Laboratory Evaluation on the Static and Dynamic Modulus of Asphalt Concrete with Different High-Modulus Additives

Lili Han¹, Mulian Zheng²*, Chongtao Wang³, Fa Che⁴, Fei Wang⁵, Hongyin Li⁶, Qinglei Ma⁷

¹ Lecturer, Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang’an University, South Erhuan Middle Section, Xi’an, Shaanxi, 710064, China, chdhanlili@yahoo.com
²* Corresponding author. Professor, Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang’an University, South Erhuan Middle Section, Xi’an, Shaanxi, 710064, China, zhengml@chd.edu.cn
³ Professor of Engineering, First Highway Consultants Co., Ltd., 63 Kejier Road, Xi’an, Shaanxi, 710075, China, 81045449@qq.com
⁴ Associate Professor of Engineering, Highway Administration Bureau of Zibo City, 7 East Gongqingtuan Road of Zhandian District, Zibo City, Shandong Province, 255038, China. cf-highway@163.com
⁵ Engineer, Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang’an University, South Erhuan Middle Section, Xi’an, Shaanxi, 710064, China, 1029138266@qq.com
⁶ Associate Professor of Engineering, Highway Administration Bureau of Transportation Department of Shandong Province, 19 Shungeng Road, Jinan City, Shandong Province, 250002, China. 752697805@qq.com
⁷ Professor of Engineering, Shandong College of Highway Technician, 26777 East Jingshi Road, Jinan City, Shandong Province, 250002, China, maqinglei@tom.com

ABSTRACT: The objective of this study is to present a systematic laboratory investigation into the static and dynamic modulus of high-modulus asphalt concrete (HMAC). The static moduli of mixtures with different additives at 15°C, 20°C and 60°C were determined based on the uniaxial compression test and their dynamic moduli were also tested using the Simple Performance Test apparatus. Moreover, the influencing factor analysis (IFA) on both moduli and the correlation between them were analyzed. Results indicate the static modulus of HMAC decreased significantly with the rise of temperature and mixture with PR Module (PRM) showed greater modulus than others. In addition, regardless of temperature and loading frequency, the dynamic modulus of HMAC was much greater than that of virgin asphalt concrete. Finally, a good correlation between static and dynamic modulus of HMAC was found which could be applied into approximate prediction of dynamic modulus in the case that dynamic modulus cannot be easily obtained.

KEYWORDS: High-modulus asphalt concrete; Static modulus; Dynamic modulus

1 INTRODUCTION

Asphalt pavements have been overwhelmingly preferred as the primary selection for many highways around the word due to its advantages of desirable riding performance, short building period et c. However, this kind of pavement presents a typical depression once subjected to heavy traffic and high temperature, i.e. rutting or permanent deformation.

It has been verified extensively that the rutting potential relates primarily to the shear flow of hot mix asphalt (HMA) surface. Fortunately, the high-modulus asphalt concrete (HMAC) that aims to increase the mixture dynamic modulus has received wide attentions worldwide to tackle rutting problems [1,2]. Originated in France, this technology has been successfully used in many nations. While in China, the French
high-modulus additive was introduced 15 years ago and despite numerous investigations, a unified performance evaluation method for HMAC has not been reached due to regional disparities.

On the other hand, modulus is the key parameter in characterizing the anti-deformation performance of HMA. The pavement design code in China has incorporated static modulus into the design procedure. However, asphalt mixture is a viscoelastic material whose mechanical response is not totally elastic but has much to do with loading frequency and temperature\textsuperscript{[3,4]}. Therefore dynamic modulus is more applicable to pavement analysis since its loading condition is comparable to actual pavement situation\textsuperscript{[5,6]}.

In this view, this paper presents a laboratory research on the modulus properties, both statically and dynamically, of asphalt mixtures with various high-modulus modifiers. The static and dynamic moduli of a set of HMACs under uniaxial compression were first tested. Then the influential factor analysis on them was carried out. Particularly, in view of the fact that dynamic modulus test is more expensive and complex, the correlation between two moduli was fitted to predict dynamic modulus in pavement design.

2 MATERIALS AND EXPERIMENTS

2.1 Binder and aggregates

The A-70 penetration grade binder was employed as the asphalt, and three optimized aggregate gradations (HMAC-16, HMAC-20 and HMAC-25) were used to prepare high-modulus asphalt concrete.

2.2 High-modulus additives

Three high-modulus additives were used in the study to fabricate HMAC. Two of them are the commercially used products, known as PR PLASTS(PRS) and PR Module(PRM). The other is the Butonite mastic asphalt labeled as BMA.

2.3 Experiments

The static modulus of various HMACs were tested strictly in conformance to the sample preparation and testing procedure in the code \textsuperscript{[7]}. The dynamic moduli of the HMACs were tested with the simple performance tester by referring to the US and Chinese specifications \textsuperscript{[7-9]}.

3 RESULTS AND DISCUSSION

3.1 Influential factor analysis on static modulus

The 15°C, 20°C and 60°C static moduli of high-modulus asphalt mixtures using different additives are shown in Fig.1 to Fig.3.
Figure 1. Static modulus of HMAC-16 mixture at different temperatures.

Figure 2. Static modulus of HMAC-20 mixture at different temperatures.

Figure 3. Static modulus of HMAC-25 mixture at different temperatures.

3.1.1 Temperature
From figures 1 to 3, it can be seen that temperature has significant impact on the modulus of all mixtures, and the modulus decreased with the temperature increasing. The reason may be asphalt mixture is a typical viscoelastic material that is susceptible to temperature. Once the temperature rises up, the mixture softens and its mechanical strength is reduced consequently, leading to a low mixture modulus. For example, according to the figures, the static modulus of the base HMAC-16 mixture, decreased by 34.1% when the temperature rose from 15°C to 20°C. As the temperature went up further, the modulus decreased by a significant 77.8%, which means asphalt mixture demonstrated apparent viscous property and its deformation resistance was significantly reduced. Similarly, like the control asphalt mixture, moduli of other mixtures also showed same tendency.

3.1.2 High-modulus additive
From the figures, it is seen that different high-modulus additives could lead to different moduli even under same temperature and mixture conditions. Basically, mixtures with high-modulus additives presented greater modulus value compared to the control mixture. For example, the moduli of mixtures with PRM, PRS and BMA are 1.4, 1.5, and 1.9 times respectively that without high-modulus additive. This suggests that high-modulus asphalt concrete is effective in improving the deformation
resistance of asphalt pavements. Moreover, higher temperature could see more evident modulus enhancement.

In addition, different improvements in the static modulus among the three additives were observed. In detail, almost similar modulus improvement could be reached by using both PRM and PRS additive, which were evidently better than using BMA. This means these two French high-modulus agents are more effective than the BMA hard bitumen modifier in enhancing the mixture modulus.

3.1.3 Nominal maximum particle size

With respect to aggregate blend, the modulus differences among four groups of mixtures are also discernible, which is shown in Fig. 4. It is seen except the control mixture without high-modulus additive, the static moduli of HMAC-16 with various additives at 15°C, 20°C and 60°C are 2300~2900MPa, 1600~2000MPa and 490~560MPa respectively. Whereas those for HMAC-20 are 2600~3300MPa, 1700~2300MPa and 520~610MPa respectively. For the HMAC-25 mixture, its moduli at these three temperatures are 2200~2900MPa, 1500~2000MPa and 490~590MPa. It seems that HMAC-20 mixture showed greater static modulus than the HMAC-16 and HMAC-25.

![Figure 4. Impact of aggregate size on the static modulus of different mixtures.](image)

Figure 4. Impact of aggregate size on the static modulus of different mixtures.
3.2 Influential factor analysis on dynamic modulus

The 15°C, 20°C and 60°C dynamic moduli of the control mixture and high-modulus asphalt mixtures with PRM and PRS are shown in Fig.5.

3.2.1 Frequency and modifier

![Graph showing dynamic modulus under different frequencies and modifiers](image)

Figure 5. Impact of frequency on the dynamic modulus of different mixtures.

It can be seen that the dynamic modulus increased with the frequency increasing, which is in agreement with the existing research \(^4\). However, at different frequency levels, the modulus showed different increase rates. The modulus increased more evidently when the frequency was ranging from 0.01 to 2Hz; whereas it increased slowly as the frequency rose from 2 to 25Hz. This phenomenon could be explained as when under high loading frequency, the mixture primarily demonstrated elastic nature and the influence of frequency was lower than that of the material property.

Fig.5 also shows that under dynamic loading the HMAC still demonstrated higher modulus than the control asphalt mixture, indicating that high-modulus modifier was helpful in improving the mechanical properties of asphalt mixtures. Notably, similar to the static modulus, the PRM was still more effective than PRS in enhancing their dynamic modulus.
3.2.2 Temperature

The impact of temperature on the mixture dynamic modulus is shown in Fig.6. It is seen that the modulus decreased as the temperature rose up, indicating that asphalt mixture is susceptible to temperature change.

3.3 Correlation between dynamic and static modulus

Dynamic modulus has been widely used in the pavement distress predicting models since it is capable of reflecting the linear viscoelastic response of asphalt pavement under actual dynamic loading. However, it is commonly tested using large imported testing systems. So this research fitted the relationship between dynamic (10Hz) and static modulus of HMACs as shown in Fig.7. These correlations were expected to be helpful when the dynamic modulus is required.

Fig.8 shows that there is a quadratic regression relationship between the dynamic and static modulus of each asphalt mixture. In addition, high coefficients of determination show that the correlations are good.

Figure 6. Impact of temperature on the dynamic modulus of different mixtures.

The impact of temperature on the mixture dynamic modulus is shown in Fig.6. It is seen that the modulus decreased as the temperature rose up, indicating that asphalt mixture is susceptible to temperature change.
4 CONCLUSIONS

1) Temperature showed significant influence on both mixture moduli, and these moduli decreased as temperature increasing, which is resulted from the viscoelastic nature of asphalt mixture.

2) High-modulus asphalt concretes exhibited greater dynamic and static modulus than the control asphalt mixture. Further among three additives, PRM was more effective than PRS and BMA in enhancing the mixture modulus.

3) Frequency had significant influence on the dynamic modulus which increased fast as frequency rose from 0.01 to 2Hz.

4) A good quadratic relationship was found between the dynamic and static modulus of the high-modulus asphalt mixtures, which could be used to predict dynamic modulus.

5 ACKNOWLEDGEMENTS

The authors appreciate the support of the Fundamental Research Funds for the Central Universities in China (No.310821163502), the 2016 Outstanding Doctoral Dissertation project of Fundamental Research Funds for the Central Universities in
REFERENCES
[1]. Han Geng (2013). "Effects of high modulus asphalt binders on performance of typical asphalt pavement structures." Construction and Building Materials, 44(2013), pp. 207-213.
[2]. Maria Esppersson (2014). "Effect in the high modulus asphalt concrete with the temperature." Construction and Building Materials, 71(2014), pp. 638-643.
[3]. Timothy R. Clyne, Xinjun Li, Mihai O. Marasteanu and Eugene L. Skok (2003). "Dynamic and resilient modulus of MN/DOT asphalt mixtures." Minnesota Department of Transportation Report.
[4]. Wei J., Cui S. and Hu J. (2008). "Research on dynamic modulus of asphalt mixtures." Journal of Building Materials, 11(6), pp. 657-661.
[5]. Ma X., Ni F., Chen R. (2008). "Dynamic modulus test of asphalt mixture and prediction model." China Journal of Highway and Transport, 21(3), pp. 35-39.
[6]. Li R. and Hao P. (2011). "Research on dynamic modulus test and master curve of BRA modified asphalt mixture." Journal of Wuhan University of Technology, 33(10), pp. 42-45.
[7]. Ministry of Transport, China. "Standard test methods of bitumen and bituminous mixtures for highway engineering (JTG E20-2011)."
[8]. NCHRP Project 9-19, Draft Test Protocol A1: Dynamic Modulus of Asphalt Concrete Mixtures and Master Curves.
[9]. NCHRP Report 465, Simple Performance Test for Superpave Mix Design, Transportation Research Board, 2002.