Developing Master Curves of Dynamic Modulus and Phase Angle of Asphalt Mortar and Asphalt Mixture Using the Least Number of Test Temperatures and Frequencies

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Abstract

Asphalt mortar and asphalt mixture are viscoelastic materials due to the presence of bitumen in their structures. The master curves of dynamic modulus and phase angle developed through the horizontal shifting of the results using the appropriate shift factors are commonly used to describe the viscoelastic properties of asphalt mortar and asphalt mixture. In this study, constructing master curves of dynamic modulus and phase angle of asphalt mortar and asphalt mixture using the least number of test temperatures and frequencies was investigated. The dynamic modulus test was performed on asphalt concrete and asphalt mortar samples at six temperatures and frequencies. Then, the Laboratoire Central des Ponts et Chaussees method was used to determine the shift factors for constructing master curves. Also, the modified Christensen-Anderson-Marasteanu model was fitted on the master curves to predict their viscoelastic properties at an arbitrary temperature and frequency. In addition, the master curves and the fitted models, which are created by using test results at two frequencies and six temperatures, six frequencies and three temperatures, or three frequencies and three temperatures, could provide the same predicted values and patterns as the original fitted model with more than 92% accuracy. So, as a result, it is possible to develop the master curves of the viscoelastic properties of asphalt mixture and asphalt mortar with a lower number of test results that have similar accuracy to the original master curves and reduce the time and cost of experiments up to 50%.

Keywords

Asphalt Concrete, Mortar, Master Curve, Frequency, Temperature

Introduction

Asphalt mixtures are viscoelastic materials faced with traffic and temperature stresses in their lifetime [1, 2]. The time-temperature superposition principle is used to examine the performance of the asphalt mixture at a vast and acceptable range of temperatures and frequencies [2, 3]. The master curves of dynamic modulus and phase angle are applied to predict the properties of asphalt mixtures [4, 5]. The master curves are created horizontally transferring the viscoelastic properties using the appropriate shift factor [6]. There are several methods to evaluate the shift factor investigated by Yusoff et al. [7]. They observed that the LCPC method (Laboratoire Central des Ponts et Chaussees) was a better performance than other methods [7]. After producing the master curves, different models can be fitted to predict the viscoelastic properties. These models were investigated by Asgharzadeh et al. [8]. They reported that the modified CAM model has an excellent performance in predicting the asphalt mixture characteristics [8].

Using frequency sweep tests to identify the properties of asphalt mortar and asphalt mixture requires a wide range of temperatures and frequencies that take much time. In this study, the master curves of viscoelastic properties of asphalt mortar and asphalt mixture were produced using a different number of temperatures and frequencies, the modified CAM model fitted on those, and the main parameters and their shape of them were compared. The main aim of this study is to generate the desired master curves and identify the bitumen composites properties using the results of the dynamic modulus test at an optimum number of temperatures and frequencies.

Theoretical Bases

The LCPC method was introduced by Chailleux et al. [9] based on Kramers-Kronig equations. This method was used to calculate the shift factor for temperature T_i at any given frequency (ω) based on Eq. 1 [9].

$$\mathrm{Log}\,(\alpha_{(T_i, T_{ref})}) = \sum_{j=i}^{j=ref} \frac{\mathrm{Log}\,(|E^*_{(T_j,\omega)}|) - \mathrm{Log}\,(|E^*_{(T_{j+1},\omega)}|)}{\delta_{avg}^{(T_j, T_{j+1})}(\omega)} \times \frac{\pi}{2} \qquad (1)$$

The modified CAM model was developed by Zeng et al. [10] to predict the viscoelastic behavior of bitumen and asphalt mixture. Eq. 2 and 3 were introduced by the modified CAM model to evaluate the dynamic modulus and phase angle, respectively [10].

$$E^* = E^*_e + \frac{E^*_g - E^*_e}{\left[1 + (f_c / f')^k\right]^{\frac{m_e}{k}}} \qquad (2)$$

$$\delta = 90I - (90I - \delta_m)\left\{1 + \left[\frac{\mathrm{Log}(f_d / f')}{R_d}\right]^2\right\}^{-\frac{m_d}{2}} \qquad (3)$$

which, E^*_e, E^*_g, and f' are equilibrium dynamic modulus, glassy dynamic modulus, and reduced frequency, respectively. Also, f_c and f_d are location parameters with dimensions of frequency, and other parameters are shape parameters (dimensionless).

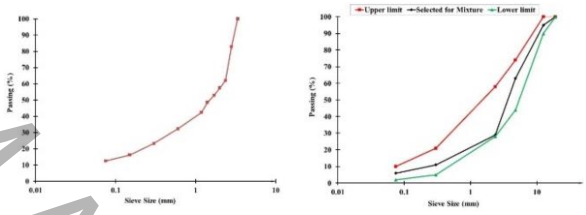
Materials and Methods

The PG 64-16 performance grade bitumen was used in this study. The properties of bitumen are represented in Table 1

Table 1: Properties of PG 64-16 performance grade bitumen

Properties	Value	Standard
(gr/cm^3) density	1.02	ASTM D7
Penetration	66	ASTM D5
Softening Point	49.5	ASTM D36
Viscosity @ 135°C (Pa.s)	331.5	ASTM D4402

The siliceous aggregate with an NMAS of 19 mm was used in this study. The gradation plot of aggregates for asphalt mortar and asphalt mixture is shown in Figure 1.



(a) (b)

Figure 1: The gradation plot of aggregates for a) asphalt mortar and b) asphalt mixture

To identify the viscoelastic properties of asphalt mortar and asphalt mixture, the dynamic modulus test based on AASHTO T342-11 was performed. The test specimen is cylindrical with 70mm and 100mm diameter and 120mm and 150mm height for asphalt mortar and asphalt mixture, respectively. Also, the test frequencies are 0.1, 0.5, 1, 5, 10, and 25Hz, and the temperatures are -10, -5, 0, 4.4, 10, and 21.1°C for asphalt mortar -10, 0, 4.4, 21.1, 37.8 and 54.4°C for asphalt mixture.

Results and discussion

The results of dynamic modulus tests were collected for both asphalt mortar and asphalt mixture. Then the master curves of dynamic modulus and phase angle were produced using the all data. In this study, two criteria were investigated for decreasing the number of test temperatures and frequencies: 1) the main parameters of the fitted model must not be changed by reducing the number of test results, and 2) The fitted model on reduced data should correctly and accurately predict the dynamic modulus and phase angle of asphalt mortar and asphalt mixture and the predicted results and experimental results should not have a significant difference.

It was shown that the fitted model on the experimental results at two frequencies and six temperatures or three temperatures and six frequencies are similar to the fitted model on all data. Figure 2 represents the models fitted on all data and the data with the minimum number of temperatures and frequencies. As can be seen, the fitted model on reduced data has the same shape and pattern as the original model. Also, table 2 displays that the main parameters of the fitted model on reduced data and all data have no significant difference. Therefore, it is possible to reduce the number of tests without causing problems in predicting viscoelastic properties.

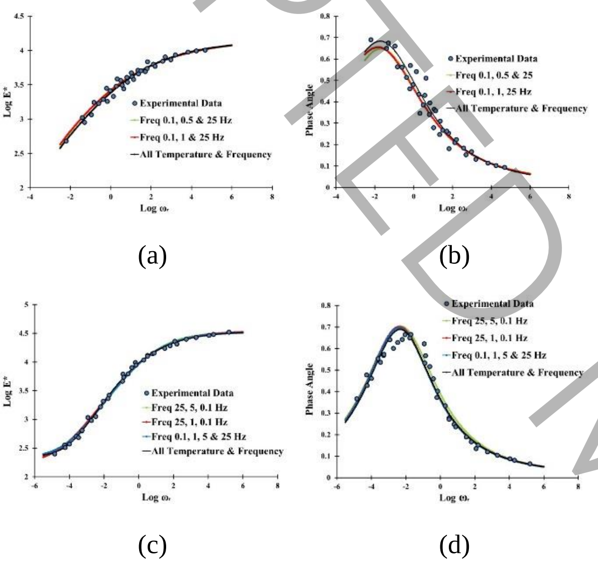


Figure 2: The master curves of dynamic modulus and phase angle for asphalt mortar (Fig. a & b) and for asphalt mixture (Fig. c & d) at the least number of temperatures and frequencies

Table 2: The main parameters of the modified CAM model fitted on master curves of dynamic modulus and phase angle at the least number of temperatures and frequencies

The main parameters of the modified CAM model	Asphalt mortar			Asphalt mixture		
	All Data	T: -10, 21.1, and 37.8°C		All Data	T: -10, 21.1, and 37.8°C	
		f: 0.1, 0.5, and 25Hz	f: 0.1, 1, and 25Hz		f: 0.1, 5, and 25Hz	f: 0.1, 1, and 25Hz
$E^*_{(g)}$ (MPa)	13596	14648	14678	34035	32518	34208
$E^*_{(e)}$ (MPa)	0	0	0	219.9	182.6	172.4
δ_m	0.683	0.648	0.654	0.688	0.703	0.700

Conclusion

This research tried to produce the master curves of viscoelastic properties of asphalt mortar and asphalt mixture using the minimum number of experiments. The results of this study can be summarized as follows:

- Using the experimental results at two frequencies (significantly the highest and lowest frequencies) can effectively generate master curves of viscoelastic properties instead of using all data with 95% precision.

- The modified CAM model can properly fit on the master curves developed using dynamic modulus test results measured at three temperatures (high, low, and of moderate temperatures). The precision of the model is more than 92% compared with the original model.

- The results of optimizing the number of temperatures and frequencies exhibit that it is possible to reduce the number of frequencies and temperatures from six to three. Therefore, it can be considered to perform the dynamic modulus test at three temperatures and frequencies and generate the master curves of viscoelastic properties with more than 92% precision.

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