Construction and Building Materials 41 (2013) 815–823

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Strength characteristics of SBS modified asphalt mixes with various aggregates

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HIGHLIGHTS

- ▶ Siliceous aggregates.
- ▶ Calcareous aggregates.
- ▶ Tensile strength ratio.
- ▶ Dynamic shear rheometer.
- ▶ Wheel tracking test.
- ▶ SBS modified bitumen.

ARTICLE INFO

Article history:
Received 25 February 2012
Received in revised form 1 December 2012
Accepted 19 December 2012
Available online 4 February 2013

Keywords:
SBS polymer
Siliceous aggregates
Calcareous aggregates
DSR
Moisture susceptibility
TSR

ABSTRACT

In recent years, many authors have researched polymer-modified bituminous (PMB) mixes and tried to better understand the effect of these modifiers on the strength characteristics of hot mix asphalt mixes. The objective of this study is to determine the effect of bitumen modification with varying percentage of Styrene bitudiene styrene (SBS 3%, 5% and 7%) for preparing the hot mix asphalt (HMA) containing various aggregates (marble, granite and quartzite) and compare the results with mixes prepared with neat VG 30 HMA. The selection of aggregates has been made on the basis of their acidic and basic nature depending upon the amount of silica oxide and calcium carbonate present in them. Dynamic shear rheometer (DSR) was used to determine the mixing and compacting temperatures of modified bitumen and performance grade based on $G^*/\text{Sin}\,\delta$ value. The physical and mechanical properties of SBS modified bitumen and neat bitumen aggregates mixes are evaluated. Retained Marshall Stability (RMS) test and tensile strength ratio (TSR) tests were carried out to determine the moisture susceptibility and wheel tracking test was performed to compare the results of permanent deformation in samples.

The results indicate that there was significant improvement in the strength characteristics, rutting resistance and moisture susceptibility of SBS modified mixes. Aggregates basic in nature i.e. with higher calcium (Ca) content show better bonding with neat bitumen compared to acidic aggregates i.e. aggregates with higher silica (Si) content. But with modified bitumen the percentage improvement in strength and moisture susceptibility is more pronounced in case of siliceous aggregates compared to calcareous aggregates.

1. Introduction

Hot mix asphalt (HMA) concrete is a mixture of bitumen and aggregate. In a road pavement, aggregate composes 93–95% by weight of the mix while bitumen makes up the other 5–7%. In India approximately 98% of the pavements are flexible. Conventional bituminous materials have tended to perform satisfactorily in most highway pavement and airfield runway applications. However, in recent years, increased traffic intensity and axle loads have added to severe demand of better highway system in varying climatic environments. Moisture damage and permanent deformation are the primary modes of distress in HMA pavements. Loss of cohesion and stiffness of bitumen film and failure of the adhesive bond between aggregate and bitumen are the main mechanisms of moisture damage in bituminous pavements. Therefore high strength and durable mixes are required for airfields and express highways [1]. This could be achieved either by improving the properties of existing bituminous material or by careful selection of type of aggregate.

Polymer modification offers one solution to overcome the deficiencies of bitumen and thereby improve the performance of bituminous mixtures. Modification of bitumen binders can increase the overall performance of a binder by widening the range between

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http://dx.doi.org/10.1016/j.conbuildmat.2012.12.062

the binder's high and low-temperature grades, or it can target a specific improvement in a binder's performance in response to a particular severe-service condition, such as a pavement carrying a very high traffic volume or a high percentage of slow-moving heavy vehicles. In recent years, different kinds of polymers have been used to improve the properties of bituminous mixtures. For a polymer to be effective in road application, it should properly blend with bitumen to produce a homogenous mix to improve its resistance to rutting, stripping, cracking, fatigue, ageing, etc. Among various available polymers elastomers are being widely used in bitumen modification [2] and among them SBS is one of the most widely used which can extremely improve the mechanical properties of bituminous mixtures [3] such as ageing [4] permanent deformation [5,6] low temperature cracking [7] moisture damage resistance [8], etc. Increase in penetration index upon SBS addition proved its contribution to reduction in brittleness and temperature sensitivity of the binder. SBS copolymers derive their strength and elasticity from physical and cross linking of molecules into three dimensional network. Increasing the SBS content results in increased polymer swelling, which in turn produces increase in asphaltenes and reduction in maltene content resulting in harder and viscous matrix [9,10].

Other method is choice of aggregate. Aggregates are a heterogeneous combination of various naturally occurring minerals. Among various compounds, silicon dioxide or calcium carbonate are the predominant compound found in most aggregates. Those aggregates that are primarily made up of silicon dioxide are typically acidic and those that are primarily calcium carbonate are typically basic [11]. Limestone aggregates typically have good bitumen bonding characteristics. Limestones, in general, are known for their stripping resistance in pavement mixtures. Lime addition to bitumen has been used for many years to reduce stripping. This supports the concept that the presence of calcium enhances pavement durability [12]. On the other hand siliceous aggregates commonly have relatively low bonding energies. In general, siliceous aggregates have more tendency to debond from bitumen than the limestone or dolomitic aggregates [12,13]. This is because in siliceous aggregates Hydrogen bonds are formed with hydroxilated surfaces (silanol groups) which are easily displaced in the presence of water whereas in calcareous aggregates, free calcium is prerequisite to form insoluble salt links which are not easily displaced by water. Curtis et al. [14,15] have shown that asphaltenes are adsorbed more on sandstone and limestone than did the parent bitumen. For given bitumen, large differences were observed in the amount of bitumen adsorbed and retained after exposure to water when using both siliceous and calcareous aggregates [16]. The net absorption of asphalt in case of sandstone was 0.34 mg/g and in case of limestone it was 1.1 mg/g. However, this acid–base bonding of bitumen to aggregate is not the only important factor in moisture damage [17,18]. The physical properties of the aggregate are also important in the bitumen–aggregate bond. The porosity and surface texture will affect the mechanical bond between the bitumen and aggregate [19]. Aggregate components such as aluminium, iron, magnesium, and calcium promote bonding whereas sodium and potassium prove to be detrimental to aggregate–bitumen bond. The strength of the adhesion between aggregate and bitumen determines the performance of the pavement.

Researchers have carried out laboratory experiments related to effect of SBS on strength of bituminous concrete mixes. However limited experimental studies have been conducted to evaluate the effect of SBS on various aggregates. The objective of this present research is to determine the compatibility of SBS modified bitumen and neat bitumen with different types of aggregates depending on their acidic and basic character based on their Ca and Si contents. In this paper VG 30 has been taken as the base bitumen and has been modified by adding 3%, 5% and 7% of SBS. The results of specimens prepared with modified bitumen have been compared with the neat VG 30 specimen results.

Table 1
Properties of base bitumen.

Properties	Standard	Results	Recommended value (by IRC)
Penetration (0.1 mm, 100 g, 5 s, 25 °C)	ASTM D5	67	50–70
Softening point (°C)	ASTM D36	49	47 (min)
Penetration index (PI)	–	−0.698	
Specific gravity	IS:1202-1978	1.01	0.99 (min)
Ductility (mm), 25 °C	IS: 1208-1978	100+	75 (min)
Viscosity at 150 °C, Pa s	IS: 1206-1978	0.172	
After TFOT			
Mass loss (%)	ASTM D2872	0.5	
Penetration (0.1 mm, 100 g, 5 s, 25 °C)	ASTM D5	37	
Retained penetration, %		57	
Penetration Index (PI)	–	−1.36	
Softening Point (°C)	ASTM D36	52	

Table 2
Properties of SBS.

Composition	Standard	SBS
Molecular structure	–	Linear
Styrene/rubber ratio	–	31/69
Specific gravity	ASTM D792	0.94
Physical form		Pellet. Powder
Shore hardness (A)	ASTM D2240	71
Melt index	ASTM D1238	<1
Elongation at break (%)	ASTM D412	875
Tensile strength at break (MPa)	ASTM D412	31.8

2. Material

2.1. Base bitumen

VG 30 paving grade bitumen obtained from Mathura refinery was used in the study for preparing various mixtures. The physical properties of VG 30 are listed in Table 1.

2.2. Modifier SBS preparation and properties

Styrene butadiene styrene (SBS) an elastomer was used to develop modified bitumen. VG 30 was used as base bitumen and three levels of SBS were used namely 3% (3S), 5% (5S) and 7% (7S) by weight of bitumen. The polymer used was in the form of pellets. The properties of SBS Kraton D 1101 are given in Table 2.

Mixing was performed in the laboratory using high shear mixer capable of maintaining temperature and regulating stirring speed. The bitumen binder was heated to 150 °C for 1 h with mixer speed maintained at 200 rpm. After the mixing temperature of 180 °C was reached, the modifier was added slowly in the required amount to avoid agglomeration of polymer and the mixing was continued for next 1.5 h at 500 rpm. [10]. After the blend was prepared the uniformity of the mix was determined by passing it through ASTM 100# sieve and on confirmation of uniformity it was stored in aluminium containers [20]. The containers were then stored in freezer at −25 °C to retain the obtained morphology. This was possible because the storage temperature was close to the glass transition temperature [21]. Tests for penetration, softening point, specific gravity were conducted on the modified binders before and after short term ageing by TFOT and the results are given in Table 3.

2.3. Aggregates

Three types of aggregates via: marble, quartzite and granite have been used in this study to prepare the mixes. The criterion for selection of these three aggregates is their acidic and basic character based on the amount of SiO_2 and $CaCO_3$ content present in them. Those aggregates that are primarily made up of silicon dioxide are typically acidic, and those that are primarily calcium carbonate are typically basic.