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Original Article

# Characterization of Hot Mix Asphalt Using the Dynamic Modulus and Wheel Tracking Testing

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**Abstract:** Pavement engineers have been facing the challenges of rutting being the premature asphalt pavement failure especially in hot climatic regions of Pakistan. Researchers have reported that the dynamic modulus test best characterizes asphalt material and can be used as a good index to address asphalt failures. This study is focused on investigating the rutting potential of asphalt concrete mixtures using the dynamic modulus and wheel tracker testing. Two mixtures treated with hydrated lime at1.5% by the aggregate weight and three mixtures without hydrated lime were designed. The neat (without hydrated lime) mixtures contained three polymer modified asphalt binders, namely PG58-16, PG64-22 and PG70-22. Two mixtures treated with hydrated lime were prepared using PG58-16 and PG64-22. Study reveals that polymer modified asphalt mixtures yielded low rutting and high dynamic modulus values under extreme temperature and load frequencies. Also, relationships exist between the rut depth factor and rutting factor. Rutting factor better distinguishes the mixtures than |E*| alone.

**Keywords*:*** Asphalt, rutting, dynamic modulus, wheel tracker

## 1. INTRODUCTION

Complex shear modulus (E*) is a complex number that defines the relationship between a stress and strain for a linear viscoelastic asphaltic materials, while dynamic modulus (|E*|) is the complex shear modulus calculated by dividing the maximum peak to peak stress by the recoverable peak to peak axial strain for an asphaltic material subjected to sinusoidal loading [1]. The dynamic shear modulus (|E*|) has been known to researchers since the 1960s [2]. Dynamic modulus (|E*|) is the absolute value of the modulus from a viscoelastic material like asphalt concrete. The dynamic modulus of a viscoelastic test is a response developed under sinusoidal loading conditions [3]. Hot mix asphalt (HMA) mixture susceptibility to resist permanent deformation (rutting) can be characterized by using the dynamic modulus test results at different temperatures and loading frequencies. Two parameters can be obtained from this test: the dynamic modulus |E*| and the phase angle (φ) [4]. The phase angle is an indicator of the viscous and elastic properties of asphalt [5].

Witczak et al [6] conducted a detailed study on rutting and fatigue performance of superpave asphalt mixtures and found that volumetric properties of mix, loading and temperature conditions are the contributing parameters that defined two kinds of distresses namely permanent deformation and fatigue cracking in the asphalt layer of road pavements. The rutting factor, a parameter to measure rutting characteristics of asphalt mixtures, is defined as |E*|/sinφ, where φ indicates the phase angle at a particular frequency and temperature [7].

According to Bahia et al [8] the theoretical basis of using a rutting stiffness factor |E*| /sinφ relates to the assumption that it gives better protection against rutting at high temperatures than the modulus alone. In the case of binder specification, two binders can have the same

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modulus value, but one may be more rut resistant, if it has a larger elastic component [9]. The Superpave binder specification has a minimum value for the |G*|/sin(δ) for rutting [10]. Hence, a high complex modulus value and low phase angle are both desirable [9]. For hot mix asphalt mixtures to be rut resistant and exhibit higher stiffness necessitates a higher dynamic modulus value and a lower phase angle. Therefore, the |E*| /sin(φ) has been used as a rut indicator to evaluate the mixture's resistance to rutting at high temperatures. Higher rutting factor value indicates a mixture's greater resistance to asphalt cement permanent deformation [3].

The present work is an attempt to provide a relationship of asphalt mix properties and its performance by which various asphalt concrete mixtures can be compared and their expected performance can be assessed using the dynamic modulus and wheel tracking test. Rutting potential of asphalt mixtures using the wheel tracking machine have been determined and results were correlated with dynamic modulus test data.

## 2. EXPERIMENTAL WORK

The experimental work comprises of characterizing the basic materials used in the asphalt mixture followed by asphalt mixtures design. Two kind of testing procedures have been adopted to evaluate asphalt mixture performance against rutting.

### 2.1. Asphalt Binder Characterization

Three performance grade (PG) asphalt binders, PG 58-16, PG64-22, and PG70-22 were used in this study. The upper numbers (58, 64 & 70) indicate that these binders qualify for average seven days temperature determined on Dynamic Shear Rheometer (DSR). The lower numbers (-16 & -22) indicate that these binders qualify minimum pavement design temperatures determined at bending beam rheometer (BBR) under aged conditions [11]. Applying DSR, the shear modulus (G*) and phase angle of binders were determined at an angular frequency of 10 radian/second and at three temperatures i.e., 25, 40 and 55°C. The viscosity (η) of the asphalt binders and its variation with temperatures were computed using following relationship developed by Bonaquist et al [12]:

$$\eta = \frac{G^*}{10}\left(\frac{1}{\sin\delta}\right)^{4.8628} \tag{1}$$

This model is known as the "Witczak-Bonaquist Model" and is capable of predicting viscosity from shear modulus and phase angle. Fig. 1a and 1b show the plot of complex shear modulus and viscosity. It has been observed that PG64-22 has higher shear modulus values at 25 and 40°C than PG 58-22, & PG 70-22, whereas PG70-22 exhibits the higher shear modulus at 55°C. PG70-22 exhibits higher viscosity (η) values at all temperatures compared to the other two binders. A summary of comparison between shear modulus and viscosity has been reported in Table 1. The viscosity calculated based on the above model characterizes the asphalt binders better than shear modulus alone, specifically for stiff binders. This has been attributed to the fact that this model

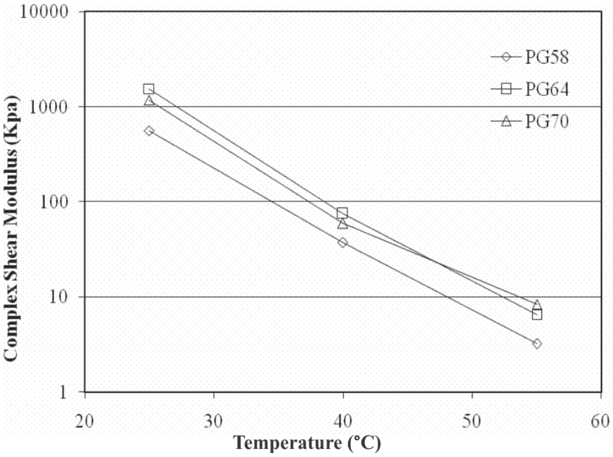

**Fig. 1a.** Typical trends of complex shear modulus with temperature.

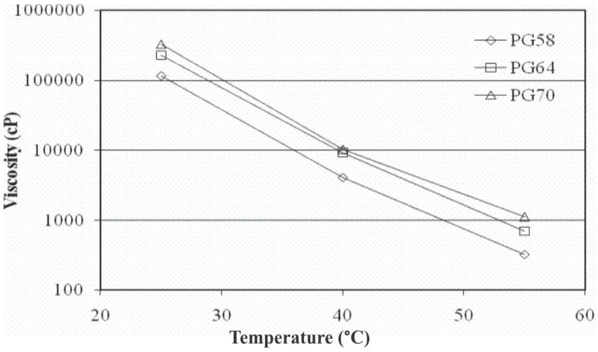

**Fig. 1b.** Typical trends of viscosity with temperature.

**Table 1.** Comparison of shear modulus and viscosity of asphalt binders.

| Temperature (°C) | Shear Modulus (G*) PG 58-16 | Shear Modulus (G*) PG 64-22 | Shear Modulus (G*) PG 70-22 | Viscosity of asphalt binders (η) PG 58-16 | Viscosity of asphalt binders (η) PG 64-22 | Viscosity of asphalt binders (η) PG 70-22 |
|---|---|---|---|---|---|---|
| 25 | 562 | 1550 | 1175 | 115947 | 230095 | 331363 |
| 40 | 37.4 | 75 | 59.8 | 4107 | 9133 | 10292 |
| 55 | 3.21 | 6.55 | 8.42 | 324 | 699 | 1122 |

includes the phase angle which represents the viscous behavior of the asphalt binder. According to Huang and Zeng, [13], viscosity determined from complex shear modulus and phase angle is an indicator of visco-elastic properties of asphalt binders that helps in predicting it's rutting and fatigue resistance. According to Bari and Witczak, [14] viscosity determined from the above model takes into account the loading frequency applied on the binder while accurately predicting the viscosity at a specific temperature.

## 2.2. Asphalt Mixture Design

Asphalt mixtures were designed in accordance with Superpave method of Mix Design [15] using a single aggregate gradation as shown in Fig. 2. Five asphalt mixtures were prepared; three without hydrated lime and two treated with hydrated lime at 1.5% by weight of aggregate in Table 2. The untreated mixtures contained three asphalt binders, namely PG58-22, PG64-22 and PG70-22 (polymer modified asphalt). The two mixtures treated with hydrated lime were prepared using PG58-22 and PG64-22. The mixture treated with hydrated lime has lower asphalt binder content than untreated mixes (Table 2). This has been attributed to the fact that hydrated lime acts as the extender, which in turn increases the binder film thickness. Hydrated lime increases binder film thickness by enhancing viscosity of the binder and improving the binder cohesion. This leads the asphalt cement to coat the aggregate particles with a thicker film and results in a reduction of mixture segregation [16].

Bari and Witczak [14] reported that hydrated lime-modified HMA mixtures had a higher dynamic modulus values than the unmodified mixtures. The hydrated lime also improves the stiffness characteristics and performance of HMA mixtures besides serving as a good filler and anti-stripping agent. Atud et al. [17] evaluated the laboratory performance-based properties (moisture damage and rutting resistance) of lime modified asphalt mixture in comparison to the polymer

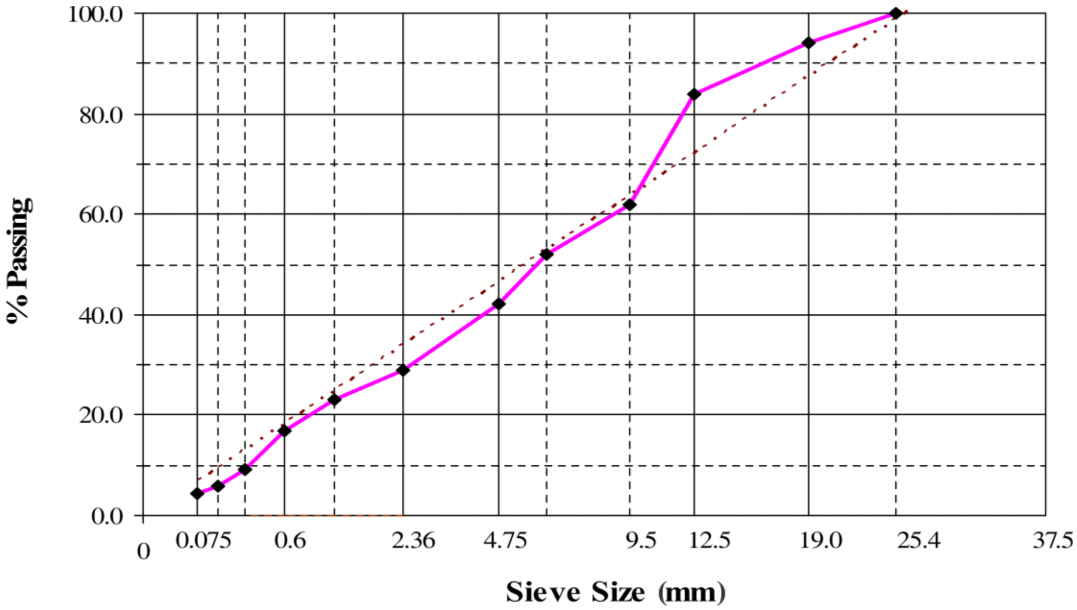

**Fig. 2.** Typical trends of aggregate gradation.

**Table 2.** Properties of asphalt concrete mixtures.

| Sr. No. | Mix designation | Binder type | Mix type | Asphalt content (%) | Voids in mineral aggregates (%) | Voids filled with asphalt (%) | Dust/effective bitumen percentage |
|---|---|---|---|---|---|---|---|
| 1 | SPM58 | PG58-16 | Untreated | 4.4 | 14 | 71 | 1.2 |
| 2 | SPM64 | PG64-22 | Untreated | 4.5 | 15 | 73 | 1.1 |
| 3 | SPM70 | PG70-22 | Untreated | 4.4 | 15 | 73 | 1.2 |
| 4 | SPM58HL | PG58-16 | Treated | 4.0 | 12 | 66 | 1.6 |
| 5 | SPM64HL | PG64-22 | Treated | 4.1 | 13 | 69 | 1.5 |

modified asphalt mixture. The results indicated that hydrated lime significantly improved both the moisture damage and rutting resistance of mixture, whereas the polymer improved the rutting resistance only. While comparing two different methods of adding lime, the authors reported that the application of hydrated lime directly in the asphalt binder (wet process) was more effective and economical method to improve the performance of HMA mixture to resist moisture damage and rutting. Kabir [18] evaluated the laboratory performance of lime modified Superpave mixtures and concluded that the addition of hydrated lime generally brought higher stiffness in HMA mixtures which in turn improved the permanent deformation characteristics in asphalt pavements and at low and intermediate temperatures it increased the potential susceptibility to fatigue.

### 2.3. Specimens Preparation and Testing Conditions

The Dynamic modulus testing requires a 150 mm high by 100 mm diameter specimen, for a target air void content in total mix of 7±0.5%, cored from 170 mm high by 150 mm diameter specimen [1]. This is typical of the air void percentage in mixtures when they are placed in the field. A sinusoidal compressive stress wave was applied to test specimens at 25, 40 and 55°C with loading frequencies of 25, 10, 5, 1, 0.5, and 0.1 Hz [1].

Roller compactor was used to compact square slab specimens, 305x305mm of asphalt mixes. Wheel tracking test was applied on slab specimens for 18000 passes at 40°C and 55°C. Standard conditions of 720N load were applied on compacted confined slab specimens [19]. The wheel tracking machine typically measures the rut, created by repeated passage of a wheel over prismatic asphalt concrete samples. It was used to assess the resistance to rutting of the asphaltic material, under standard defined conditions of load and temperature. The rut resistance can be quantified as the rate of rutting during the test or the rut depth at the conclusion of the test, measured with linear variable displacement transducers (LVDT) [20].

## 3. RESULTS AND DISCUSSION

Results were computed from the data sheets of dynamic modulus and wheel tracking test and relationship have been established between the mix parmeters and performance indicators.

### 3.1. Using |E*| as Asphalt Cement Rutting Indicator

The rutting factor and **|E*|** were analyzed at high temperatures as 40 and 55°C and frequency of 5Hz & 0.5 Hz as shown in Fig. 3. These frequency levels correspond to intermediate and low traffic speeds, respectively [21]. Fig. 3 shows that the dynamic modulus and rutting factor have similar trends at 5Hz, but Fig. 4 shows that when comparing the mixes on the basis of |E*| alone at 0.5 Hz, mix SPM64 has slightly higher |E*| than SPM70, while the rutting factor of SPM70 has higher value than SPM64. It can also be observed that the SPM70 mixture showed more resistance to rutting mainly due to the asphalt binder type (PG70) which has the highest viscosity and G* at 55°C compared to the other asphalt binders in this study. Both SPM58 and SPM58HL mixtures exhibit the same |E*| values, but SPM58 showed higher rutting factor than SPM58HL. It shows that both the |E*| and rutting factor follow the same trend, but exhibits different values of mixtures under different conditions. It may be due to the fact that the rutting factor is phase angle dependent.

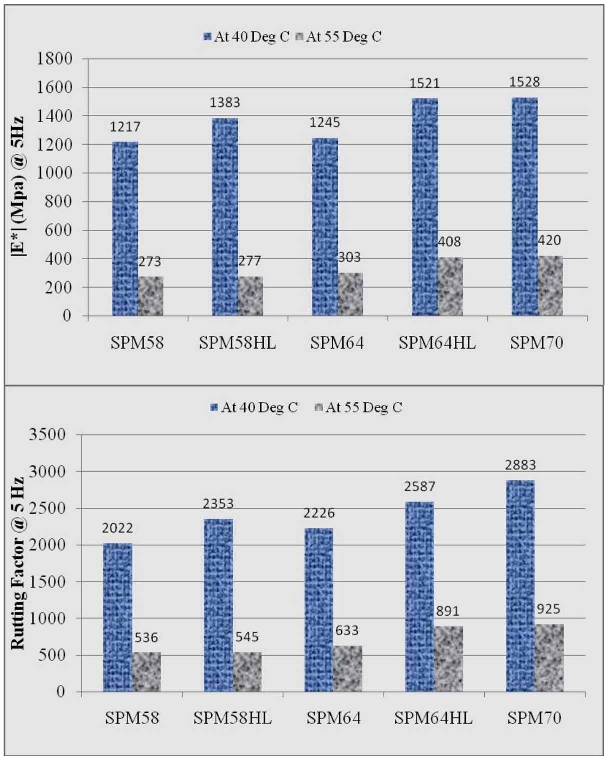

**Fig. 3.** Typical trends of dynamic modulus and rutting factor at 5Hz.

### 3.2. Performance Evaluation of Mixtures by the Wheel Tracking Machine

The wheel tracking machine typically measures the rut, created by repeated passage of a wheel over prismatic asphalt concrete samples. Since the rutting factor (|E*|/sin φ) was determined at 40 and 55ºC,the mixtures were tested at this temperature under the wheel tracker in order to find out whether the performance of the mixtures would follow a similar trend to that observed through the rutting factor. Fig. 5 presents the rut depth of the mixtures considered. It was worth mentioning here that the general ranking by wheel tracker machine and rutting factor were similar. Figure 5 shows minimum influence of temperature on rut depth development in mixture SPM70. Also, SPM60 mixture with and without hydrated lime produced equal percentage change in rut depth with increase in temperature. Mixture SPM 58 showed minimum resistance to rut at 40 and 55$^{o}$C.

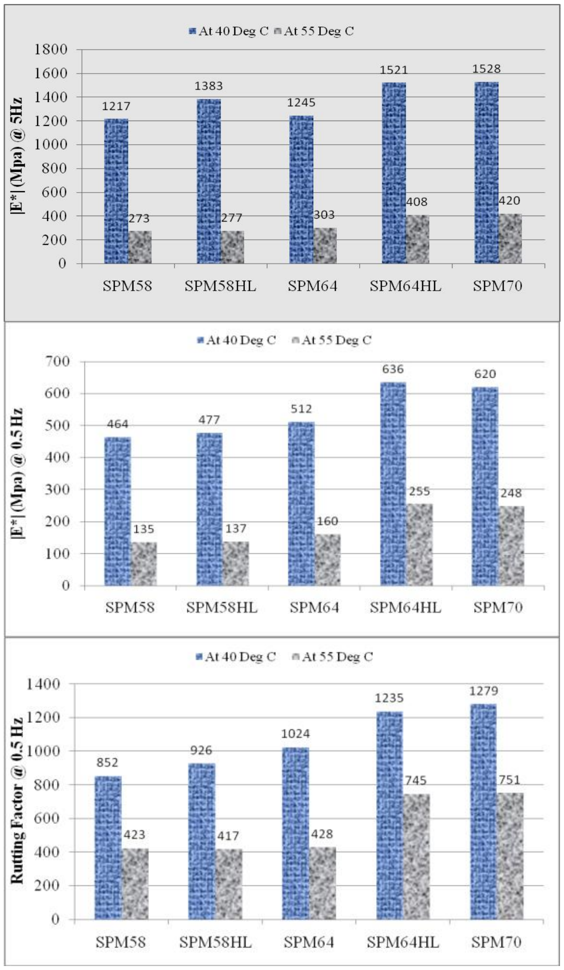

**Fig. 4.** Typical trends of dynamic modulus and rutting Factor at 0.5Hz.

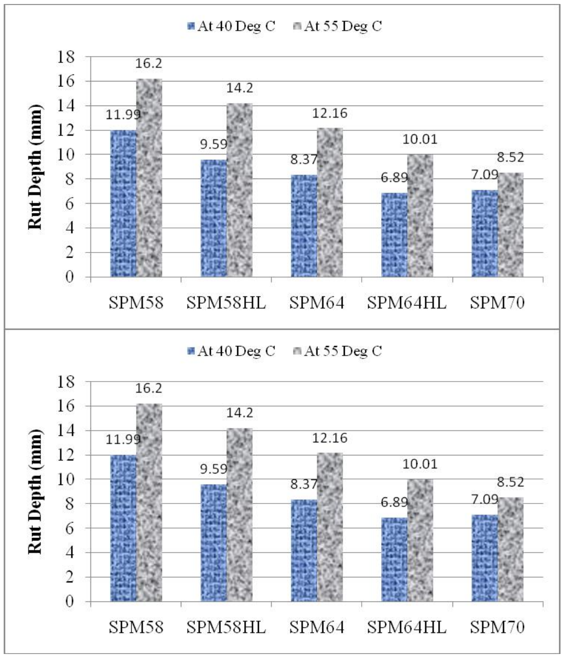

**Fig. 5.** Typical trends of rut depth of mixes under the wheel tracking machine.

### 3.3. Correlation between Rutting Factor and Rut Depth

Following correlation between the rut depth measured from wheel tracker and the rutting factor from the dynamic modulus test were determined at 40 and 55$^o$C and at frequency of 5 and 0.5 Hz.

| | | |
|---|---|---|
| At 40$^o$C & 5 Hz | Rut Factor = -142.5 (rut depth)+3723 | $R^2$ =0.710 |
| At 55$^o$C & 5 Hz | Rut Factor = -65.59 (rut depth)+1512 | $R^2$ =0.895 |
| At 40$^o$C & 5 Hz | Rut Factor = -96.85 (rut depth)+1914 | $R^2$ =0.863 |
| At 55$^o$C & 5 Hz | Rut Factor = -49.75 (rut depth)+1171 | $R^2$ =0.769 |

General trends of above correlations have been shown in Fig. 6. Plots show that strong relationship ($R^2 \geq 0.7$) exists between the rut depth measured from the wheel tracking machine and the rutting factor computed from the dynamic modulus testing. Also, with increase in temperature from 40 to 55$^o$C, slope of best fit line reduces gradually. This indicates low rutting factor values at low frequency of 0.5 Hz and high temperature of 55$^o$C.

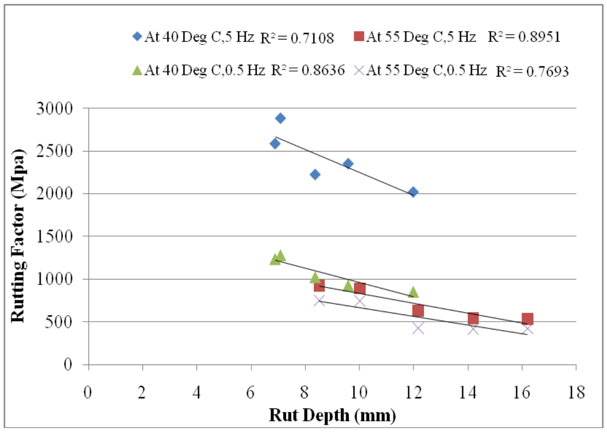

**Fig. 6.** Correlations between rutting factor and rut depth (mm).

## 4. CONCLUSIONS

Based on the experimental and analytical study on five asphalt mixtures, following conclusions have been drawn:

- A relationship exists between the wheel tracking machine rut factor and rutting factor from the dynamic modulus testing.
- The rutting factor (E*/sinφ) better distinguished the mixtures than |E*| alone due to viscous component and phase angle.

SPM70 mixtures with polymer modified bitumen showed least influence of on rut depth with an increase in temperature. Rut depth increased by 20% with an increase in temperature from 40 to 55$^o$C.

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