Evaluation of Hybrid-Modified Asphalt Mixtures Performance Using Bending Beam Rheometer

Mohammed A Abed 1,* and Alaa H Abed 2

1 Assist. Lecture, (M.Sc.) in Civil Department Department, Al-Nahrain University, Baghdad, Iraq. 
2 Professor, (PhD) in Civil Department, Al-Nahrain University, Baghdad, Iraq

* Corresponding Author: E-mail: eng.mohammedassi@gmail.com

Abstract This study elucidate a test methodology to execute the creep tests to assess the performance of the hot asphalt mixture (HMA) beams by utilizing the bending beam rheometer (BBR) and explain the most issues related to performing this test. Firstly, a comprehensive samples preparation technique has illustrated and the experimental data were presented to evaluate the reliability of this technique. To perform this test, one aggregate gradation and two types of polymer modifiers with three percent of modification for each type of polymers were used. However, experimental results showed that decreasing the testing temperature by an increment of 10 oC can reduce the deflection by 95.6, and 99.13%. Decreasing the temperature from 25 to 15 and 10 oC can increase the creep stiffness by 12.6 and 36.6 time. Which indicate that temperature was a predominant factor affecting the most responses of the hot asphalt Mixtures. besides polymer modification significant effect on the stiffness which is clear that using 4, 6, and 8 % of SBS can increase the creep stiffness by 9.8, 44.6 and 196 % respectively. Although, the hybrid modification had been increased the creep stiffness for asphalt mixtures by 16.3, 72.5, and 186.7% respectively.

1. Introduction

Adequate fracture resistance is an important feature for asphaltic pavements durability. Hence, the present Superpave specifications examine the cracking properties by adopting the creep and tensile strength of asphalt binder and HMA specimens[1, 2]. Regarding asphaltic mixes, the indirect tension test (IDT) has been used to achieve creep and/or strength properties for cylindrical samples subjected to a compression load laterally to the diameter according to ASTM D6931[3]. IDT testing protocol involves using the expensive loading instruments and extensometers[4], which necessitate luxurious and laborious maintenance and calibration actions. The asphalt samples are usually thick and unable to be utilized to acquire valuable data about the variation of mixes attributes in corresponding to the asphaltic layer thickness. AASHTO T313/ASTM D6648 designates the bending beam rheometer (BBR) to execute investigations for asphalt cement beams of conditioning process at the chosen temperature [5-7]. The test presents the deflection and creep stiffness by implementing the elastic theories to a "simply supported beam". These aspects have been employed to compute internal stresses[8]. Marasteanu et al. had been used the BBR to assess HMA properties in various researches instead of asphalt cement [4, 9]. Previous researches exhibited an excellent correlation between the curves of the compliance formulated by the IDT and those produced BBR. This paper was further sophisticated research by Ho and Romero [10, 11] who revealed that BBR test for small quantities of the materials can reflect behavioral responses that may represent for the whole mixture. Previous research performed [12, 13] to articulate that the BBR presently used to characterize the asphalt cement, possibly used to attain dependable amounts of creep peculiarity for HMA. The BBR testing method has a many of significant characteristics: (i) the apparatus has a rational value and most laboratories and organizations owing this apparatus, (ii) The
BBR has a positive history with positive performance, (iii) the test process has been not complicated and the reproducibility of the test consequences is excellent [14]. This technique is feasibly employed as uncomplicated means to examine the influence of micro-cracking, surface ageing, and compaction on the mechanical features of flexible pavements through analysis of thin asphalt layers recovered from dissimilar depths, that is impossible with an existing IDT technique [15]. Additionally, by means of uncomplicated back-calculation procedural steps [9], it can arrange for an advantageous tool for assessing the effectual binder characteristics in the asphalt mix having recycled asphalt pavement. In the last year, the attentiveness about this test was augmented. This paper supply full information procedure about formulating the thin beams of HMA, loading, analyzing the acquisitioned data. The objectives of this paper were focused on evaluating the effect of aggregate gradation, polymer modification and temperatures on the "creep stiffness" of HMA using bending beam rheometer (BBR).

2. Materials and Methodology

One type of gradation mixes was adopted in this research as revealed in Figure 1 to disclose the effect of aggregate tensile and flexural properties, referred as fine mix which adopted by the State Commission of Road and Bridges (SCRB) [16], one performance grade asphalt PG(64-16) and two types of polymers have been used with various doses to show their effect on locally produced asphalt, the two polymer types have been used in this work: the Styrene Butadiene-styrene (SBS), polyvinyl copolymer (PVC), with three percents for each type of polymer (1, 2 and 3 percents) for PVC as a hybrid modification with 4% SBS while percent of modification for SBS was (4, 6 and 8 percent). In particular, optimum asphalt contents were found to the mixtures (4.8%) and by weight of aggregate.

Gyratory cylinder compacted specimens (SGC) (15cm in diameter17cm ± 2mm in thick) had been employed to manufacture a 1.25 cm-thick slices by the cut from the upper and the bottom end of 1.5cm of the SGC sample had been cutted by a typical masonry rotary saw for HMA sample to achieve a flat face. The specimens were further cut to attain BBR thin beams. Firstly, a thin slice, approximately 1.26 cm thick. This slice is further processed in the following two steps to formulate the "BBR beams". The 12.5 mm-thick slices are further cut from three edges to attain a 6.35 mm-wide disparate slices and the slice got in former is additional cut into about 5 beams rely upon on the thickness of the saw blade as presented in Figure 2.

![Figure 1. Mixes gradation](image-url)
2.1 Testing BBR Mixture Beams Procedure

Particularly, The bending beam rheometer "BBR" is employed to execute the creep tests for bitumens characterization (at low temperature) according to AASHTO designation "T313". Asphalt concrete is one order of scale less creep compliance in comparison with asphalt cement at low temperatures levels, and the challengeable issue is the capability to subject a sufficient loading to attain sensitive reading of deflections for the asphalt concrete beams. At primary tests, which severely imitated the bitumens testing procedure, the induced deflection was not enormous or sufficient and might not be collected with a sensible value at low-temperature but could be attained at a higher level.

The manufacturer designated that the typical BBR equipment able to supply loading as high as 1980mN (200 g) (which adopted through the tests) unaccompanied by changing the air-bearing scheme. The memorable point is the load cell capability is 4413mN (450 g); however, no calibration needed for compliance above the 1980 mN (200 g) which is the air-bearing scheme amplitude, therefore, the software did not senses loading magnitudes after this limit as illustrated in Figure 3 and Figure 4.

The asphalt cement requirement a duration creep tests of 240 s. in this specification. The binder characterization depends on the creep stiffness and m-values measured at the time of loading of 60 s. The stiffnesses of the binder are determined from the measured deflections at the time of loading of 60 s; however, the m-value is gained by adapting a second-order polynomial for the complete 240 s. log time log vs. stiffness curve and is an indication for the whole experimental data, although only the 60 s value is reported. During the mixtures testing, it had been realized to execute creep tests by BBR at the same testing conditions (i.e. test duration and specimen conditioning) as shown in Figure 5. Posteriorly, mixtures characteristics fluctuate expressively with relation to the testing temperature, the proposed load magnitude in this study were recognized distinctly for each temperature.

However, the creep stiffness is time-dependent which calculated by the theory of Euler- Bernoulli beam and the accordance principles. For each specimen and level of temperature, the creep stiffness was calculated by[17]:

\[ S(t) = \frac{L^3}{48 \delta(t)I} \left[ P + \frac{5wL}{8} \right] \]  

Where,
S = creep stiffness (MPa),
L = beam span length,
P = constant subjected load (mN),
w = weight of the beam (distributed uniform load),
\( \delta(t) \) = deflection of the beam, and
I = moment of inertia.
3. Results and Discussion

3.1 The sensitivity of Asphalt Mixtures to Fixed Load

The results in Figure 6 showed that the induced deflection tendency of mixtures under a constant load that coarse mixtures higher values of fine mixtures. At a specific time of loading (i.e. 60 sec.) The emergence of this tendency is the result of the mobilization in the aggregate in response to the slow external load to prevent induced distortion, also existing of fine particles can increase the cohesion effect of the mixture which decreasing the deflection.
3.1.1 Effect of Temperature on the Response of HMA

BBR test can easily use to detect the influence of temperature on the responses for hot mix asphalt such as deflection, stiffness and so on. Figure 7 and can easily reflect the influence of temperature on the deflection of non-modified fine and coarse asphalt mixtures respectively. Which is cleared that decreasing the testing temperature by an increment of 10 °C can reduce the deflection by 38.5, 95.6, and 99.13% respectively. Rationale commentary for experimental results above is that when the temperature approaches decrease, the asphalt binder exhibit similar physical properties especially when temperature close to zero degree and enter the glassy transition area were its stiffness somewhat close at low temperatures as normal behavior of rheological materials as a strong response to the effects of temperature variation.

3.2 Estimating of the Stiffness of HMA using BBR

The essential output of the BBR test is the stiffness and deflection of the asphalt binder, so it became easy to resort to the BBR to assess the behavior of asphalt mixtures because of ease and rapidity of the
test and availability of the device in many laboratories and agencies that are concerned with methods and tests for paving materials. This part of the study had been observed the effect of many variables on the stiffness of hot asphalt mixtures and the extent of the impact on those variables on the hot mix asphalt response such as the temperature of the test, modifier types, and percent of modifier to present a comprehensive indication about the behavior of asphalt mixtures.

3.2.1 Effect of Temperature Variation on the Creep Stiffness for Asphalt Concrete
In this methodology, the deferent range of temperature levels data had been used to assess the creep stiffness using the BBR. Figure 8 demonstrates the influence of temperature variation on the creep stiffness for asphaltic mixes. However, at a specified time of loading such as 60 second, decreasing the temperature from 25 to 15 and 10 °C can increase the creep stiffness by 12.6 and 36.6 time. Which indicate that temperature is the predominant cause affecting the most responses of the hot asphalt Mixtures as an improvement to the validity of BBR to perform asphalt mixtures characterization testing protocols, the discrepancy between the mechanical attributes for the constituents of hot asphalt mixes reduces significantly as asphalt cement began to perform as a fragile linear viscoelastic. As the materials, at a selected time, show a comparable behavior, the overall performance of the HMA converts to independent on the considerations of aggregate particles such as the distribution and size. Probably, the mechanical performance of HMA at upraised-service temperatures (+0 degree centigrade temperatures) is expressively affected by the aggregate dimensions or constituents distribution.

![Figure 8. Creep Stiffness vs. Time of Loading at Low, Intermediate and High-Temperature Levels](image)

3.2.2 Polymer Modification of Asphalt Concrete and Repeatability in Bending Beam Rheometer
Several types of research have been committed to improving the mechanical behavior, durability of asphalt cement or even the asphalt mixtures through variation in chemical or physical properties, all of which might compromise a vision in extenuate the harmful effects of deicers. One method was to modify asphalt mixtures using the modifiers to develop the ductility, viscosity, and durability. Polymer modifiers such as styrene-butadiene-styrene (SBS), styrene-butadiene rubber (SBR), and polyvinyl chloride and polyethylene had been one of the best widespread materials to increase the flexibility and elasticity of asphaltic concrete. This paper focus to examine the influence of SBS and hybrid modification on the stiffness of hot asphalt mixtures. Figure 9 illustrates the relation between the creep stiffness versus loading time for SBS-modified fine asphalt mixtures at a high-temperature level of 25 °C. However, it obvious that there was a significant effect for modification on the creep stiffness.
From Figure 9, it is clear that using 4, 6, and 8% of SBS can increase the creep stiffness by 9.8, 44.6 and 196% respectively for fine mixtures. While, the hybrid modification were increased the creep stiffness for asphalt mixtures by 16.3, 72.5, and 186.7% respectively. The rational explanation is Polymers promote the bitumen by developing the cohesive strength, creating binders tougher and more resilient. Therefore, polymers increase the ability of asphalt mixtures to creep resistance, stimulating the effect of a stable load.

4. Conclusions:
Two types of Polymer types had been used in this study Elastomer polymer “Styrene Butadiene Styrene (SBS)” and Hybrid-Modification (SBS+PVC) at different percentages the following conclusions can be gotten:
- BBR is very accurate apparatus to sense the responses to the asphalt specimens to the fixed loads. Which facilitated to find significances influence of temperature on the stiffness and tensile strain for HMA particularly wide range of temperature.
- The influence of temperature on the deflection of non-modified asphalt mixtures respectively. Which is cleared that decreasing the testing temperature by an increment of 10°C can reduce the deflection by, 95.6, and 99.13%.
- Polymer modification has a significant effect on both deflection tendency and stiffness for hot asphalt mixtures. Where the results showed that using SBS with 4, 6, and 8% can increase the creep stiffness by 9.8, 44.6 and 196% respectively.
- The hybrid modification had been increased the creep stiffness for asphalt mixtures by 16.3, 72.5, and 186.7% when using 4% SBS with 1, 2, and 3% PVC respectively.

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