Effect of oil shale ash on rheological properties of asphalt binders

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ABSTRACT: Energy is the key factor in the modern civilization. Continuous increase of oil prices make it essential to look for other energy sources. Oil shale rock is a good energy source that may be used as an alternative of oil. Jordan land contains more than 40 billion tones of oil shale rocks. Oil shale ash is a byproduct of oil shale rock processing to produce crude. This oil shale ash is a waste material. A good way to waste this material is to use it as an additive to the asphalt binder. In this study, the effect of adding oil shale ash to asphalt binder on rheological properties at higher temperatures will be investigated. Oil shale ash was added to asphalt binder at different percentages by volume (5%, 10%, 15%, 20%, and 25%). The rheological properties including the complex shear modulus and the phase angle of asphalt binder mastics was investigated using the Superpave Dynamic Shear Rheometer (DSR). It was found that increasing the oil shale ash percentage in the asphalt binder blend increased the complex shear modulus (G*). On the other hand, the phase angle was not significantly affected by adding different percentages of oil shale ash to the asphalt binder.

1. INTRODUCTION

Energy is very important in the modern civilization. Oil represents the most important source of energy in recent era. Demand on oil is very high and is expected to continue increasing due to the increase in the world population and due to the development activities in most parts of the world. Oil prices are increasing dramatically due to the fact that oil reserve is limited and due to the continuous increase on demand. Therefore, it is essential to look for other energy sources. Sustainable energy sources such as solar energy are the best ones. However, there are still many challenges facing these sources of energy.

Oil shale rocks represent one of the available energy sources that may be used in the future to release demand on oil. Jordan land contains more than 40 billion tones of oil shale rocks which can be used to produce billions of barrels of crude. With the dramatic increase of oil prices Jordan starts looking into manufacturing oil shale rock to produce oil. Oil shale rocks spread all over most of Jordan area. Figure 1 shows the locations oil shale deposits in Jordan. To manufacture oil shale rock it has to be heated where it breaks down into a crude oil, gases, and char. The main component of oil shale rock is Kerogen, which is a complex organic substance.

Different modifiers may be used in asphalt binders such as polymers, crumb rubber and fillers. Oil shale ash is a byproduct of oil shale rock processing to produce crude. This oil shale ash is a waste material. A good way to waste this material is to use it as an additive to the asphalt binder.

To be effective, adding oil shale ash to asphalt binder should improve its physical and rheological properties. Additives may enhance binder resistance to fatigue cracking, rutting, and thermal cracking. Furthermore, the thickness of the required structural section may be reduced when modified binders are used.

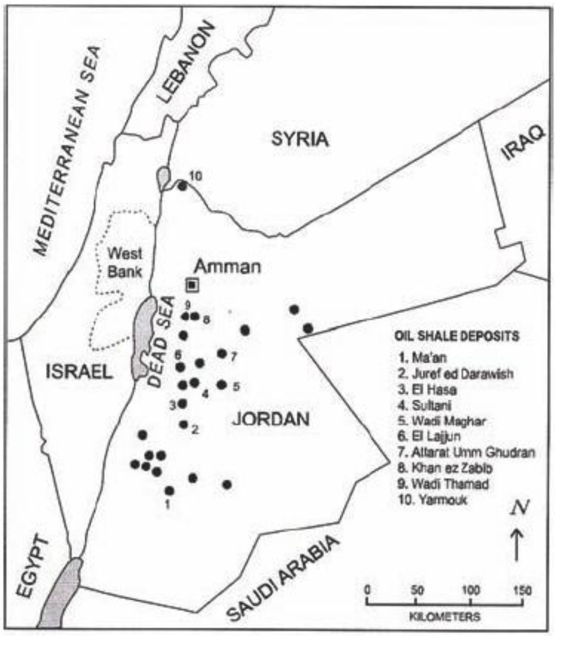

Figure 1: Oil Shale Locations in Jordan (after Jaber et al, 2008).

Khedaywi and Abu-Orabi (1989) added 0, 5%, 10%, 15%, and 20% of oil shale ash by volume to the asphalt binder. The effect of adding oil shale ash to the asphalt binder was investigated. Specific gravity, softening point, penetration and ductility for the modified binders were tested. It was found that increasing the percentage of oil shale ash decreased the penetration and ductility of the modified binder. On the other hand, increasing the amount of oil shale ash increased the specific gravity. Additionally, increasing the amount of oil shale ash in the binder increased the softening point of the modified binder.

AL-Massaid et al., (1989) evaluated the influence of adding oil shale ash to binder on the asphalt concrete mixtures properties under normal as well as freezing and thawing conditions. Oil shale ash percentages, varied from 0 to 20 % by volume of asphalt binder. Results indicated that asphalt concrete mixes produced with binders modified with oil shale ash had improved the behavior of the asphalt concrete mixes under dry and freeze-thaw conditions. The improvement was noticed by the addition of oil shale as up to 10% by volume of the asphalt binder.

Al-Khateeb and Al-Akhras (2010) studied the effect of cement additive on some properties of asphalt binder using Superpave testing methods. Asphalt binder was prepared by adding 5%, 10%, 15%, 20%, 25% and 30% by volume of asphalt binder. The properties of modified asphalt binder were investigated. Superpave rotational viscosity (RV) and the dynamic shear rheometer (DSR) tests for the modified binders were conducted. Results of the study showed that the increase in cement to asphalt ratio increased the stiffness of asphalt binders represented by the complex shear modulus (G*) value and also improved the rutting parameter, G*/sin δ value, at all temperatures.

Several researchers added different materials to asphalt binders to improve its behavior; oil shale ash was one of these additives. Most investigations included traditional tests such as ductility, penetration and softening point. However, view previous studies were conducted using the Superpave tests to investigate the effect of adding oil shale ash to binder on the rheological properties of the modified binder.

In this study, the rheological properties of asphalt binders modified with oil shale ash were investigated using the Dynamic Shear Rheometer (DSR). Different oil shale ash to asphalt binder ratios by volume was used. In addition, different testing temperatures were used.

2. OJECTIVES OF THE STUDY

The main objective of this study is to investigate the effect of adding oil shale ash with different percentages to asphalt binder on the rheological properties using the Dynamic Shear Rheometer (DSR).

3. EXPERMENTAL WORK

3.1 *Materials*

One type of fresh binder (60/70) produced by the Jordan Petroleum Refinery (JPR) was used in this study. The equivalent Performance Grade (PG) for this

60/70 asphalt binder is PG 64-10. Oil shale rock obtained from El-Lajjun deposit at the western part of central Jordan was burned by the Natural Resources Authority in Jordan. The oil shale ash obtained from this process was used in this study. The oil shale ash was sieved (passing) using sieve No.200. The specific gravity of oil shale ash was determined according to the ASTM C128 standards and found to be 2.699.

The oil shale ash to asphalt binder (OSA/A) mastics were prepared with 5%, 10%, 15%, 20%, and 25% OSA/A ratios by volume of asphalt binder. The American Society for Testing and Materials (ASTM) temperature–viscosity relationship was used to determine the mixing temperature (found to be between 145 and 152° C). Mechanical mixer was used to prepare the mastics at the desired mixing temperature.

3.2 *Sample Preparation*

DSR test samples were prepared according to AASHTO T315 and ASTM D7175. The fresh asphalt binder (or OSA/A mastic) was heated until it became sufficiently fluid to pour. Then it was poured into the silicone mold (25.0 mm in diameter) to get the required DSR test sample (Figure 2). Then the sample is cooled down to be able to remove it from the silicone mold and put between the plate and the spindle of the DSR.

3.3 *Dynamic shear rheometer (DSR) test*

Asphalt binder is a *viscoelastic* material. Asphalt binder behaves like both viscous and elastic material at the same time. Asphalt binder is not completely elastic and not completely viscous; it is a combination of both materials.

Temperature and time of loading have great influence on the viscoelastic behavior of asphalt binder. Temperature may be used to compensate the loading time (superposition concept of asphalt binder). Asphalt binder behavior at low temperature and long times is equivalent to the behavior at short time and high temperature.

Asphalt binder as a viscoelastic material behaves at the same time as viscous material and elastic material. Fatigue cracking and rutting are controlled through the relation between these two modes of behavior. Stiff and elastic asphalt binders are more rut resistance. On the other hand, it is desired to have flexible and elastic asphalt binders to resist fatigue cracking. Best pavement performance can be achieved through the balance between these two parameters. The viscous and elastic properties of asphalt binder should be characterized to ensure good pavement performance. The Dynamic Shear Rheometer (DSR) is used to capture the viscous and elastic properties of the asphalt binder.

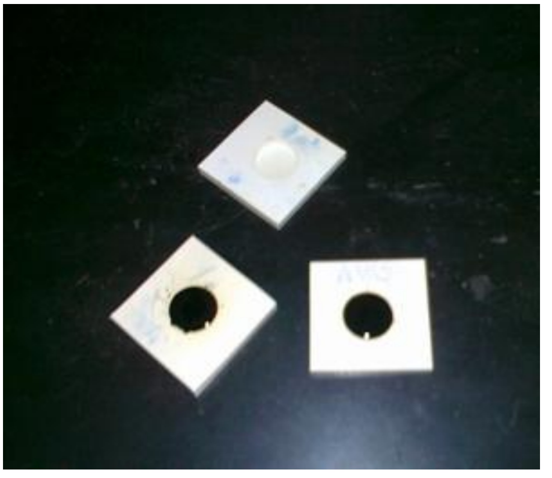

Figure 2: DSR Silicon Molds with Test Samples.

The DSR (Figure 3) measures the two parameters; the complex shear modulus (G*), and phase angle (δ) that used to characterize the viscoelastic behavior of the asphalt binder. The complex shear modulus (G*) is defined as the ratio of the maximum shear stress to the maximum shear strain. Phase angle (δ) is defined as the time lag between the applied shear stress and the response (shear strain). The following equations are used to calculate the complex shear modulus (G*), and phase angle (δ):

$$\tau_{\max} = \frac{2T}{\pi r^3} \qquad \text{.....................................(1)}$$

$$\gamma_{\max} = \frac{\theta r}{h} \qquad \text{.....................................(2)}$$

$$\left|G^*\right| = \frac{\tau_{\max}}{\gamma_{\max}} \qquad \text{.....................................(3)}$$

$$\delta = 360(t)(f) \qquad \text{.....................................(4)}$$

Where:

$\tau =$ Maxi maximum applied shear stress

T = maximum applied torque

r = radius of binder specimen (either 12.5 or 4 mm)

$\gamma_{\max} =$ maximum resulting shear strain

θ = deflection (rotation) angle

h = specimen height (either 1 or 2 mm)

G* = complex shear modulus

δ = phase angle (The time lag, expressed in radians, between the maximum applied shear stress and the maximum resulting shear strain)

Figure 3: Dynamic Shear Rheometer DSR.

In the DSR test the asphalt binder sample is sandwiched between an oscillating spindle from the top and a fixed plate at the bottom. The force (shear stress, τ) is applied to the asphalt sample, and then the resulting shear strain (γ) is measured. The time lag between the shear stress and the resulting shear straın ıs also measured (phase angle). Finally, the complex shear modulus (G*) is calculated using equation 3, full details on how to perform the DSR test is given in AASHTO T315.

The phase angle will vary between 0 (perfect elastic material) and 90 degrees (perfect viscous material). The complex shear modulus (G*) represents the total resistance of the material to deformation when repeatedly sheared. It consists of two parts, the elastic and the viscous parts. The elastic part, indicates that the asphalt binder behaves like an elastic solid and return to its original shape after a load is removed (recoverable deformation); the viscous part (deformation due to loading is not-recoverable i.e. permanent deformation), indicates that the asphalt binder behaves like a viscous liquid and cannot return to its original shape after a load is removed. The phase angle, δ represents the relative amount of recoverable and permanent deformation (Figure 4). Thus, the DSR, by measuring G* and δ, is able to determine the total complex shear modulus as well as its elastic and viscous components.

In this study, fresh asphalt binder and OSA/A mastics ratios of 5%, 10%, 15%, 20%, and 25% by volume of asphalt binder were tested using the DSR. The DSR test was conducted at a frequency of 10 rad/s (1.59 Hz) and four test temperatures: 58, 64, 70, and 76 °C at 6 °C increment similar to the increment used in the Superpave grading system for asphalt binders. High temperature properties of the OSA/A mastics were obtained, the testing matrix is shown in Table 1.

Viscous Behavior

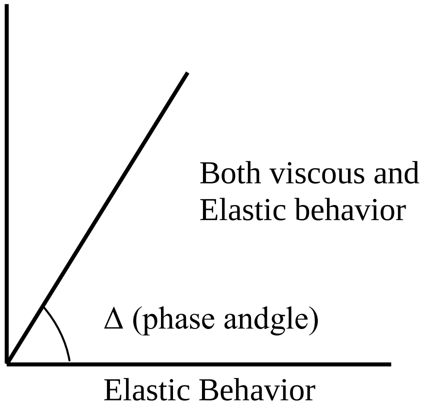

Figure 4: Elastic and Viscous Behavior of Viscoelastic Material.

Table 1: DSR Testing Matrix.

OSA/A Ratio	6	0.0, 0.05, 0.10, 0.15, 0.20, 0.25
Temperature (°C)	4	58, 64, 70, 76
Frequency, rad/sec (Hz)	1	10 (1.59)
Replicates	2	
Total	6*4*1* 2 = 48	

4. RESULTS AND DISCUSSION

The DSR test was used to measure the complex shear modulus (G*) values for all OSA/A ratios at the four test temperatures as shown in Tables (2). The G* values obtained for different OSA/A ratios at each temperature were plotted as shown in Figure 5. In this Figure it is clear that the G* value increases exponentially with the increase in the OSA/A ratio.

The Phase Angle (δ) values were obtained for all OSA/A ratios at the four test temperatures. Table (3) shows the phase angle values of the modified binder obtained at each OSA/A ratio and at each test temperature. The effect of the

OSA/A ratio on the phase angle (δ) of the asphalt binder was illustrated in Figure 6. It is obvious that the phase angle (δ) is not affected significantly by the increase in the OSA/A ratio. In other words, the elastic behavior of the asphalt material remains the same with the addition of the oil shale ash material.

Rutting in HMA pavements is defined as the accumulation of non recoverable (permanent) deformation. In the Superpave system rutting was addressed through using what is called rutting factor. Rutting factor is defined as G*/sin δ (sometimes called the high temperature stiffness). The Superpave specifications specify a minimum value of 1.0 kPa for the G*/sin δ of original asphalt binders at the high performance grade temperature and 2.2 kPa for the G*/sin δ for RTFO aged asphalt binders.

The rutting parameter (G*/ sin δ) values were obtained for all OSA/A ratios at the four test temperatures. Table (4) shows the Rutting Parameter (G*/ sin δ) values of the modified binder obtained at each OSA/A ratio and at each test temperature. The G*/sin δ values were plotted against the OSA/A ratios at the different temperatures as shown in Figure 7.

The relationship between G*/ sin δ versus the OSA/A ratios were plotted as shown in Figure 7. The Superpave rutting parameter criterion (the G*/sin δ value of 1.0 kPa minimum) is displayed by the dashed horizontal line as shown in Figure 7 (SP-1 manual series, 2001). The 58 °C and 64 °C curves passed the Superpave minimum requirement of the G*/sin δ value at all OSA/A ratios including the 0.0 ratio. On the other hand, the 76 °C curve failed to meet the minimum requirement of the G*/sin δ value at all OSA/A ratios except the 25% OSA/A ratio. However, the 70 °C curve passed the criterion of the G*/sin δ value at OSA/A ratios of 0.15 and higher. In general, adding the Oil Shale Ash to the asphalt binder improves the G*/sin δ value at all temperatures.

Table (2): Average G* Values in Pa.

		Temperature (°C)			
		58°	**64°**	**70°**	**76°**
OSA/Asphalt Ratio	**0%**	4089.14	1858.59	866.47	434.26
	5%	4699.25	2333.26	1096.53	569.59
	10%	6165.71	2920.97	1491.76	728.50
	15%	7668.88	3637.41	1701.41	884.51
	20%	8576.48	4257.15	2114.22	1105.03
	25%	12037.80	5578.49	2825.01	1505.67

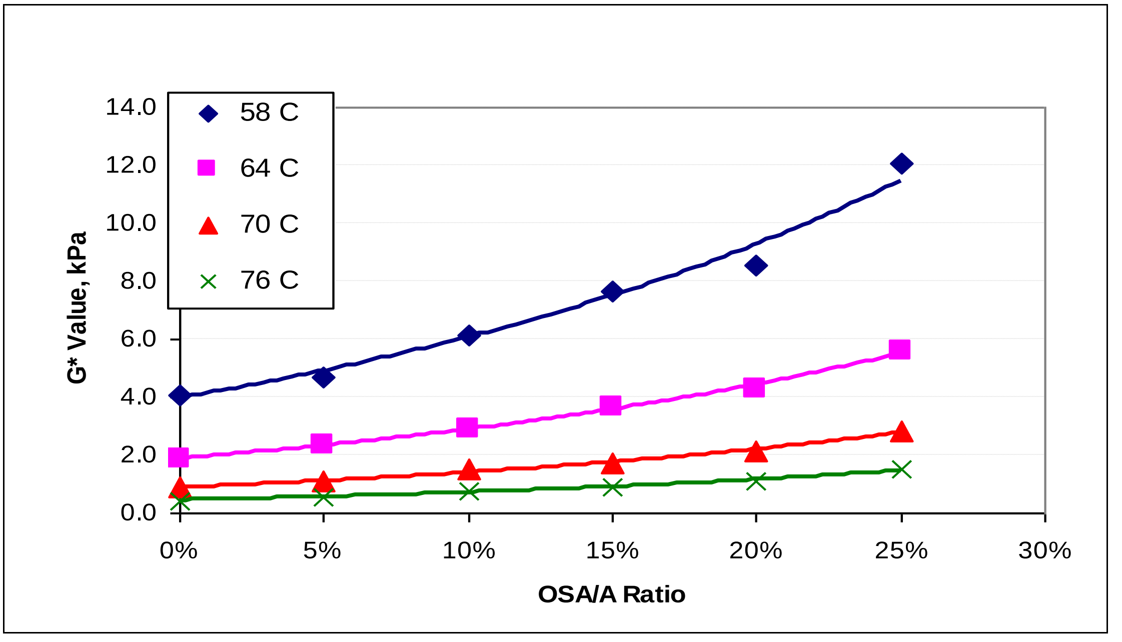

Figure 5: G* Values versus OSA/A Ratio at Different Temperatures.

Table (4): Average δ Values in Degrees

		Temperature (°C)			
		58°	**64°**	**70°**	**76°**
OSA/Asphalt Ratio	**0%**	77.6	80.5	82.7	84.0
	5%	77.2	79.9	82.2	83.9
	10%	78.4	81.0	83.2	85.0
	15%	78.6	81.1	83.3	85.0
	20%	79.2	81.5	83.6	85.2
	25%	79.0	81.5	83.6	85.1

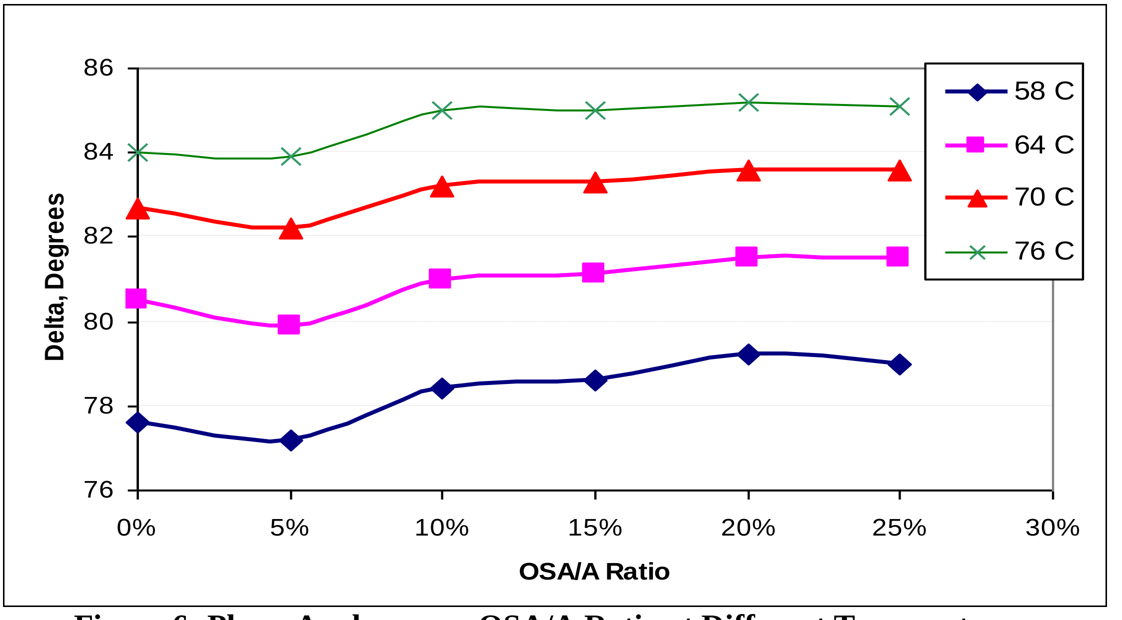

Figure 6: Phase Angle versus OSA/A Ratio at Different Temperatures.

Table (5): Average G*/ sin δ Values in Pa.

		Temperature (°C)			
		58°	**64°**	**70°**	**76°**
OSA/Asphalt Ratio	**0%**	4186.63	1884.72	873.59	436.65
	5%	4818.94	2370.16	1106.74	572.81
	10%	6294.43	2957.18	1502.32	731.29
	15%	7823.92	3682.25	1713.05	887.87
	20%	8731.78	4304.44	2127.66	1108.91
	25%	12262.23	5641.01	2843.03	1511.27

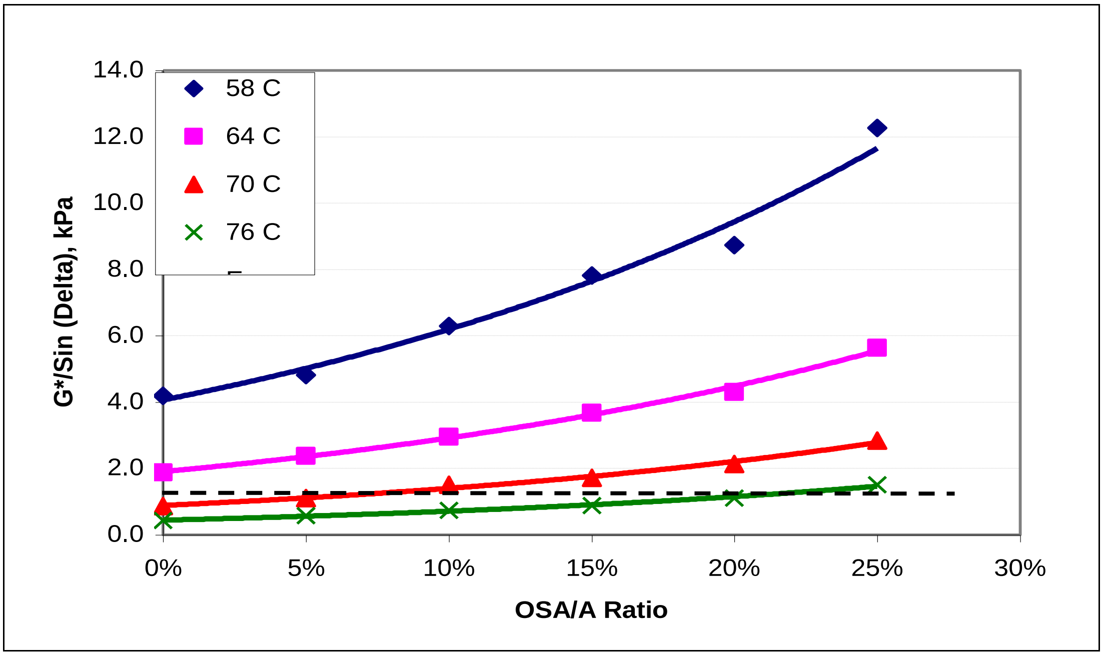

Figure 7: G*/sin δ versus OSA/A Ratio at Different Temperatures.

5. CONCLUSIONS

Based on laboratory testing and based on the analysis in this study, the following conclusions were drawn:

- The increase of the OSA/A ratio increase the complex shear modulus (G*) of the asphalt binder (asphalt binder stiffness).
- The effect of the increase of the OSA/A on the phase angle (δ) and the elastic behavior of the asphalt binder was insignificant effect.
- The increase in the OSA/A ratio improved the Superpave rutting parameter, G*/sin δ value, at all temperatures.
- The increase in OSA/A ratio improved the Superpave high performance grade temperature (the high temperature at which the asphalt binder passed the Superpave criteria for G*/sin δ value).

6. REFERENCES

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