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Rheological studies of performance grade bitumens prepared by blending elastomeric SBS (styrene butadiene styrene) co-polymer in base bitumens

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ABSTRACT

Performance of bituminous binder in terms of viscoelastic behavior can be improved by addition of requisite polymers. Two performance grade bituminous binder PG58 and PG64 were prepared by blending an elastomeric styrene butadiene styrene (SBS) co-polymer in 60/70 and 80/100 grade base bitumen respectively. The rheological properties of prepared bitumens have been studied by AR 1500 eX Asphalt Rheometer at minimum instrument inertia of 16.85 μNm^2. Resistance to permanent deformation or deformation resistance is also determined in terms of $G'_{\text{modified bitumen}}/G'_{\text{base bitumen}}$, $G''_{\text{modified bitumen}}/G''_{\text{base bitumen}}$ and $G^*_{\text{modified bitumen}}/G^*_{\text{base bitumen}}$; which helps to predict the viscoelastic behavior of bituminous binder.

Introduction

Bitumen is a mixture of asphaltene, aromatic and naphthenic hydrocarbons. Small quantities of organic acids, bases, and heterocyclic components containing nitrogen, oxygen, sulfur are also present along with some metals e.g. Fe, V, Ni [1]. The use of synthetic polymers to modify the performance of conventional bitumen binder's dates back to the early 1970, when a decrease of temperature susceptibility, increased cohesion and modified rheological characteristics were observed for these modified bitumen binders [2]. Polymers for such purposes should have a number of requirements [3]. It must be compatible with bitumen and not cause phase separation during storage at high temperature [1–4]. Styrene butadiene styrene (SBS) is probably the most frequently used polymer in the bitumen modification [1,5–8]. SBS itself shows cross-linked elastomeric network behavior [9]. It is usually added in the concentration of 3–6% wt. When mixed with base bitumen, SBS is swollen and disperse throughout the bulk and behaves as cross linker [9–12]. This cross linkage increases the elasticity, recovery and cohesion of the bitumen. These parameters play vital role in the rheological properties of modified bitumen. SBS copolymers derive their strength and elasticity from physical cross linking and the molecules into a three dimensional network [1–4,9–11]. Extent of polymer modification depends on the nature of base bitumen (feed stock) and subsequently the compatibility of the bitumen-polymer system [11,12]. SBS is one of the most commonly used polymers to modify the performance of bitumen as it forms high interaction with maltene components [13].

In this paper the modification was carried out by using SBS in the concentration range of 0.5–1.5% wt of base bitumen to prepare performance grade bitumen PG58 and PG64. The comparison of rheological properties of PG58 and PG64 bitumens was done. The variation in different rheological parameters like δ, G*, G*/Sin δ and $G'_{\text{modified bitumen}}/G'_{\text{base bitumen}}$, $G''_{\text{modified bitumen}}/G''_{\text{base bitumen}}$ and $G^*_{\text{modified bitumen}}/G^*_{\text{base bitumen}}$ has been studied against temperature.

Experimental

Materials

Two base bitumens, 60/70 and 80/100 were obtained from Haldia Refinery (Indian Oil Corporation), India and styrene butadiene styrene (SBS) elastomeric copolymer was supplied by DuPont.

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Preparation of SBS modified bitumens

Six SBS modified bitumens were prepared at laboratory scale using 500 mL glass assembly. Three different concentrations of SBS copolymer as 0.5% wt, 1.0% wt and 1.5% wt were taken with 60/70 and 80/100 base bitumens each to prepare six modified bitumens. Pre-weighted amount of polymer was added to base bitumens at 100 °C and then reaction mixture is thermally agitated at 170 °C with vigorous stirring at ~800 rpm for the period of 90 min (Fig. 1).

Physicochemical characterization

A Stanhope-Seta penetrometer with built in Julabo-25B water bath was used to determine penetration of bituminous materials at 25 °C in terms of dmm as per ASTM D5-05a [14]. The value of penetration index was determined by the empirical formula given by Pfeiffer and Van Doormaal [3]. Softening point was determined by using Ring & Ball apparatus from Koehler instruments. The heating rate was maintained at 4–5 °C per min until the two balls weighing 3.5 g touches the bottom plate of the apparatus [15]. Ductilometer from Akash-Deep Scientific Industry, India was used to determine ductility as per ASTM D113-99 [16]. Flash point was determined by using Cleveland Open Cup (COC) apparatus as per standard test method IS: 1206-1978 [17]. Solubility of different bituminous material was determined as per test method ASTM D3279-97 [18]. Aging characteristics were determined by Rolling Thin Film Oven Test (RTFOT) machine supplied by James Cox & Sons (model No CS 325A) as per standard ASTM D2875-04 [19].

SARA analysis and colloidal index of base bitumens

SARA analysis of both the base bitumens was performed as per ASTM D4124-01 [20] while the colloidal index (CI) was determined following the common literature method [21].

NMR and SEM measurements

^{1}H and ^{13}C NMR spectra have been recorded for 60/70 and 80/100 base bitumens on a Bruker Avance 500 spectrometer in the proton noise-decoupling mode with a standard 5-mm probe at 300 K using 10 wt % (w/w) sample solution in $CDCl_3$ taking TMS as an internal reference. Microscopic structure of base and modified bitumens were studied using FEI Quanta 200F SEM (FEI, Hillsboro, OR, U.S.A.) equipped with EDX analysis. The parameters used are as follows; chamber pressure: 10 Pa; High voltage: 20.00 kV; Tilt: 0.00; Takeoff: 35.00; AMPT: 102.4; Resolution: 133.44. The image of all the samples were taken at 1200× magnification using ETD detector.

Dynamic shear rheometer (DSR) analysis

The dynamic shear rheometer from TA Instrument (model no. AR 1500eX) was used to characterize viscous and elastic behavior of bottom base bitumens and prepared PG bitumens (Fig. 2). DSR is used for rheological characteristics of original binder (un-aged bitumen), after RTFOT (short aged bitumen) and after PAV (long aged bitumen). All these tests were carried out at minimum instrument inertia of 16.85 μNm^2. Rheological properties predict the flow/deformation of bituminous material under constant stress or strain mode. Bitumen being a viscoelastic material so its properties changes with the change in temperature and angular frequency. DSR measures complex shear modulus (G^*), phase angle (δ), and dynamic viscosity (η) etc. by subjecting the small quantity of sample to oscillatory shear stress. The complex modulus is a measure of total resistance of material to deformation when repeatedly sheared. The phase angle is an indicator of relative amount of recoverable and non-recoverable deformation. DSR studies are carried out as per ASTM D7175-05 [22] at variable temperatures ranging from 46 °C to 84 °C i.e. in temperature sweep mode. Dynamic viscosity (ω) of different SBS modified bitumens were also determined by DSR in the temperature range of 52–76 °C.

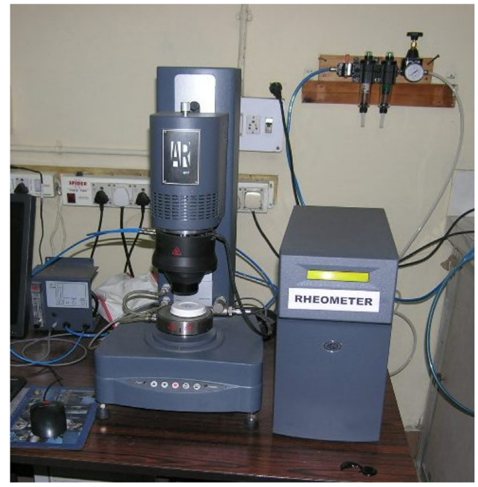

Fig. 2. Dynamic shear rheometer (DSR).

Result and discussion

Physicochemical properties of base bitumens

The key physicochemical properties of 60/70 and 80/100 base bitumens are mentioned in Table 1. Both the base bitumens have specific gravity in the range of 0.97–1.02 and °API in the range of 7.22–8.59. This indicated that both are aromatic rich. Low colloidal index (CI) and SARA analysis also showed that 60/70 is more aromatic rich (Table 2) and thus may have good potential compatibility with SBS. 60/70 base bitumen is also harder than 80/100 as it has low penetration and high softening point and thus have higher compatibility (high solvolysis) to disperse the polymer in it. These are the reasons why these two base bitumens were used

Fig. 1. Preparation of SBS modified bitumens.

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