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COMPARISON OF TWO ASPHALT MIXTURES USING COMPLEX MODULUS TEST IN LIBYAN WEATHER

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Abstract **–** The complex modulus test is dependent on temperature and loading frequency. Thus, the results produced from this test will give a more accurate representation of traffic load effects on asphalt pavement. Laboratory experiments were conducted on two different asphalt mixtures for road research projects (Libya/Roads). All specimens had the same mixtures of aggregate gradation GB-20 incorporated with two different asphalt binders PG70-10 and B (60/70). To obtain the master curve, there were some errors at low temperatures (-25, -10 ºC) and high temperature (54 ºC), so these values were discarded. In addition, 2-complex modulus (CM) and phase angles (Phi) in the test were measured at temperatures of -25, -10, -5, 10, 25, 35, and 54ºC, as well as frequencies of 25, 10, 5, 1, 0.5 and 0.1 Hz. The results displayed the influence of the type of binder on the rheology of the mixtures and gradation on the intensity. Hence, using binder PG 70-10 in Libyan asphalt roads may reduce the binder content, increase the mixture workability, and decrease the thermal cracking. The intrinsic characteristics related to binder properties and weather temperature exhibited the most significant impact on the predicted dynamic modulus.

Keywords: complex modulus, frequencies, temperatures, sinusoidal, phase angles

1.0 INTRODUCTION

Insertion of the properties of asphalt mixture into a new design procedure being developed is indeed a challenging task. A complex module refers to a test that measures both elastic and viscous material properties. However, in order to use the test results for asphalt mix design, it is necessary to assume that the mixture has linear and isotropic attributes [1]. A review of current literature shows both valid assumptions for the elastic properties of the asphalt mixture under certain environmental conditions. The literature review is also used to provide reference information for developing a standard test method by considering the effect of the asphalt binder and environmental temperature on the results of a complex module [2]. Due to the Libyan climate, pavements are subjected to severe conditions, such as rain, cold, dry winds, showers, and severe changes in temperature from 0 ºC to over 54 ºC, which can lead to complicated behaviour of the asphalt pavement. Hot-mix asphalt (HMA) is a viscoelastic material, wherein in high temperatures, it behaves as a viscos material and as plastic at low temperatures, which is characterized by a certain level of rigidity of an elastic solid body. It flows and dissipates energy by frictional loss as a viscous fluid [3]. As with any viscoelastic material, the HMA's response to stress depends on both temperature and loading time. At high temperatures or with slow moving loads, the HMA may exhibit a purely viscous flow. Pavement temperatures are perhaps the most important elements for an asphalt mixture design and influence almost all the important properties of HMA mixtures, such as stiffness, stability, and durability. Therefore, the following research adopted a new asphalt binder, PG, which should be related to the climatic conditions of Libya.

2.0 OBJECTIVES

Complex modulus of asphalt mixture is largely dependent on the asphalt binder properties, loading frequency and weather temperature. Therefore, this research summarized the results and the experiences gained so far through laboratory testing methods. The objectives of this paper are as follows: first, the purpose of this test is to demonstrate the difference in | E * | results between two asphalt mixes that were tested for the same frequency and temperature. Second, it presents the laboratory experiments of two different asphalt mixtures for road research project (Libya/Roads) to improve the local mix design formulation of the pavement asphalt mixture and to obtain an economical mixture that would meet the requirements for the characteristics of the pavement in Libya. Third, the results of the test and how the various variables influenced the rheology and complex modulus of the asphalt mixtures are presented. Finally, this study is concluded by presenting the correlations between asphalt binder, traffic load, and temperature on the test results.

3.0 BACKGROUND

The AASHTO 2002 design guide aims to introduce more rigorous measures of performance into hot mix asphalt mixtures and pavement design procedures. The NCHRP project I -37A has produced the new 2002 design guide for New & Rehabilitated Pavements. In 1999, the NCHRP panel for Project 1-37A selected E* for this purpose. The selection was based on a paper authored by Witczak, which compared E* to an Indirect Diametral Test (MR), in which both test procedures have been in use by the research community for years [4]. Overall, the most current methods of asphalt mix design almost entirely rely on the volumetric composition of asphalt mixtures. The MTS machine has developed the test method known as LC 26-700 to determine the complex modulus of asphalt mixtures [5]. A repeatability study was also conducted to describe the quality of the test and the influence of air voids on the complex modulus of asphalt mixes. There are various tests to characterize bituminous mixtures. These tests can be divided into two main categories: homogeneous and heterogeneous tests [6]. In this study, the complex modulus was observed in homogenous tension-compression tests. The AASHTO provisional test standard TP62-03 performed at temperatures of -10, 4.4, 21.1, 37.8, and 54 ºC and frequencies of 25, 10, 5, 1, 0.5, and 0.1 Hz had been specified for loading the sample at each temperature. The recommended protocol is a stress-controlled version of the complex modulus test, in which the sinusoidal (haversine) cyclic load applied to the specimen is adjusted so that the specimen is subjected to axial strains between 50 and 150 micro strain ($\mu\varepsilon$). This constraint is in place to guarantee that testing is being performed within the linear viscoelastic zone. Based on the current test protocol, the stress level was selected from a certain range set for each test temperature [7].

3.1 TENSION-COMPRESSION TEST

This homogeneous test can be carried out in stress or strain-controlled conditions. Figure 1 shows the uniaxial tension-compression complex modulus test setup. It was developed in the DGCB of the ENTPE laboratory [8].

Figure 1 Uniaxial tension-compression complex modulus test setup

The master curve allows one to compare asphalt mixes that have been tested at different frequencies and temperatures [9]. In addition, it allows one to calculate the values of the module for frequencies that are not experimentally available. A few different equations can be used to describe the ratio of time and temperature in viscoelastic materials Ta, but the most commonly used is Williams, Landell and Ferry's (WLF) Eq. (1) (William, Landel et Ferry, 1955):

$$log\ a_T\ \frac{-C_1(T-T_0)}{C_2\ (T-T_0)} \qquad (1)$$

Where: a_T: Horizontal shift factor; C_1 *and* C_2*:* Material constants; T: Temperature of curve to be shifted in ºC; and T_0: Reference temperature in ºC.

4.0 METHODOLOGY

In this study, the complex modulus of two asphalt mixtures had been observed in homogenous tension-compression tests. The complex modulus was measured at different frequencies and temperatures. The tests were performed at strained criterion of 50×10^{-6}m/m, based on experience and to make sure that it was well below the limit of $50\ \times 10^{-4}$m/m to avoid fatigue cracking. Two different asphalt mixtures for road research project (Libya/Roads) were evaluated in this study. The mixtures had similar aggregate gradation, GB-20, after incorporating two different asphalt binders PG70-10 and B (60/70). The 2-dynamic modulus and phase angles were measured at temperatures of -25. -10. -5. 10. 25. 35 and 54 ºC, as well as frequencies of 25, 10, 5, 1, 0.5, and 0.1 Hz. The influences of the binder type on the rheology of the mixtures and of the gradation on the intensity of the complex modulus are demonstrated. Specimen preparation, test procedures, and data analysis adhered to the recommendations of NCHRP Project 9-29.

5.0 LABORATORY EXPERIMENTS

Over the years, several design and development methods have been implemented by various agencies. Hence, this review focuses on the complex modulus of two different HMA in a hot climate, such as that in Libya.

5.1 SAMPLE PREPARATION

Both AASHTO TP 62-07 and ASTM D 3497-79 test methods call for the use of a shear gyratory compactor (SGC) to prepare the specimens in order to determine the E* of asphalt mixes. Two cylindrical specimens, 100-mm by 150-mm, were prepared according to NCHRP Project 9-29. Cylindrical (150-mm by 170-mm) specimens were compacted in the laboratory using SGC. They were then cored to a 100-mm diameter and saw cut to a final height of 150 mm. The air voids were measured on the finished test specimens. Adjustments were made to the number of gyrations during compaction to achieve about 4.075, 4.016 and 5.0% air voids for mixture with PG 70-10 and 4.003, 4.099 and 5% air voids for mixtures with B (60/70). This sample preparation procedure was performed to generate four samples for each of in the two mixtures from B (60/70) and PG 70-10 respectively. Tables 1 and 2 present the parameters obtained during sample preparation.

Table 1 Calculation of air voids (va) in complex modulus specimens

Calculation of air voids (va) in complex modulus specimens						
Sample No	wt of dry sample (g)	wt of sample in water (g)	wt of SSD. (g)	G_{sb}	G_{mm}	% Va
S1-B 60/70	1662.800	1015.200	1663.700	2.564	2.513	4.075
S2-B 60/70	1662.600	988.000	1663.100	2.463		4.099
S1-PG70-10	1684.100	1001.450	1684.600	2.465	2.515	4.003
S2-PG70-10	1667.800	1018.250	1668.300	2.566		4.016

Table 2 Dynamic modulus fitted values at T_{ref} 15 ºC

Temperature (°C)		Frequency (f_r(Hz))	S-PG 70-10		S-B 60/70	
			|E*| (MPa)	Phi (E*)	|E*| (MPa)	Phi (E*)
Temp 1	-34.68	0.01	41308	2.49	34916	4.13
	-34.67	0.03	41070	181.36	35001	2.47
	-34.93	0.10	43114	91.95	36024	2.59
	-35.20	0.30	43654	1.38	36812	1.53
	-34.91	1.00	44103	1.16	37456	1.25
	-35.07	3.01	44437	0.98	38115	1.14
	-35.07	10.13	45316	0.73	38709	0.87
Temp 2	-25.29	0.01	33034	2.12	28213	5.23
	-25.35	0.03	35768	3.83	29083	5.05
	-24.63	0.10	37111	3.14	31686	3.85
	-24.80	0.30	38825	2.93	32895	2.60
	-24.86	1.00	40110	2.20	33944	2.57
	-25.11	3.00	41086	2.03	34877	2.10
	-25.28	10.06	42450	1.52	36226	1.53
Temp 3	-14.89	0.01	25231	7.18	20742	7.47
	-14.36	0.03	27405	9.38	22881	6.18
	-15.35	0.10	30182	5.69	24585	5.73
	-15.12	0.30	31655	4.73	26419	5.22
	-15.28	1.01	33853	4.49	28404	4.51
	-15.27	3.02	35604	3.89	29906	4.04
	-15.14	10.04	37477	3.16	31874	3.09
Temp 4	-5.07	0.01	15606	14.22	12873	11.42
	-4.89	0.03	17394	11.22	14809	10.96
	-4.03	0.10	19544	10.31	17061	9.49
	-4.10	0.30	22476	8.60	19066	8.07
	-4.09	1.00	25108	8.17	21070	7.43
	-4.15	3.01	27563	6.86	22939	6.99
	-4.64	10.17	30237	5.96	24996	6.00
Temp 5	5.10	0.01	6791	22.64	6743	18.28
	5.12	0.03	8885	19.88	8334	15.44
	5.01	0.10	11227	17.08	10199	14.63
	5.07	0.30	13600	14.66	12064	12.67
	5.02	1.01	16229	13.16	14017	11.11
	5.01	3.01	18805	11.48	15953	10.56
	5.04	10.03	21657	9.83	18254	9.23
Temp 6	15.24	0.01	2204	31.43	2905	25.56
	15.24	0.03	3149	30.05	3932	23.48
	15.23	0.10	4531	27.25	5167	21.09
	15.22	0.30	6147	25.36	6583	19.09
	15.27	1.01	8297	22.42	8304	17.09
	15.30	3.02	10562	19.24	10098	15.47
	15.19	10.05	13375	16.33	12242	13.51
Temp 7	25.26	0.01	765	31.88	1129	28.60

	25.24	0.03	1032	34.06	1545	28.43
	25.21	0.10	1552	34.70	2175	27.25
	25.27	0.30	2305	33.59	2966	25.57
	25.22	1.01	3471	31.44	4092	24.12
	25.19	3.01	4905	28.96	5391	22.29
	25.21	10.07	6999	25.58	7134	19.93
	35.00	1.01	1359	36.14	922	29.99
Temp 8	34.98	3.01	2026	35.74	1297	29.92
	34.98	10.05	3164	34.26	1865	29.43

5.2 COMPLEX MODULUS EXPERIMENTAL RESULTS

In this experiment, a Tensile-compression (T-C) test was performed on a cylindrical specimen. The results obtained from this test reflect the linear viscoelastic behaviour of these materials. Comprehensive testing of the complex modulus was performed on two samples for each mixture. The calculation of air voids (Va) in complex modulus specimens is shown in Table 1. The range of the content of voids between samples had been within the permissible range of + 0.5%. The content of air voids in all tested samples was in the range of 4 + 03%. In order to compare the mixtures, it is possible to deal with the average value of two samples for mixtures, if they are close to the content of air voids or refers to 1:1 sample result. In this study, the first option was chosen, and for comparison, carefully selected samples with similar air voids as distant as possible. Only the results that were obtained with good quality index, QI (less than 15%), are presented and used in the analysis. Apart from the results at low temperatures, the value of QI can be higher than 15%. It can be referred that the stiffness of the asphalt mix can be slightly higher, and this can reduce the level of deformation. Other results that did not meet the conditions of acceptance were rejected from the analysis. Figure 2(a) and 2(b) present respectively the isothermal curves of the norm of complex modulus based on the frequency and the temperature for the both mixtures. It can be observed that the norm of complex modulus increased when the frequency increased, but decreased when the temperature increased, as implied in both mixes. However, the results show that the behaviour of mix PG 70-10 is more reliable than that of mix B 60/70 under high temperatures. The results for dynamic modulus of each mixture are shown in Table 2. The range of the measured complex modulus of mix S-PG 70-10 is between 765 MPa and 43,654 MPa, while the phase angle ranged from 0.73 to 36.14 degrees. The complex modulus was measured from 922 MPa to 38709 MPa and the phase angle from 0.87 to 99.99 degrees for mix S-B60/70.

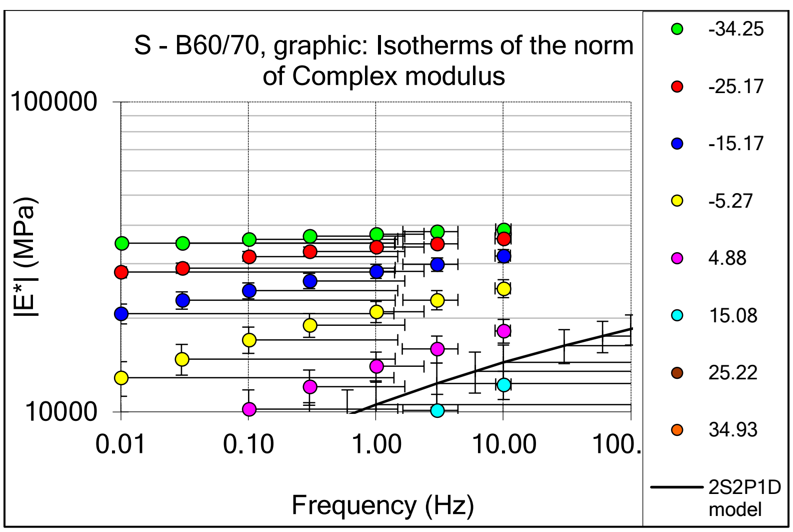

Figure 2(a), Graphic of isotherm curves of the norm for complex modulus

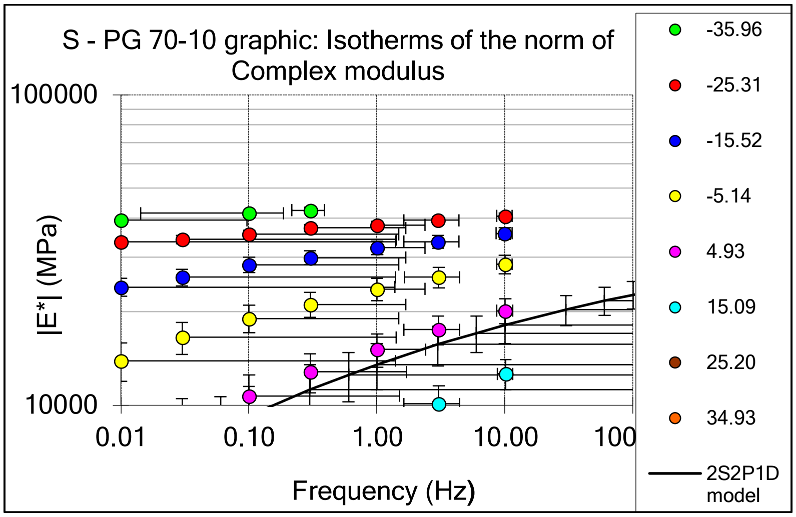

Figure 2(b) PG70-10 Graphic of isotherm curves of the norm for complex modulus

The master curves of the norm complex modulus results are shown in Figure 3(a) ,(b), (c) and (d) under different test temperatures and frequencies. The shift factors obtained during the master curve construction related to frequency and phase angle of some selected materials are presented in Figure 3(a) and 3(b), while Figure 3(c) and 3(d) are related to frequency and complex modulus. These figures show how shift factors vary between mixtures with repetition, which had been carried out. The complex modulus test results for both mixtures S-B 60/70 and S-PG 70-10 are presented in Table 2. The shift factors are defined graphically after this study used the classical WLF law to match the values of C1 and C2.

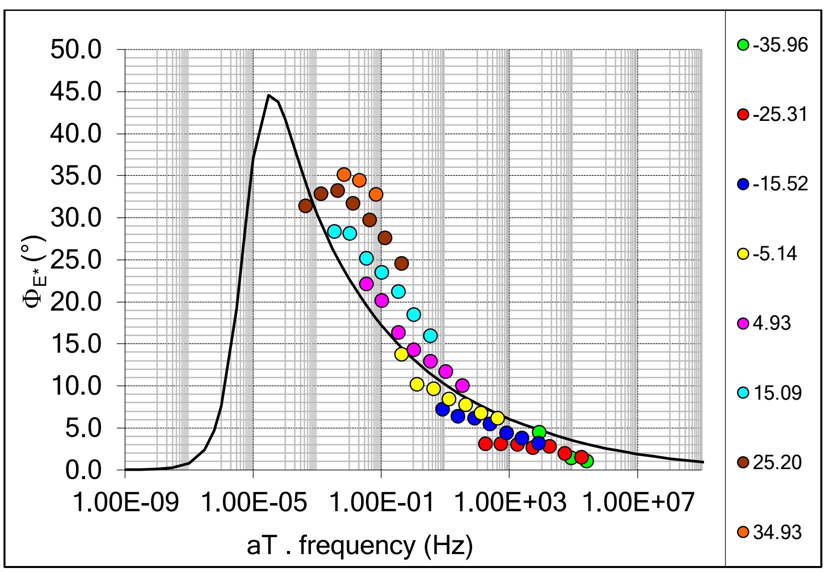

Figure 3(a) Master curve of the phase angle for asphalt mixture B60/70

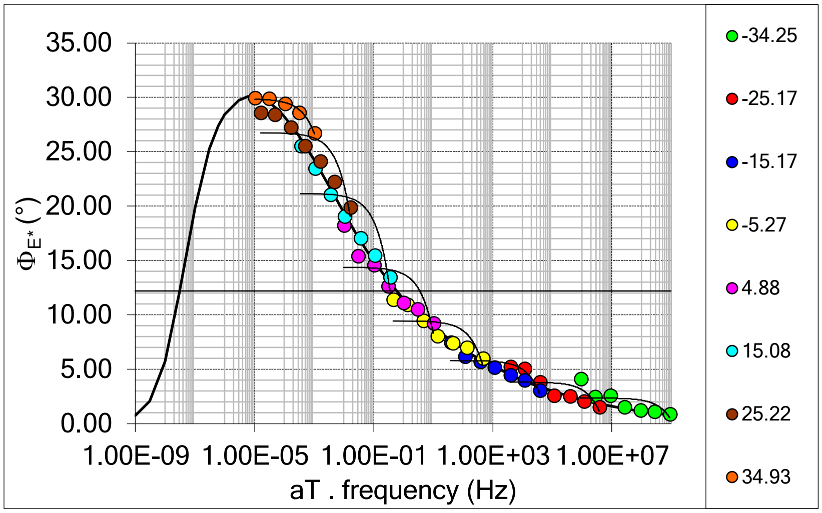

Figure 3(b) Master curve of the phase angle for asphalt mixture PG 70-10

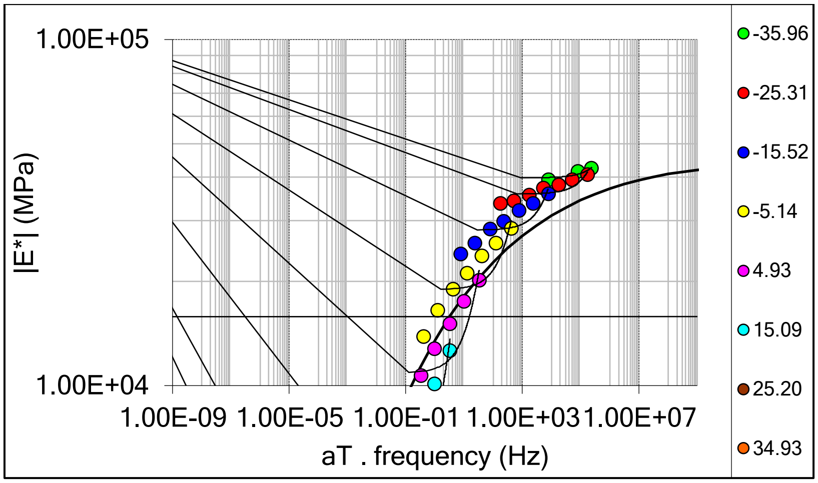

Figure 3(c) Master curve of the norm for asphalt mixture B 60/ 70

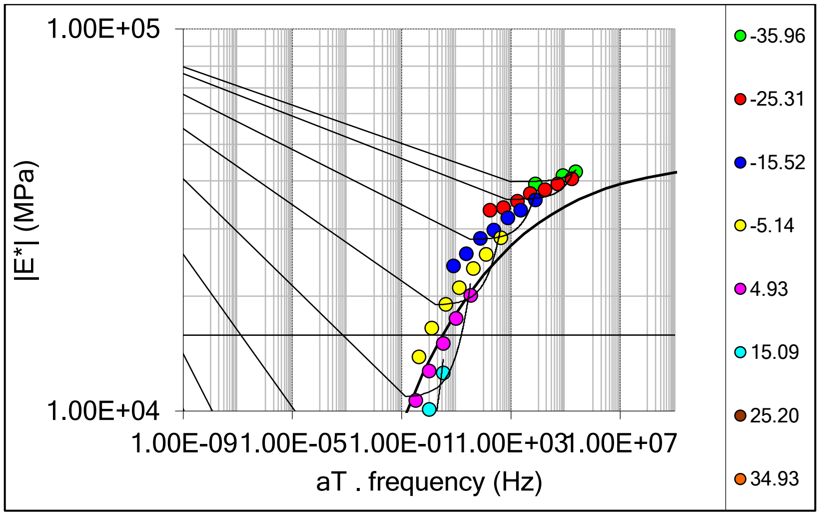

Figure 3(d) Master curve of the norm for asphalt mixture PG 70-10

The values of the coefficients, C1 and C2, are given earlier in Table 3, corresponding to each sample. The main curves obtained in this study of the complex modulus to various HMA mixtures were examined at a reference temperature set at 15°C (Tref).

Table 3 William, Landel & Ferry (WLF) τ's quadratic fited values

Temp. (°C)	**S-PG 70-10** **aT** (WLF)		**S-B60/70** **aT** (WLF)	
-34.93	790751.3798		34052011.47	
-25.05	17167.86149		289528.6379	
-15.06	769.5616324		2716.423572	
-4.42	41.25788985		44.00281822	
5.05	3.255295136		1	
15.24	0.324691906		0.032696996	
25.23	0.040702925		0.001507265	
34.99	0.006587013		0.000102941	
Parameters C_1 & C_2	C_1= 19.49	C_2 =197.80	C1= 29.57	C2 =192.73

To construct the main curves, shear coefficients were determined for each mixture at the selected reference mixture temperature (Tmix_ref) with respect to one of those used for each tested mixture. The curves of the complex modulus on the Cole-Cole plane and diagrams of the Black space are presented in Figure 4(a) and 4(b), respectively. The unit curve obtained in the Cole-Cole plane shows the principle of time-temperature superposition (TTSP) in the Linear Viscoelastic (LVE) region of the asphalt mixture. Figure 5(a) and 5(b) show the black curves, in which some scattered results can be observed, which means that the black curve is not unique.

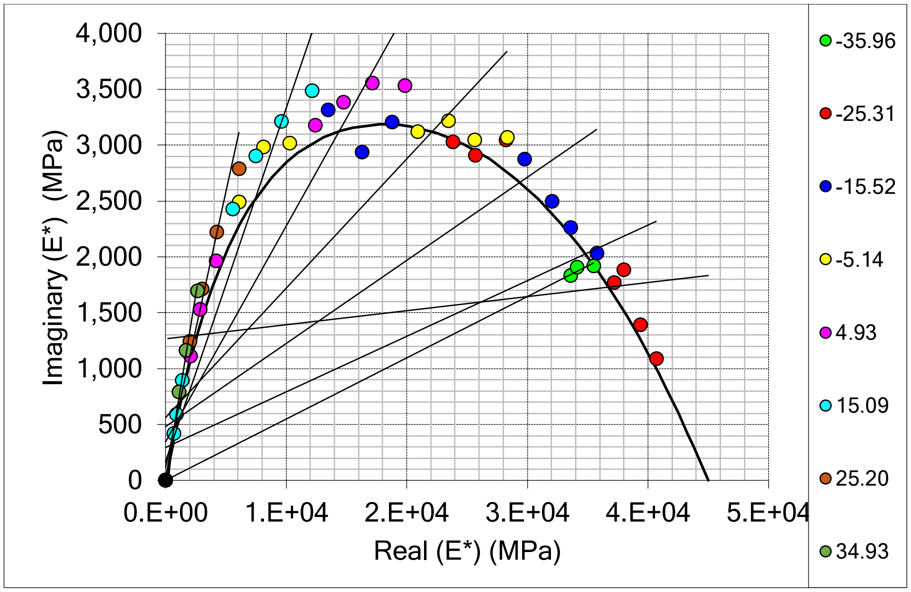

Figure 4(a) Graphic of Complex Modulus in Cole-Cole axes for asphalt mixture B60/70

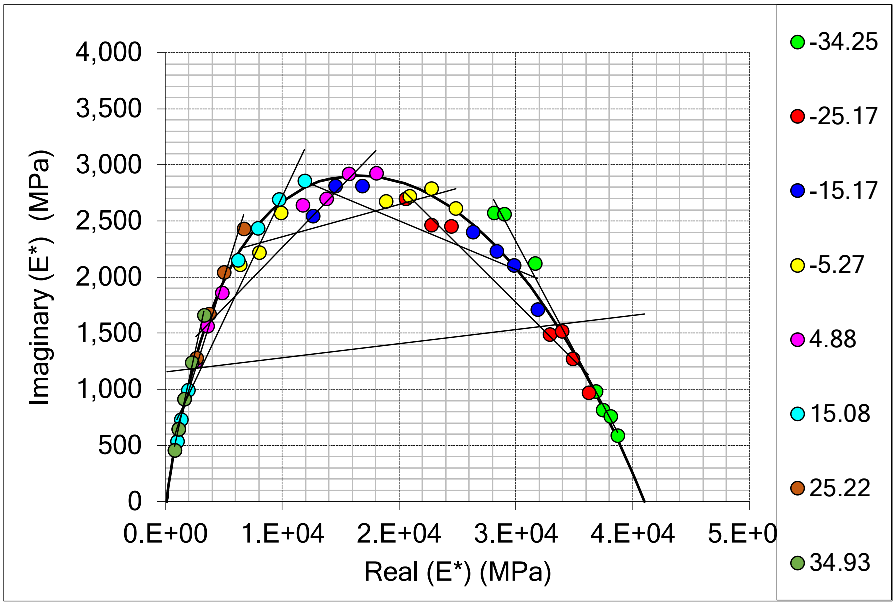

Figure 4(b) Graphic of Complex Modulus in Cole-Cole axes for asphalt mixture PG 70-10

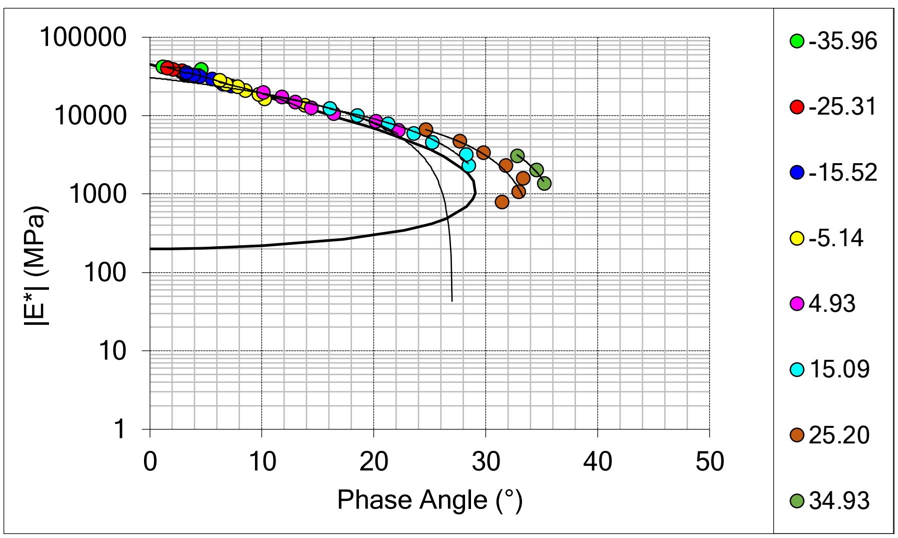

Figure 5(a) Graphic of Complex Modulus in Black space for asphalt mixture B60/70

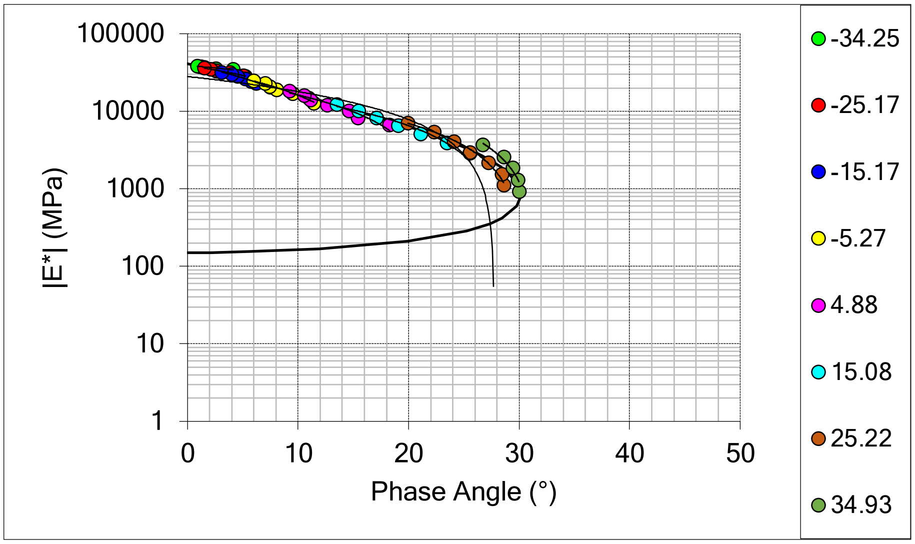

Figure 5(b) Graphic of Complex Modulus in Black space for asphalt mixture PG 70-10

6.0 SYNTHESIS AND DISCUSSION OF THE FINDINGS

In general, it is not easy to maintain a complex modulus test at a low temperature of -35 °C due to the freezing of measuring instruments and this may produce an audible sound during the test. Additionally, there were some problems when testing at a high temperature (54 ° C), such as melting asphalt binder and unstable test device setups. Thus, the measured test data at -35 ° C and 54 ° C produced more noise. This causes an error to the main curve for each asphalt hot mix. The study clearly displays that the amount of air voids in both mixtures were the same. Although the number of air voids had a significant effect on the complex modulus in the asphalt mixtures, this parameter could not be used to predict the E* in this study (see Table 1). This study conducted eight different test temperatures to produce a master curve. As shown in Figure 2(a) and 2(b), respectively, the norm of complex modulus increased when the frequency increased, but decreased when the temperature increased, as implied in the literature. Figure 3(a) and 3(b) show that the phase angle decreased upon increased frequency. Figure 3(c), Figure 3(d), and Table 3 reveal how shift factors vary in the case of the varied selected materials. The values of coefficients C1 and C2 are shown in Table 3, corresponding to each sample. In fact, there is no huge difference between the basic curve for the standard and simplified mixtures, in the range of log-reduced time from - 4 to 6. On the other hand, at low testing temperatures, the difference for the master curve can be ignored, but at high temperatures, the master curve for both mixtures is not similar. For the design of asphalt pavement, logging reduction time in the range from -5 to 5 will be used, which can simulate vehicle speed, loading time on asphalt, and temperature. Nevertheless, Figure 4(a) and 4(b) display the incorporation of laboratory data based on the master curves, Cole-Cole. Figure 5(a) and 5(b) display the incorporation of the laboratory data at the Black spaces, which displayed some scattered results and that means, the curves are not unique. However, the conventional asphalt mixture with asphalt binder B 60/70, which were used in this study, did not perform well at Cole-Cole plane and Black space diagram, and thus, yielded inadequate results. On the other hand, the mixes that were designed using the asphalt-binder PG 70-10 manifested proper performance as expected, which means that they do not conform entirely to the Time-Temperature Superposition Principle (TTSP). This could be due to the differences in the binder properties.

7.0 SUMMARY AND CONCLUSION

The purpose of this test is to demonstrate the difference in | E * | results between the two different asphalt mixes that were tested for the same frequency and temperature. The results of this test are important, even if we focus on the obtained results and the comparison of mixes using 1:1 sample. The test results of the dynamic modulus of elasticity for each mixture are given in Table 2. The range of measured complex modules is from 765MPa to 43,654 MPa, and the phase angle is from 0.73 to 36.14 degrees for S-PG 70-10 mixture. Simultaneously, the complex modulus was measured in the range between 922 MPa and 38,709 MPa and the phase angle was measured from 0.87 to 99.99 degrees for the S-B 60/70 mixture, respectively, while the values of coefficients C1 and C2 are shown in Table 3. These values are not the same for both mixtures, and the main curves obtained from the tests of various HMA mixtures were examined at a reference temperature set at 15 °C (Tref) for comparison of mixes. Eventually, in Fig. 3(a), and Fig. 3(b), one can observe some scattered results, which means that these curves are dissimilar. Indeed, the complex module of the asphalt mixture increased with frequency increase. The dynamic module decreased with increasing test temperature for the same mixture. However, the usual asphalt mix with asphalt binder B 60/70, which was used in this study, did not show good results on the Cole-Cole plane and on the black space diagram, thus providing inadequate results. The mixtures developed using asphalt binder PG 70-10 demonstrated proper performance, as expected, which means that they do not fully comply with the principle of time and temperature superposition (TTSP). The proper selection of the asphalt binder can improve the pavement performance. However, the most important factor that affects the pavement performance is the selection of the type of asphalt binder related to the climatic conditions at the project site.

8.0 ACKNOWLEDGEMENT

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