A Review on low temperature stiffness of bitumen binder and its correlation with stability

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Abstract: In order to prevent some problems associated with binder-related pavement failures, it is very important to be able to characterize the performance of bituminous binder. Low temperature cracking is one of the most common distress types in asphalt concrete pavements, particularly in cold regions. Many factors influence the behaviour of asphalt concrete pavements at low temperatures, such as the applied traffic load, environmental conditions and material characteristics. In this perspective now test methods and specifications have been developed to more accurately predict field behaviour of all binders, regardless of how they are manufactured.

Hence, in order to predict the low temperature at which the binder reaches some limiting stiffness and becomes sensitive to thermally induced cracking, the SHRP has developed the (bending beam rheometer) BBR. In this study, bending beam rheometer was used to explore low temperature properties evolution during aging for viscosity grade bitumen binders and various PMB and CRMB-55. BBR tests were performed, using the specimens at temperatures of -6°C, -12°C and -18°C.The ageing effect through BBR parameters (creep stiffness and m-value) was evaluated.

Keywords: Bending Beam Rheometer, Low temperature cracking, Creep stiffness, m-value, Modified binders, CRMB-55.

I. INTRODUCTION

Bituminous binders have been used in the construction of asphalt pavement for more than a century, but new tools to address relevant performance properties are still under investigation. As a visco-elastic material, bitumen binders behave as viscous fluid at high temperature and brittle solid at low temperatures. This brittleness at low temperatures induces thermal cracking of asphalt pavements and can be a serious problem in cold areas.

However, thermal cracking is one of the forms of binder-related distress that was considered during the SHRP in USA. SHRP developed the BBR for the direct measurement of low temperature stiffness as opposed to estimating stiffness from empirical measurements. The BBR test also known as the standard test for binder at low temperatures, is a simple and cost effective method used to determine the creep behaviour of asphalt mixtures.(From literature, this technique seems to be the most appropriate test to predict low temperature behaviour, for unmodified as well as modified binders.)

II. RESEARCH AND STUDIES ON LOW TEMPERATURE STIFFNESS OF BITUMEN BINDER

Relevant research work and studies are reviewed here:

[1] Kandhal PS, Dongre R, Malone MS., (1996) studied that six different AC-20 asphalt cements were used in a Pennsylvania project in September 1976. Cracks were developed in two pavements out of the six in January 1977 due to low temperature cracking. The remaining four test pavements started to develop cracks to different degrees after three years. The samples of these six asphalt cements which were saved from 1976 to 1995 (19 years) have now been tested using Superpave binder test procedures such as bending beam rheometer (BBR). This research project was undertaken to verify whether these Superpave test procedures and specifications could have predicted the low temperature cracking of the six AC-20 asphalt cements in the Pennsylvania project. The maximum stiffness criteria of 300 MPa and the minimum m-value criteria of 0.30 recommended in Superpave binder specifications generally appear to be reasonable in mitigating low temperature cracking. However, the behavior of one asphalt cement (T-3) could not be explained by these criteria. Although Asphalt T-3 had stiffness exceeding 300 MPa at the minimum design temperature it did not crack at all during its 7 years service life. There are some indications from ductility data that Asphalt T-3 may have a high failure strain. However, this needs to be confirmed by direct measurements at low pavement temperatures using the Superpave direct tension tester (DTT).

[2] Rowe GM, Sharrock MJ, Bouldin MG, Dongre RN., (2001) studied that from BBR data the relaxation modulus master curve of the binder is calculated. Once the BBR creep compliance data was fitted to a master curve, the data was converted to a relaxation modulus master curve using Hopkins and Hamming procedure. Data from the lansmont test road in Canada is analyzed using various methods and recommendations were made for master curve analysis of binders with the test data from bending beam rheometer.

[3] Lu X, Isacsson U, Ekblad J., (2003) studied the effects of polymer modification on low-temperature properties of bituminous binders and mixtures. Three bitumen were blended with 6% SBS, SEBS, EVA or EBA. Dense graded asphalt mixtures were prepared using a gyratory compactor. The low-temperature properties of the binders were characterized using dynamic shear rheometer and bending beam rheometer, and the low-temperature cracking of the mixtures evaluated by tensile stress restrained specimen test. The mixture cracking temperature was found to correlate with the limiting temperatures (in bending beam rheometer) of the binders, weakly with Fraass breaking point, but not with parameters obtained using dynamic shear rheometer. Upon isothermal storage at low temperatures, the bitumens displayed physical hardening, and effect of polymer modification was small.

[4] Soenen H, Vanelstraete A., (2003) carried out the study on results from binder test methods, believed to be relevant regarding low temperature cracking have been evaluated, making use of literature and common data of binders belonging to different penetration classes. The data included bending beam rheometer results (BBR), Fraass breaking temperatures and some direct tensile test data. When possible, they were compared with Thermal Stress Restrained Specimen Tests (TSRST) on the corresponding asphalt mixes. Unmodified and modified binders were considered. Out of these tests, BBR seems, at this moment to be the best binder test to predict low temperature behavior; it is suitable for unmodified binders and still acceptably good for polymer modified binders. The database made it possible:

- To compare the BBR-temperatures corresponding to the S(60s) = 300 MPa and the m(60s) = 0.3-criteria, for a large number of binders.
- To obtain ranges for the highest limiting BBR-temperatures and mix fracture temperatures for different grades of bitumen.

It follows from this database that the addition of polymer generally has only a limited effect on the highest limiting BBR temperature compared to the original base binder. However, if binders of the same penetration class are compared, polymer modified binders generally perform better at low temperatures. Ageing as well as blowing of bitumen binders generally leads to a higher effect on the limiting temperature deduced from the m-value than on the temperature deduced from the S-value.

[5] Olard F, Di Benedetto H, Dony A, Vaniscote JC., (2005) carried out the study on a research work, including a large experimental campaign on the thermo mechanical behavior of bituminous materials at low temperatures was proposed. The aim was to establish the links between the characteristics of the binder and the properties of bituminous mixes at low temperatures. Four different bitumens have been used with one type of aggregate and grading. The low temperature behavior of binders was evaluated with three fundamental tests: the complex modulus determination, the Bending Beam Rheometer and the tensile strength at a constant strain rate and constant temperatures.

[6] Velasqueza R, Zofkab A, Turos M, Marasteanua MO., (2011) carried out the study on test protocol for performing creep tests on asphalt mixture beam specimens using the bending beam rheometer, and addresses the issues related to performing this test. First, a detailed sample preparation procedure was presented and the experimental data were provided to assess the consistency of this method. Then, three loading methods were investigated, and the results were analysed and compared using statistical tools. Finally, a preliminary investigation on the representative volume element of asphalt mixtures at low temperatures was performed by testing beams of different sizes.

[7] Yero SA, and Mohd. Rosli Hainin., **(**2012) This study reviewed the bitumen modification process in relation to warm mix asphalt (WMA) technology, using S as a modifier. The study investigated the viscosity measurements of modified bitumen, using the Brookfield viscometer. The binders mixed with various percentage of the wax S 1%, 2%, 3%, 4%and 5% were investigated. The results from the study showed the viscosity of the binder decreasing at higher temperatures while at midrange temperatures the viscosity increases with an increase in the additive. This study has provided valuable data on the effect of the additive S on increasing the dynamic viscosity of the binder at low temperature and decreasing the kinematic viscosity at high temperature, been attributed to the presence of the S wax with high hydrocarbons molecular content in the binder, which is expected to improve the viscosity properties of the modified binder and enhance its resistance to deformation when used in warm asphalt concrete mixtures.

[8] Santagata E, Baglieri O, Dalmazzo D, Tsantilis L., (2016) concluded that the main goal of this paper was to investigate the influence of physical hardening on low temperature properties of bituminous binders tested in different ageing conditions. Moreover, reversibility of hardening phenomena was directly assessed by means of a dedicated testing protocol. The study, carried out by making use of the Bending Beam Rheometer (BBR), considered four binders of different type and origin (two neat bitumens and two commercial SBS polymer-modified binders) and three ageing conditions (original, short-term ageing and long-term ageing). Obtained results, expressed in terms of a Physical Hardening Rate (PHR), showed a significant effect of chemical ageing on low temperature hardening of binders. In particular, the rate of hardening was found to vary with temperature and to decrease with the degree of ageing. Reversibility of the hardening process was also verified.

[9] Lu X, Uhlback P, Soenen H., (2017)] investigated the low temperature rheological properties of bitumen using a dynamic shear rheometer with 4 mm parallel plates (4-mm DSR). Different procedures of sample preparation were tested and evaluated. For comparison, low temperature measurements were also carried out using a bending beam rheometer (BBR). Test results show that the 4-mm DSR can perform rheological measurements at very low temperatures (below -30°C). With this geometry, very little amount of bitumen sample is required. There are certain statistical correlations between complex modulus measured by 4-mm DSR and creep stiffness by BBR, and also between phase angle and m-value. With the BBR data at 60s loading time, higher correlation coefficients were observed at lower DSR frequencies or at a frequency corresponding to the 60s loading time.

[10] Abdelaziz A, Ho CH, Snyder M., (2018) studied that Low temperature cracking is one of the most common distress types in asphalt concrete pavements, particularly in cold regions. Many factors influence the behavior of asphalt concrete pavements at low temperatures, such as the applied traffic load, environmental conditions and material characteristics. Asphalt binders are one of the primary factors that influence material properties. The purpose of this study was to compare the performance of two types of asphalt binders: styrene-butadiene-styrene (SBS) modified asphalt binder and unmodified asphalt binder in resisting low temperature cracking. The study was conducted in Flagstaff, located at the area of Northern Arizona, in the United States. Asphalt samples were collected from the paving sections and were compacted and trimmed into small beams. Bending Beam Rheometer tests were performed, using the trimmed specimens at temperatures of -6°C, -12°C and -18°C. Based on the results of the study, it was concluded that, SBS modified asphalt binder performs better in resisting low temperature cracking, compared to the unmodified binder. Based on the study outcomes, it is recommended to use SBS polymer modified polymers in areas subjected to severe cold weather events to maximize the life span of asphalt concrete pavements.

[11] Pszczola M, Jaczewski M, Rys D, Jaskula P, Szydlowski C.,(2018) investigated that low-temperature cracking is one of the most common road pavement distress types in Poland. While bitumen performance can be evaluated in detail using bending beam rheometer (BBR) or dynamic shear rheometer (DSR) tests, none of the normalized test methods gives a comprehensive representation of low-temperature performance of the asphalt mixtures. This article presents the Bending Beam Creep test performed at temperatures from −20°C to +10°C in order to evaluate the low-temperature performance of asphalt mixtures. The performed test indicated that the source of bitumen and its production process (and not necessarily only bitumen penetration) had a significant impact on the low-temperature performance of the asphalt mixtures, comparable to the impact of binder modification (neat, polymer-modified, highly modified) and the aggregate skeleton used in the mixture (Stone Mastic Asphalt (SMA) vs. Asphalt Concrete (AC)). Obtained Bending Beam Creep test results were compared with the BBR bitumen test. Regression analysis confirmed that performing solely bitumen tests is insufficient for comprehensive low-temperature performance analysis.

III. CONCLUSIONS

After going through the variant studies carried out by different researchers, it may be concluded that:

1. The BBR can be used with minimal software modifications to measure the creep stiffness of asphalt mixtures at low temperatures.
2. Low voids in the asphalt mixture and surface sealing and overlay can prevent aging of binder.
3. The physical properties of bitumen such as penetration, softening point and viscosity are improved with addition of cement.
4. BBR seems to be the best binder test to predict low temperature behavior; it is suitable for unmodified binders and still acceptable for modified binders, PMB,CRMB,NRMB.
5. The aging process caused a slight decrease in dynamic viscosity.
6. The reversible aging process of binders stored at low temperatures is a probable cause for premature low-temperature cracking in pavements in northern climates.
7. More studies need to be done with various binders in Indian context.

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