prior to testing. The Wessex wheel tracking test is a torture test that simulates wheel passes within a pavement and the procedure is described in BS 598: Part 110: 1998. The test was conducted at 60^{o}C and the specimens were subjected to a simulated trafficking with a simple harmonic motion by applying 520 N load for one hour. The LVDT transducer monitors the rut depth at the centre of the specimen. A schematic diagram and setup of the equipment is as shown in Figure 4.

Fig. 4. Wessex wheel tracking test setup

III. Results and Discussion

Dynamic Modulus Simple Performance Test

A master curve constructed from results obtained is important because the test was conducted at broad range of temperatures and frequencies. Using the principle of time-temperature superposition, data collected at different temperatures were shifted relative to the time until the curves merge into single sigmoidal function representing the master curve using a second order polynomial relationship between the logarithm of the shift factors, log a(T) and the temperature. Figures 5 and 6 show the master curves of the HMA mixes. Results showed that QS Superpave designed mixes exhibit higher stiffness compared to QS PWD Marshall designed mixtures for both gradations. However, the trend with effect to the test temperature on dynamic modulus showed that the stiffness of asphaltic mixtures respond to variations in temperature. At constant frequency, dynamic modulus values are higher at lower test temperature and start to decrease as test temperature increases. The variations in dynamic modulus results are also observed to be less at higher temperature compared to lower test temperature. As asphalt binder tends to softens, the stiffness of HMA reduces and is controlled by aggregate structure within the mix.

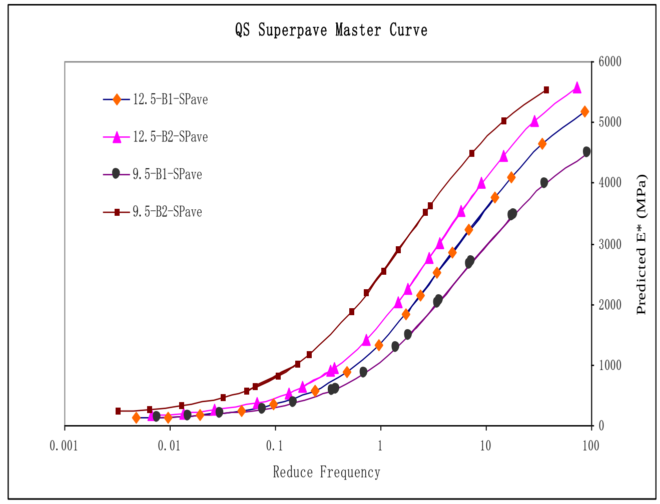

Fig. 5. Mastercurves for QS Superpave mix

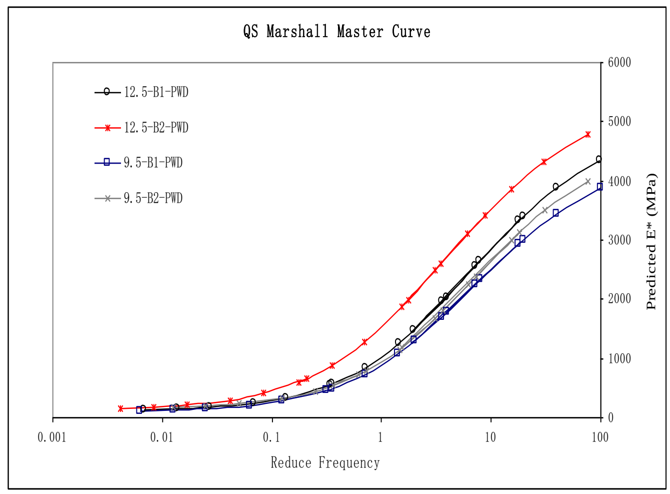

Fig. 6. Mastercurves for QS PWD Marshall mix

Wheel Tracking Test

Results of the wheel tracking test in Figure 7 shows the plots of rutting for QS Superpave and QS PWD Marshall HMA mixes. Results showed that HMA Superpave mixtures are more resistant to rutting compared to Marshall designed mixtures. Two parameters are considered in a wheel tracking test to ensure that the performance of HMA materials is correctly assessed. The wheel tracking rate is measured as the primary measure of the resistance to rutting and the maximum rut depth is a secondary measure. This is important because different mixtures may deform differently and some rut excessively at early stage of rutting test compared to latter part of the test. Figure 8 shows the wheel tracking rate of the HMA mixtures evaluated.

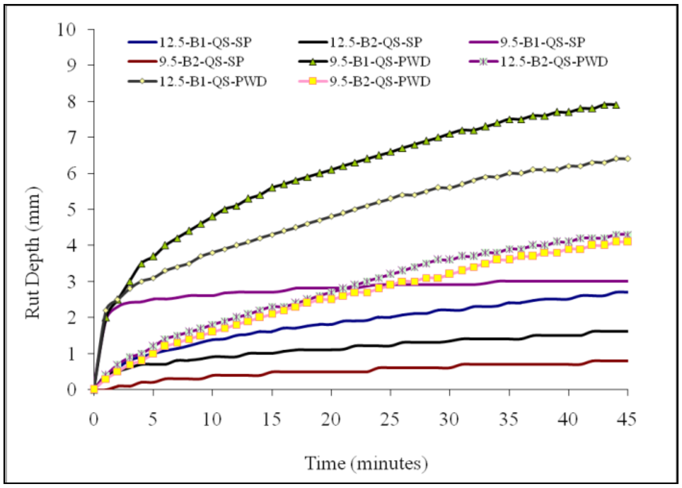

Fig. 7. Wheel tracking rut test

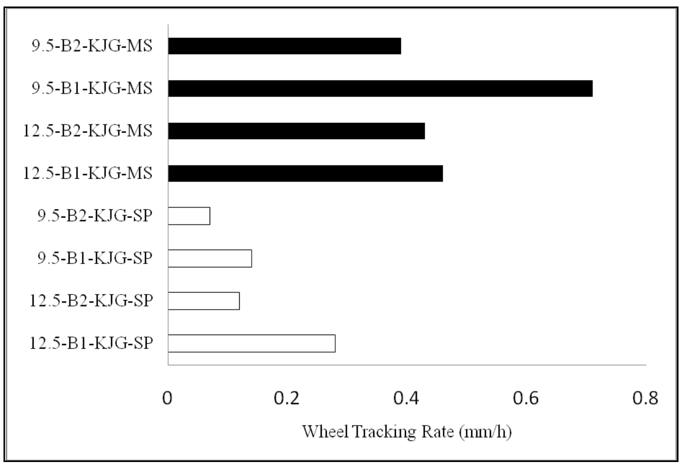

Fig. 8. Wheel tracking rate of HMA mix

Relationship between SPT Dynamic Modulus and Wheel Tracking Test

Rutting characteristics of HMA mixtures can be characterized from the dynamic modulus test performed at high temperatures. Stiffness from the SPT dynamic modulus test is the parameter chosen from the NCHRP 9-19 Project as well as from the AASHTO 2002 design guide. Previous study conducted selected a loading frequency of 5 Hz and 54.4°C testing temperature as the rutting factor. This study showed that evaluation of rutting can be selected at 5 Hz loading frequency and temperatures ranging from 40°C to 50°C. In this study, a relationship was established with a hypothesis that stiffness of HMA mixtures from dynamic modulus test can be used to evaluate rutting. The rut stiffness factor, E*/sinΦ values were plotted against the rut results from wheel tracking test to determine the relationship between the two tests. The temperature chosen was at 40°C, 45°C and 50°C and 5 Hz, 2 Hz, 1 Hz and 0.5 Hz loading frequencies because rutting is expected to occur at high temperatures and lower loading times. Figures 9 to 11 show the correlation plots for rut stiffness factor at 40°C, 45°C and 50°C against the rut depth for all the HMA mixtures.

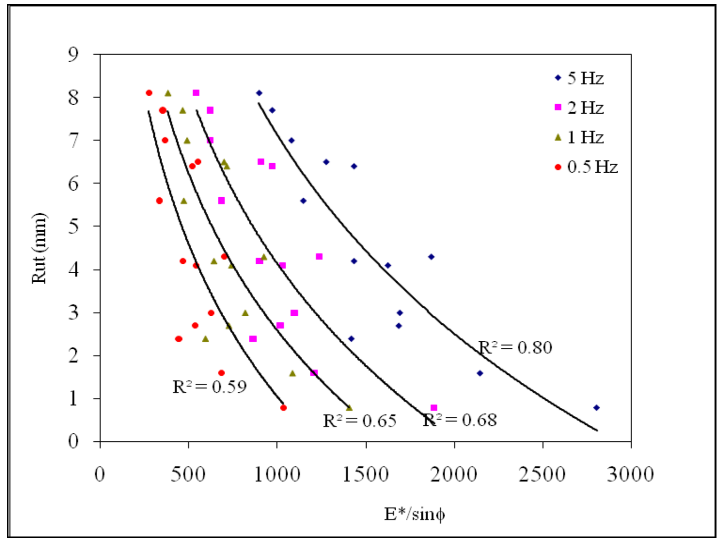

Fig. 9. Rut depth vs. rut factor at 40°C

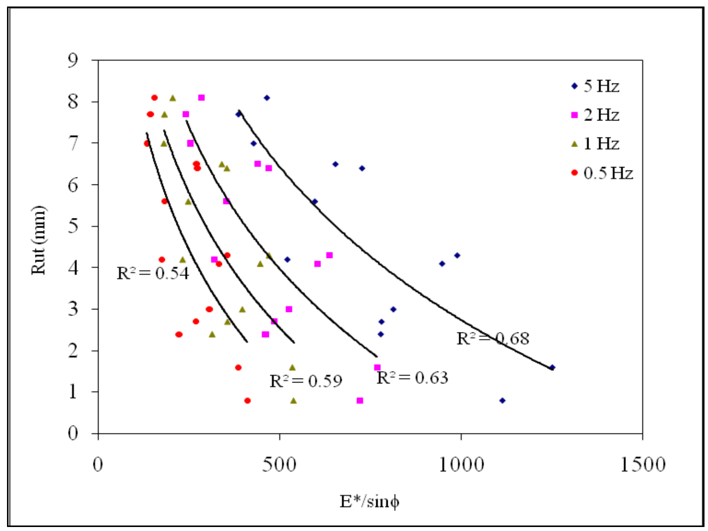

Fig. 10. Rut depth vs. rut factor at 45°C

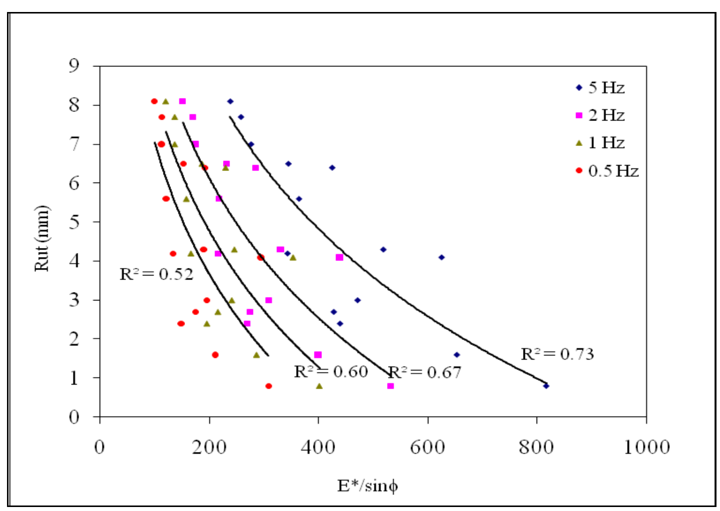

Fig. 11. Rut depth vs. rut stiffness factor at 50°C

Results plotted showed there is a correlation between rut stiffness factor and rut depth. A strong correlation is observed for specimens tested at higher loading frequency. Results obtained from the plot are tabulated in Table I.

TABLE I.
CORRELATIONS BETWEEN RUT STIFFNESS FACTORS AND RUT DEPTH

Tests	SPT Dynamic Modulus Test (Parameters 0.5Hz, 1Hz, 2Hz, 5Hz)		
Wheel Tracking	40°C	45°C	50°C
	Strong	Strong	Strong
	Strong	Moderate	Moderate
	Moderate	Moderate	Moderate
	Low	Low	Low

IV. CONCLUSION

A laboratory study has been conducted to evaluate the rut resistance of dense graded HMA mixture using SPT dynamic modulus test and Wessex wheel tracking device. Based on the laboratory experiments and analyses, it can be concluded that the change in HMA mixture behavior from SPT dynamic modulus test was effective to identify rutting potential of HMA mix when tested at different range of temperatures and loading frequencies. A strong correlation exists between rut stiffness factor and rut depth from wheel tracking test at 5 Hz loading frequency when tested between 40°C and 50°C range of temperature. The SPT dynamic modulus test is viable and reliable in rutting evaluation, as such large amount of specimen fabrication can be minimized.

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