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Effect of warm mix additives on creep and recovery response of conventional and polymer modified asphalt binders

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HIGHLIGHTS

- Sasobit improves the creep and recovery response of asphalt binder.
- Rediset led to the deterioration in the rutting performance of the asphalt binders.
- Usefulness of η_M as a prediction parameter can be appreciated.
- Extent of improvement using sasobit was found to be higher at longer loading times.

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ABSTRACT

This study appraised the effect of three warm mix additives (sasobit, evotherm and rediset) on the creep and recovery response of a conventional viscosity graded binder (VG 30) and a polymer modified binder (PMB 40). Multiple stress creep and recovery (MSCR) test was done at five different temperatures (30–70 °C) and two stress levels of 0.1 and 3.2 kPa. The output of MSCR test was simulated using Burger's four element model and time temperature superposition principle (TTSP) was used to assess the long term creep behavior of the binders at a reference temperature of 50 °C. Amongst the three warm mix additives, sasobit improved the resistance to permanent deformation characteristics of the control binders, followed by evotherm. Rediset was found to be ineffective in improving the creep and recovery response of the control binders. Its use led to increase in the unrecoverable creep compliance (J_{nr}) and reduction in percent recovery. Burger's model was found to be apposite in simulating the measured response for all the binders at different test conditions. The viscous parameter, η_M could be correlated with the other model parameters using a power law equation and also had an excellent association with J_{nr}. The long term creep behavior of the asphalt binders indicated that the difference in creep strain is more pronounced at higher loading times. Findley's power law model was found to be more appropriate for fitting the creep master curves in comparison to Burger's four element model.

1. Background

The demand of highway has increased in the recent years owing to increase in loading, high temperatures and introduction of new axle configurations. To satisfy this demand, use of better materials, improved design techniques and efficient quality controlled construction are required. Polymer modification is one of the simplest and effective techniques to improve the load carrying capacity of pavement [1–3]. Globally, approximately 75% of the modified binders are elastomeric [4], within which styrenic block copolymers have shown the greatest potential to ameliorate the rheological performance when blended with bitumen [5–7]. Though an effective technique, practitioners and contractors remain skeptical of its use, mainly because of increased cost and high temperature requirements [8]. Parallel to the demand of highways, environmental concerns has also increased and the current interest has shifted to development of energy efficient new technologies [9–12]. Warm mix asphalt technology is one such innovation developed primarily with the aim of reducing the high temperature requirements for manufacturing and laying of asphalt mixes [11]. These environmental friendly techniques has proven to produce asphalt mixes, which can be laid at 20–40 °C lower temperatures,

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in comparison to hot mix asphalt (HMA) without affecting its performance [11,13]. Many WMA additives has been developed that involve the use of organic additives, chemical additives, and water-based or water-containing foaming processes. A detailed review of warm mix additives has been presented by Rubio et al. [11]. Even though these technologies are quite different, they all target the same goals, namely, lower bitumen viscosity, better mat workability, and improved workability and emissions conditions.

It has been found that Superpave performance grade (PG) specification is not able to quantify the performance of modified binders [14,15]. Federal Highway Administration (FHWA) introduced Superpave plus testing protocol for better characterization of these materials [14,16,17]. Multiple stress creep and recovery (MSCR) is one of the various new test methods which were introduced. This method has been introduced as a part of new Superpave grading system (AASHTO MP 19-10) and is accepted as a standard. Usually the test is done on rolling thin film oven (RTFO) aged samples at high PG temperatures. The binder is subjected to creep loading and unloading cycle of 1 s and 9 s respectively, at stress levels of 0.1 kPa and 3.2 kPa. Ten cycles of loading is given at each stress level. The output of MSCR test is used to calculate non-recoverable creep compliance (J_{nr}) and percent recovery (*% rec*) for quantifying the rutting susceptibility of asphalt binders. Results have shown that, the unrecoverable creep compliance (J_{nr}) at 3.2 kPa, measured using this test method, correlates fairly well with the actual field performance [18–22]. A schematic representation of MSCR result is presented in Fig. 1. Tables 1 and 2 presents the desired specification values for different traffic conditions as outlined by the Asphalt Institute (AI) [23].

Time temperature superposition principle (TTSP) is an important tool to study the rheological behavior of linear viscoelastic polymers at a wide range of loading time, at any reference temperature. Many studies have reported its use in the study of bitumen through construction of master curves corresponding to different rheological parameters such as complex shear modulus (G*) and phase angle (δ) [24–26]. However, its use in the study of long term creep behavior of asphalt binders has not been reported in many studies. Modeling the response of any material to the imposed stress/strain is one of the popular techniques to quantify and study their mechanical and physical properties [27]. Various researchers have attempted to model the experimental output of MSCR test using different rheological models [27–31]. Complex models such as the generalized Maxwell model or the Kelvin-Voigt model tends to give better results [32]. Nevertheless, other rheological models such as Burger's four element model and Findley power law model could well fit the laboratory test results. A simple model, however, has its own benefits since its parameters can easily be determined

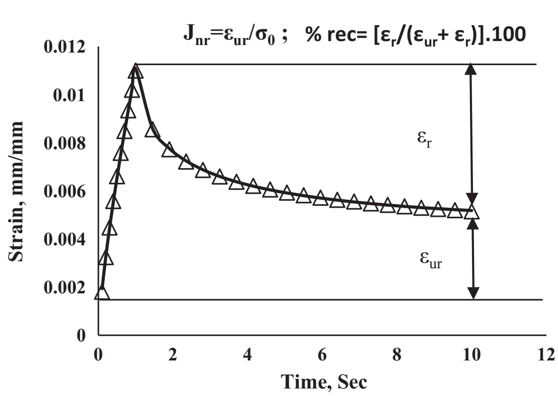

Fig. 1. Schematic representation of creep and recovery [33].

Table 1
Specification for maximum J_{nr} at different traffic level

Type of Grade	$J_{nr,3.2kPa}$, kPa^{-1} Maximum	$J_{nr,diff}$ %, max
S	4	75
H	2	
V	1	
E	0.5	

Note: S-Slow; H-Heavy; V-Very heavy; E-Extremely heavy.

Table 2
Specification for minimum% recovery for different J_{nr}.

$J_{nr,3.2kPa}$, kPa^{-1}	Minimum% Recovery
2.0–1.01	30
1.0–0.51	35
0.5–0.251	45
0.25–0.125	50

and each of them has a clear physical meaning. Burger's four element model had been very promising in characterizing the creep and recovery behavior of viscoelastic materials [27–29].

This study aims at studying the effect of warm mix additives (WMA) on the properties of viscosity graded (VG) and polymer modified binders (PMB) at different temperatures. The response of asphalt binder in MSCR test will be simulated using Burger's four element model and its applicability for studying the long term creep behavior of the binders using TTSP principle will be explored.

2. Materials

2.1. Asphalt binders

A viscosity graded binder (VG 30) was used as the control binder in this study. It was then modified using 3.5% of elastomeric polymer, styrene-butadienestyrene (SBS). These two binders further acted as control binders for modification using WMA. Basic tests were performed on the binders in accordance to IS 73-2013 and IS 15462-2004. The results are shown in table 3. It was found that polymer modified binder (PMB) satisfied the requirement for PMB 40 as per the standard and hence was designated as PMB 40. Both the binders were found to be acceptable as per the standards.

2.2. Warm mix additives (WMA)

Three warm mix additives: wax based-Sasobit®, surfactant based-Evotherm® and surfactant based-Rediset® were used in this study. As per the manufacturer's recommendation, 3% sasobit, 0.5% evotherm and 3% rediset were used in both VG 30 and PMB 40. Sasobit and rediset were obtained in pellet form, while evotherm was procured as a liquid. In this paper WMA modified binders will be represented as VG 30 S, VG 30 E and VG 30 R, indicating modification corresponding to sasobit, evotherm and rediset. Similarly, for PMB 40, it will be denoted ad PMB 40 S, PMB 40 E and PMB 40 R.

Sasobit (S) is a fine crystalline, long chain aliphatic hydrocarbon produced from coal gasification using the Fischer-Tropsch process [13,34]. It is typically mixed directly with the asphalt binder at 2–4% by weight and can lower plant production temperatures by 10 °C–30 °C. Sasobit melts between temperatures of 85 °C–115 °C, and is completely soluble in asphalt binders above 115 °C. At temperatures below its melting point sasobit forms a lattice structure in asphalt binders that is a basis for the stability of asphalts modified with sasobit. Evotherm used in this study is