UTILIZATION OF SHRP BINDER DEVICES TO IMPROVE PAVEMENT PERFORMANCE FOR EASTERN ASIAN COUNTRIES

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abstract: Traditional testing procedures for asphalt binders are deficient because they are empirical, and cannot be adequately used at various temperature ranges and loading times. In 1988, the Strategic Highway Research Project (SHRP), a comprehensive five-year study, was conducted to address these problems. SHRP program addresses a number of different distress mechanisms including rutting, load-associated fatigue, thermal cracking, moisture damage and premature aging of the binder. In the consideration of climate and traffic situations around the eastern Asia, this paper presents the theoretical interpretation and modification of SHRP binder devices to improve pavement performance.

1. INTRODUCTION

The asphalt binder testing methods used in the eastern Asia are all developed in the early 1900's. These testing procedures include penetration at 25°C, capillary viscosity at 60°C and 135°C, ductility at 25°C and softening point. Based upon these methods, three sets of asphalt cement grading systems, i.e., penetration, viscosity, and the aged residue (AR), have been adopted.(Roberts et al. 1991) Current specifications are not, however, performance-related. The measurements obtained from previous tests (1) are empirical in nature, (2) can be deceptive to pavement performance at higher or lower service temperatures, and (3) do not include fundamental engineering properties that can be related to fundamental mixture properties or to pavement performance. For example, the primary distress modes such as rutting and cracking are not considered in the conventional testing methods. Because of these reasons, current asphalt binder testing devices are not adequate.

From 1988 to 1992, the Strategic Highway Research Project (SHRP) was conducted to address these problems. The US-led SHRP program is a comprehensive study on highway facilities and costs US$150 million. One of the major products of SHRP is a set of performance-related test methods and specifications for hot-mix asphalt concrete. These test methods and specifications are referred to collectively as SUPERPAVE™ which an integrated system for characterizing and specifying materials (binders and mixtures), for designing asphalt concrete mixtures, for predicting maximum and minimum pavement temperatures, for modeling pavement response to traffic load and the environment, and for predicting pavement performance.(Anderson et al. 1993) The SUPERPAVE™ Program addresses a number of different distress mechanisms:

- Rutting
- Load-associated fatigue
- Thermal cracking caused by low pavement temperatures

- Moisture damage
- Premature aging of the binder

This paper presents the test methods and specifications for asphalt cements with the application to the eastern Asia. The research results can be beneficial to the eastern Asian countries if they are properly implemented.

2. SHRP BINDER TEST DEVICES

It is known that the stiffness of asphalt binders can vary widely with temperatures and loading times, and is also source-dependent. Consequently, it is important that specification properties be selected at the temperature and loading rate specific to the environment and the distress mechanisms related to eastern Asian countries. At intermediate to low service temperatures the resistance to deformation may result from the elastic or recoverable portion of the viscoelastic properties of binders. The ratio of elastic to viscous portion of a viscoelastic material can be characterized by the phase angle (δ), and is important on the understanding of rutting, fatigue, and cracking, and must be considered in a performance-related material specification.(Anderson et al. 1991) Four test devices have been adopted for specification testing in the new SHRP binder specification as shown in Figure 1.

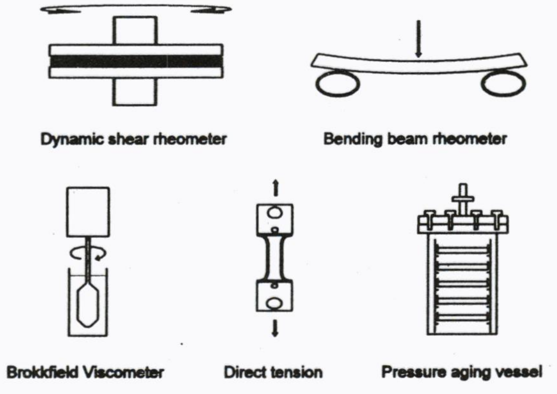

Figure 1. Overview of SHRP Binder Test Equipments

2.1 Brookfield Viscometer

The Brookfield viscometer was chosen for the replacement of the traditional capillary tube viscosity testing equipment at mixing or compaction temperatures at which binders exhibit Newtonian in their flow behavior. This device allows a controlled shear rate that is more representative during pumping, mixing, and compaction. Not only can tests be performed at various temperatures for the same sample, but also the device is easier to clean and requires less solvent than capillary tube viscometer. The concept of few cleaning materials used is an important environmental consideration. The testing procedure is described in ASTM Test

Method D4402.

2.2 Bending Beam Rheometer (BBR)

The bending beam rheometer (BBR) as shown in Figure 2 was especially designed for low-temperature measurements where asphalt binders become stiff.(FHWA 1993) For example, the stiffness range for most binders is typically encountered at temperature below 0°C, and the BBR resolution allows stiffness as large as 3 GPa. For higher temperatures, the dynamic shear rheometer (DSR) can be used to determine the engineering properties. It should be noted that stiffnesses and shear moduli can be transformed to each other to construct a master curve.(Ferry 1980) Furthermore, the BBR device measures creep deformation in an extension-compression loading mode which is representative of low-temperature thermal cracking.

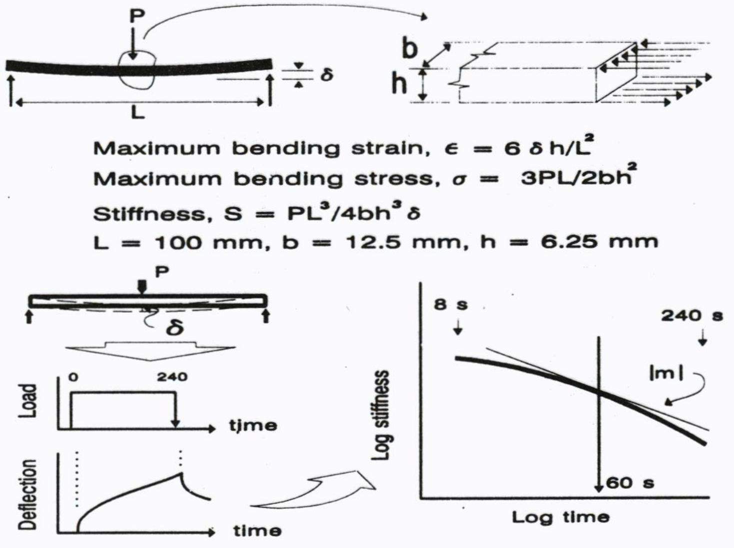

Figure 2. Bending Beam Rheometer

Test specimens are cast in silicone rubber or plastic-lined aluminum molds. To conduct a test, the test beam is submerged in a fluid bath controlled at the test temperature. A 100 gram load is applied to the beam for 240 seconds during which the load on the beam and the midpoint deflection are measured. The stiffness modulus, S(t), of the binder is calculated form the geometry of the beam, the applied load, and the deflection of the beam as shown Figure 2. The absolute value of the slope, referred to as the m-value, is calculated by fitting a curve to the data obtained in the interval from 8 to 240 seconds. The stiffness and the m-value at 60 seconds loading time are reported as specification criteria.(FHWA 1993) The m-value represents the time dependency of the binder and can be related to the tangent of the phase angle determined from DSR. The BBR is an adequate device to predict thermal cracking in countries such as Japan and Korea.

2.3 Dynamic Shear Rheometer (DSR)

Researchers have used dynamic shear rheometers for a numbers of years to characterize the viscoelastic properties of plain and modified binders.(Goodrich 1991) In the SHRP specification test method, the parallel plate geometry with two sample size is used.(Anderson et al. 1993) The 25-mm-diameter plates with a 1-mm gap are used for testing at the maximum pavement design temperature where the complex modulus is in the range of 1.0 to 2.2 KPa, and the 8-mm-diameter plates with a 2-mm gap are used for testing at the intermediate pavement design temperature where the complex modulus is approximately 5.0 MPa. The testing is conducted at 1.6 Hz and the strain level is specified according to the value of the complex modulus of the binder to ensure linear response.

By measuring the torque (stress) required to oscillate the plates and by measuring the resulting angular deflection of the plates (strain), the complex shear modulus can be obtained as illustrated in Figure 3. The DSR provides rheological measurements at intermediate to high pavement service temperatures where the dynamic shear modulus is typically greater than 1 KPa but less than 10 MPa. Data available from each test include the complex modulus, G*, and the phase angle, δ. At the maximum pavement design temperature (T_{max}) the parameter, G*/sinδ, is used as a specification criterion; and at the intermediate temperature (T_{int}), the parameter, G*sinδ, is used as the specification criterion.(Anderson et al. 1993) Thus, the DSR provides measurement at the critical pavement design temperatures and at a shear rate commensurate with those encountered in the pavement. The DSR can be an appropriate equipment to measure the rutting tendency for countries such Thailand and Indonesia.

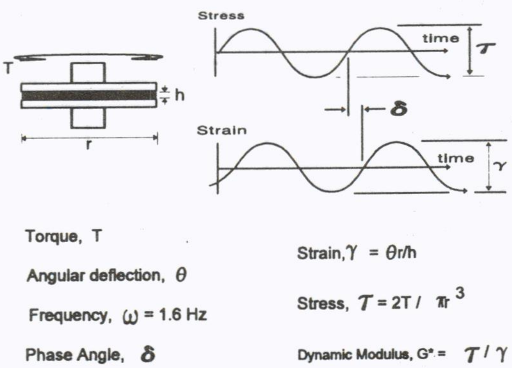

Figure 3. Dynamic Shear Rheometer

2.4 Direct Tension Test (DT)

In a true performance-related specification based on fundamental material properties, fatigue and fracture properties of the binder should be specified. Early in the research program it was recognized that fundamental fracture parameters are inappropriate for specification purposes, because the sample preparation and testing procedures used for other brittle materials, e.g. steels, are not applicable to asphalt binders. Therefore, the direct tension test was developed as a surrogate for the more sophisticated fracture mechanics parameters.(Anderson et al. 1993)

The direct tension test, shown schematically in Figure 4, was used to measure the failure properties of asphalt binders at low temperatures. The test is valid in the temperature regions where the strain-to-failure ranges from less than 1% to approximate 10%. In this region, between 1% and 10%, binders typically undergo a rapid transition from brittle to ductile failure. The obtained stress relaxation moduli from the direct tension test can be converted to shear moduli or stiffnesses. Therefore, the results of BBR, DSR and DT are comparable.(Chen 1994)

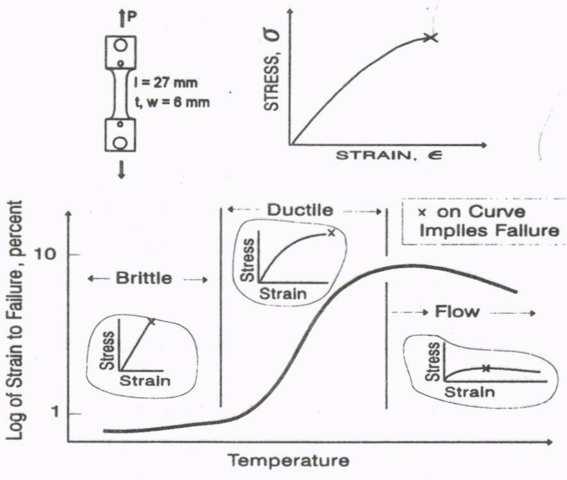

Figure 4. Direct Tension Test

The test specimens are formed by casting the specimen in silicone rubber molds using plastic end inserts. The end inserts and the specially designed grip allow the specimen to be pulled in an axial, moment-free manner. In the specification test, the test specimen is pulled at 1 millimeter per minute until the test specimen ruptures or the strain exceeds 10%. At very small strain, approximating 1%, the non-contact laser measurement is needed in order to obtain accurate strain data. In the specification version of the test method, only the strain at failure is recorded.(FHWA 1993) The DT can be used to understand the fatigue cracking for eastern Asian countries.

2.5 Aging and Moisture Damage

Moisture damage is primarily aggregate-related and is addressed as part of mixture design and devaluation and not as part of binder specification. Aging that occurs during the mixing, laydown, and compaction process is currently considered with the Thin Film Oven Test (TFOT) as in ASTM D 1754, or the Rolling Thin Film Oven Test (RTFOT) as in ASTM D 2872. Properties of the residue form either of these tests are considered to closely approximate the properties of the binder during the first year of service. There is, however, no commonly accepted specification test method that can be used to simulate the properties of the binder after an extended period of service. The new SHRP binder specification include a pressure aging vessel (PAV), which is intended to simulate 5 to 10 years of in-pavement service. In this test, 50 grams of binder are placed in a flat 140-mm-diameter (TFOT) plan. The binder is pressured at 2.1 MPa for 6 hours at 90, 100, or 110°C, depending on the grade of the binder.(Anderson et al. 1993; FHWA 1993)

3. SHRP BINDER SPECIFICATION

In the SHRP binder specification, the Cleveland open cup flash point temperature is retained for safety purposes. The RTFOT loss on heating is kept to control the use of fluxes and other volatile materials that can degrade the quality of a bitumen as well as cause environmental concerns.

A number of rheological measurements are required for the SUPERPAVE™ binder specification. These are selected to address specific distress mechanisms and are performed at temperatures at which the mechanisms predominate. Distress mechanisms specifically addressed and the relevant temperatures are as follows:

- Rutting – tank and RTFOT material, minimum value of $G^*/\sin\delta$ at the maximum pavement temperature.
- Thermal cracking – PAV residue, maximum value of stiffness and a minimum m-value at the minimum pavement design temperature plus 10°C.
- Fatigue– PAV residue, maximum value of $G^*\sin\delta$ at the intermediate pavement temperature.

4. SPECIFICATION CRITERIA

4.1 Temperatures Used for Grading

The SHRP binder specification is based on fundamental measurements obtained at pavement temperatures representative of the maximum (T_{max}) and minimum (T_{min}) pavement temperatures. These temperatures determine the grade of the binder needed for a specific geographical location. The maximum and minimum pavement temperature for a given geographical location can be generated using algorithms contained within SUPERPAVE™. Alternatively, the pavement design temperatures may be chosen at the discretion of the specifying engineer. Certain reliability factors are included in the selection of the maximum and minimum pavement design temperatures and the reader is referred to the SUPERPAVE™ design procedure and software for further details and for guidance in selecting design temperatures.

The low-temperature tests are conducted at the minimum pavement temperature plus 10°C (18°F).(Anderson et al. 1993) The stiffness at T_{min} after 2 hours loading time is approximately equal to the stiffness after 60 seconds loading time at T_{min} + 10°C. This allows the specification criteria to be determined after 60 seconds loading time at T_{min} + 10°C. Because this common temperature dependency also apparently extends to the fracture properties, the direct tension test is also performed at T_{min} + 10°C at an elongation rate of 1.0 mm/minute. Selecting a grading test temperature 10°C above the minimum pavement design temperature shortens the test time considerably.

4.2 Consideration of Rutting

Rutting in the upper pavement layers is caused by the accumulated plastic deformation in the mixture that results from the repeated application of traffic loading. Although the rutting tendencies of a pavement are primarily influenced by aggregate and mixture properties, the properties of the binder also contribute to the rutting resistance of mixtures. Rutting is more prevalent at the upper range of service temperatures than at intermediate or low temperatures, implying that the critical properties should be specified at the maximum pavement temperature, or at least weighted according to the maximum temperatures experienced by the pavement. Because the elastic or non-recoverable portion of the response of the binder to loading is of significance to rutting resistance, some consideration of the phase angle is also considered necessary in the specification criterion.

On the basis of these observations, a measurement of the nonrecoverable deformation of the RTFOT residue, $G^*/\sin\delta$, was chosen as the specification parameter.(Anderson et al. 1991) A requirement that $G^*/\sin\delta$ for the tank (as-supplied) binder be greater than 1.0 KPa was added to the specification to provide protection in those cases where the RTFOT test may not be representative of the hardening that occurs during mixing and laydown. Certain binders may harden less during mixing and laydown than predicted by the RTFOT test. This situation can be aggravated by operation at low mixing temperatures, inadequate drying of the aggregate, and a number of other factors.

4.3 Thermal Cracking

Thermal shrinkage cracking is a serious problem in much of the Japan and Korea where local pavement temperatures may range from +30 to -30°C. Thermal shrinkage cracking can result from a single thermal cycle where the temperature reaches a critical low temperature and therefore a maximum limit is specified for the stiffness, S(t).(Readshaw 1972) Although different researchers have chosen different combinations of stiffness and loading time to specify the limiting stiffness temperature, 300 MPa obtained after a loading time of 2 hours was chosen as the limiting value.(Anderson et al. 1993)

The time dependency of the creep stiffness also influences the magnitude of the thermal shrinkage stresses that develop during thermal cycling. Thus, the absolute value of the slope of the creep stiffness was also included in the binder specification. The slope of the creep curve was also related by other SHRP researchers to both fatigue and thermal cracking and has been related by others to the cracking resistance of plastics and other polymeric materials.(Roque et al. 1993; Tayebali et al. 1992)

Early investigators observed that, for plain bitumens over a rather wide range of temperatures (stiffness), the strain to failure measured in a direct tension test is related in a general way to the stiffness of the bitumen. However, for data generated with polymer-modified materials it was observed that the addition of polymers can have a very significant effect on the low-temperature strain and energy to failure, often without affecting the rheological properties. Thus, it was rationalized that strain tolerance as well as stiffness should be considered with respect to low-temperature thermal shrinkage cracking. Including the strain at failure as a specification criteria ensures that the pavement will not transcend into the brittle region within its service temperature regime. This transition occurs at approximately 1.0 percent strain when the strain rate is 4 percent per minute.

In the final version of the SUPERPAVE™ binder specification, the direct tension test was retained as an optional test, to be applied at the request of a supplier in the event that a binder exhibits strain tolerance at the grading test temperature (T_{min} + 10°C), but does not meet the stiffness requirement at the grading test temperature. Thus, in the final version of the specification as developed by SHRP, the maximum stiffness at the grading test temperature may be between 300 and 600 MPa as long as the strain to failure at the grading temperature is greater than 1 percent. No waiver is permitted for the m value.

4.4 Fatigue Cracking

The onset of fatigue cracking in mixtures has been shown by a number of researchers to be related to the cumulative energy dissipated prior to the onset of cracking.(Schapery 1973) The parameter $G^*\sin\delta$ is related to the energy dissipated during sinusiodal loading; therefore, $G^*\sin\delta$ was selected as a specification criterion for fatigue. In the final version of the specification as developed by SHRP the loss modulus, $G^*\sin\delta$, at 1.6 Hz must be less than 5.0 MPa at the intermediate pavement design temperature. Limiting the m value is also of potential importance in resistance to fatigue cracking. The slope of the log of creep compliance versus log time mastercurve was shown by other SHRP researchers to be related to the propagation of fatigue cracking based on work done previously on polymeric materials.(Anderson et al. 1993)

4.5 Physical Hardening

Interim versions of the binder specification included criteria to control physical hardening. Physical hardening is a time-dependent increase in the stiffness of bitumen that occurs at low temperatures and is associated with a time-dependent shrinkage of the binder.(Anderson et al. 1993) Because the significance of physical hardening on pavement performance is not known, no specification criteria could be established for this phenomenon. Instead, the specification allows the stiffness and m-value to be reported after 1 and 24 hours of isothermal storage at the grading test temperature. Further research will be required to establish criteria for physical hardening. Physical hardening is, however, strongly related to wax content, and this alone may warrant its inclusion in the specification in the future.

5. SUMMARY

A new set of performance-based specification criteria for plain and modified bitumens has been developed as part of the SHRP asphalt research program. These parameters were proposed collectively as being related to the rutting, fatigue, and thermal cracking behavior of plain and modified bitumens to the extent that they affect the performance of dense-graded hot-mix asphalt concrete mixtures. The test methods, criteria, and specifications were designed to be applicable to both plain and modified binders. The eastern Asian countries should take advantage of these research results to improve pavement performance. Extreme care should, however, be taken before one implements the SHRP binder specification. Complete validation of the SHRP binder test methods and specification criteria will require well-controlled field test trials that should be conducted in one's country, or under similar environmental and traffic conditions.

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