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Performance Evaluation of Bituminous Concrete Mixes Modified with SBS Polymer and Warm mix Additive

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Abstract: ***The main objective of this study was to investigate the effect of SBS polymer and warm mix additive on the performance of bituminous concrete mixes. SBS polymer dosage was kept 3%, 5% and 7% and Zycotherm additive dosage was kept 0.1% for all binder mixes. Comparisons were made between Base bitumen, SBS modified bitumen and Zycotherm modified bitumen. For preparation of bituminous mixes, two different types of aggregates were used in this study i.e. Limestone and riverbed aggregate. To evaluate the performance of modified binder; Marshall Stability test, Indirect Tensile Strength (ITS) test and Rheological test were performed on binders and bituminous concrete mixes. From Marshall Stability test, SBS dosage of 5% was found to be optimum polymer content for both aggregate mixes. Maximum tensile strength for both the aggregate bituminous mixes was achieved at 5% SBS content. It was observed that maximum Marshall Stability was achieved when Limestone aggregates were used for preparation of bituminous mixes. Zycotherm additive does not have any significant effect on the properties of bituminous concrete mixes. However Zycotherm additive tends to decrease viscosity of binder at a temperature above 100 ˚C which will result in lower mixing temperature without compromising the performance of bituminous binder. Rheological test on different binders has shown that Zycotherm additive has very less affect on rutting resistance of modified bitumen. It was finally concluded that best results were obtained from Limestone aggregates using 5% of SBS polymer and Zycotherm additive has no significant effect on mechanical properties of mix.***

Keywords: Base bitumen, SBS modified bitumen, Zycotherm additive, Stability, ITS, Marshall stability, Dynamic Shear Rheometer, Limestone Aggregate, Riverbed aggregate

I. INTRODUCTION

In a flexible pavement, bituminous surface layer undergoes various distresses due to severe climatic condition and heavy traffic load [1-2]. These distresses include Rutting, Fatigue Cracking, Shoving, bleeding and Ravelling etc.

Recently in India, Ministry of Road Transport & Highway (MoRT&H) has increased the maximum legal axle load for commercial vehicles plying on Indian roads [3]. Various studies have shown that with an increased axle load there is a significant increase in distresses on the surface layer of Flexible
Pavement due to increase in Tyre-Pavement contact pressure [4-6]. To overcome the distresses caused due to Traffic and severe climatic, more efficient and durable bituminous mixes is required. Modification of bitumen is one of the most common approaches to improve the performance of bituminous mixes under various traffic loading and temperature conditions [7-12]. It is well-known that the performance of the asphalt mixture is highly related to the performance of bitumen [13]. Styrene butadiene Styrene (SBS) is a thermoplastic elastomer consisting of two monomers i.e. Styrene and Butadiene. Styrene part of SBS polymer provides bitumen its hardness which increases its rutting resistance and butadiene part make bitumen more rubbery which increases thermal cracking resistance of modified bitumen [14, 15]. SBS polymer enhances the strength and elastic properties of bitumen binders in a wide range of temperature; it is the most widely used polymer for modification of asphalt binders [16]. However, SBS modified bitumen has a disadvantage that it makes bitumen highly viscous which requires higher temperature for mixing on site [17]. It is generally observed that the mixing/compaction of SBS modified asphalt mixtures is 40 °C higher than mixing/compaction of asphalt mixtures with unmodified bitumen [18]. Warm mix additive is another technology used worldwide to reduce the mixing and compaction temperature of bituminous mixes. Various warm mix additives like Zycotherm, Sasobit, Entira Bond 8, Rheofalt etc. are added in bitumen which reduces the viscosity of bitumen so as to reduce the mixing and compaction temperature of bituminous mixes [18 - 24]. This reduction in mixing and compaction temperature reduces the energy required to make bituminous mixes [18]. There are many other advantages of using WMA technologies, including reduced bitumen ageing, better aggregate-binder adhesion and reduced cracking. Zycotherm additive is an odorless nano-organosilane additive for bituminous mixes which increases moisture resistance and decreases mixing temperature for bituminous mixes [25 - 27]. Zycotherm additive reduces the energy required for preparation of bituminous mixes without compromising the performance of bituminous mixes [28, 29]. Researchers have already carried out laboratory experiments to evaluate the effects of SBS Modified binder on the properties of bituminous concrete mixes.

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However, limited experimental studies have been conducted to evaluate the effect of Warm Mix Additive on the properties of SBS modified binder and bituminous concrete mixes. In this study the effect of different percentages of SBS polymer in bitumen and the effect of Zycotherm additive on the conventional and rheological properties of neat binder and polymer modified binder is determined.

Dynamic Shear Rheometer (DSR) is used to determine the rheological properties of each binder at desired temperature range. Marshall Stability and Indirect tensile strength test (ITS) is also performed to evaluate the mechanical properties of bituminous concrete mixes.

II. MATERIALS

A. Base Bitumen

In this study bitumen of viscosity grade VG30 obtained from Panipat Refinery, India was selected as a base binder. Properties of Base binder are given in Table 4.

B. Modifiers

(i) SBS Polymer: SBS polymer was purchased from LG Chemicals with product ID: LG411S. Physical properties of SBS polymer is given in Table 1. SBS polymer was supplied in the form of porous pellets. For preparation of SBS modified bitumen, laboratory blender capable of maintaining constant temperature and uniform blending speed for long duration was used. Different percentages of SBS polymer was added in bitumen i.e. 3, 5, 7% by weight of bitumen. Bitumen was heated to a temperature above 160˚C. When mixing temperature of 170-180˚C was attained then SBS polymer was slowly added in bitumen. Then mixing was continued for 2 hrs at 4000 rpm so as to achieve a homogeneous blend of SBS modified bitumen.

(ii) Zycotherm: Zycotherm additive was procured from Zydex Industries; Gujarat. Zycotherm dosage was kept same for all mixtures i.e. 0.1% by total weight of binder. Zycotherm mixing was done using a blender rotating at 100 rpm for 5 min at 120˚C. Properties of Zycotherm additive is given in Table 2.

Table 1: Properties of SBS polymer

Properties	Results
Styrene content	31 %
Density	0.94 g/cm^3
Toluene solution viscosity	28.2 cSt
Melt index	<1 g/10min
Hardness	84 Shore A
Volatile matter	0.3 %
Yellow index	1
Flash point	288 ˚C
Solubility	Insoluble in water

Table 2: Properties of Zycotherm additive

Property	Results
Specific gravity	0.97 g/cm3
Viscosity	1 – 5 pas
Flash point	>80 c
Colour	Pale yellow
Physical state	Liquid
Solubility in water	Soluble in water

C. Aggregates

Two different aggregates were used in this study i.e. limestone aggregate and riverbed aggregate. Limestone aggregates were procured from Shillai (Himachal Pradesh) and riverbed aggregates were procured from Paonta sahib (Himachal Pradesh). Aggregate gradation was chosen as per MoRT&H specification for bituminous concrete layer of thickness 30-40 mm with nominal aggregate size of 13.2 mm [30]. Aggregate gradation for bituminous concrete surface is given in Figure 1. Midpoint gradation was selected for preparation of bituminous mix. Difference in physical properties of aggregates was determined by performing various tests on aggregates. Aggregate physical property is given in Table 3.

Table 3: Physical properties of different aggregates used in this study

Test description	Aggregate		Standard	Recommended value
	Limestone	Riverbed		
Specific gravity fine aggregate	2.7	2.7	ASTM C128 [31]	-
Specific gravity coarse aggregate	2.62	2.69	ASTM C127 [32]	-
Impact value (%)	22.33	19.66	IS:2386 Part 4 [33]	Max 24%
Crushing value (%)	22	20		
Abrasion value (%)	23	19	ASTM C131 [34]	Max 30%
Water absorption (%)	0.91	0.50	ASTM C127 [32]	Max 2%

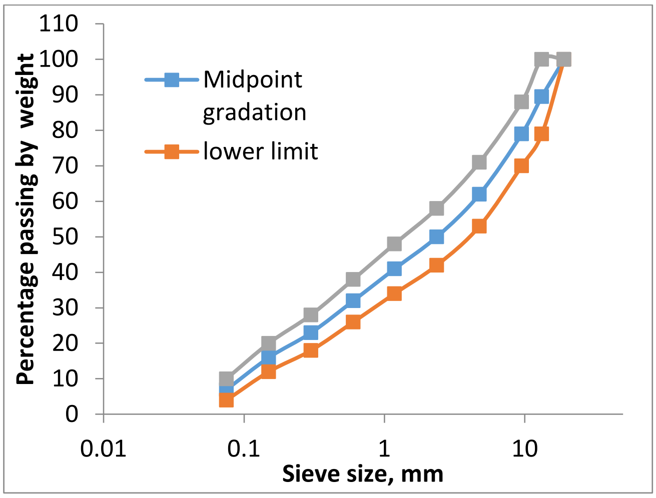

Figure 1: Aggregate gradation for bituminous concrete

III. EXPERIMENTAL

A. Conventional Test on Binder

Base Binder, SBS modified binder and Zycotherm modified binder were subjected to different conventional binder tests. For Penetration test; temperature, load, and time are taken to be 25°C, 100 g, and 5 s, respectively as per ASTM D5 [35]. Penetration test was used to determine the consistency of binder material. Higher penetration value indicates softer consistency of binder. Softening point of binder was determined as per ASTM D36 [36]. Softening point value signifies the tendency of the material to flow at elevated temperatures.

B. Rheological Test on Binder

Dynamic Shear Rheometer (DSR) MCR 52 was used to characterize the viscous and elastic behavior of bituminous binder at different temperatures. DSR is capable of measuring rheological properties of a bituminous binder like complex shear modulus (G*) and phase angle (δ). G* and δ are used to predict parameters like rutting and fatigue failure. Larger phase angle signifies higher viscosity of binder. In order to resist rutting, bituminous binder should be stiff however it should posses sufficient elasticity so that it can return to its original shape after load deformation; therefore G*/sin δ value should be large i.e. G* value should be high and δ should have lower value. To resist fatigue cracking bituminous binder should be more elastic and less stiff since stiff substances will crack rather than deform and rebound; therefore G*.sin δ value should be less. DSR can characterize the viscous and elastic properties of bituminous binder over a range of temperature and loading times. During testing sinusoidal shear stress is applied to bituminous binder sandwiched between two parallel plates. Based on this stress strain measurement, elasticity and viscosity of a binder is obtained at different temperature. All the test specimens were subjected to sinusoidal loading at a frequency of 10 rad/sec which corresponds to a traffic speed of 80Km/hr. 25 mm parallel plate geometry is used with a gap of 1.00 mm for conducting the entire test in Dynamic Shear Rheometer (DSR). Variation in viscosity with temperature was determined using DSR MCR 52 at a shear rate of 4 (1/s) with temperature ranging from 60 to 120˚C.

C. Mechanical Test on Bituminous mixes

To determine the effect of bitumen modification on the mechanical properties of bituminous mixes, Marshall Test and Indirect tensile strength of bituminous mixes was evaluated. In real life bituminous surfaces are subjected to traffic load and severe temperature variation. These tests simulate the similar conditions for bituminous mixes which they will face in real life. For bituminous mixes, optimum binder content was determined using Marshall Method of mix design confirming to ASTM D6927 [37] specifications. For preparation of Marshall Specimen, aggregate and binder mixing temperature was kept 160-170˚C for all specimens. Sample was compacted using a rammer by applying 75 blows on either side of specimen.At same optimum binder content (as that of conventional bitumen), all the bituminous mixes were made with variation of different modification in binder. Indirect Tensile strength (ITS) test is also performed to determine the tensile strength of bituminous mixesas per standard specification conforming to ASTM D6931-17 [38]. The values of indirect tensile strength (ITS) can be related to the cracking properties of the bituminous pavement. Higher tensile strength corresponds to higher cracking resistance [39]

IV. RESULTS AND DISCUSSION

A. Effect of modification on conventional properties of binder

With an increase in SBS concentration from 3 to 7% in bitumen, a gradual decrease in penetration value of bituminous binder was observed. Further, with an increase in SBS percentage from 5 to 7%, penetration value begins to stabilize. Moreover, there was a formation of continuous film of tiny droplets around the surface of bitumen when SBS percentage was 7%; this may be due to phase separation of SBS polymer in bitumen at higher percentages of SBS polymer. Therefore, to avoid phase separation of polymer in bitumen, maximum 5% SBS modification is suggested. With addition of Zycotherm additive in base binder, there was a decrease in penetration value [27]. However, Zycotherm additive has slightly increased the penetration value for SBS modified bitumen when Zycotherm was added to SBS modified binder which means that Zycotherm additive has reduced the viscosity of SBS modified bitumen.

Increase in softening point was observed with an increase in SBS percentage from 3 to 7% in bitumen. Softening point for VG30 binder increased from 52 to 75 ˚C for 7% SBS modification. 5% and 7% SBS modification in bitumen has nearly same value for softening point. Zycotherm additive showed no significant effect on the softening point for conventional bitumen and SBS modified bitumen.

Table 4: Effect of modification on conventional properties of mix

Binder	Penetration Value (0.1mm)	Softening point (˚C)
VG30	65	52
VG30 + 3% SBS	50	60
VG30 + 5% SBS	45	74
VG30 + 7% SBS	42	75
VG30 + Zycotherm	62	53
VG30 + 3% SBS + Zycotherm	52	60
VG30 + 5% SBS + Zycotherm	46	74
VG30 + 7% SBS + Zycotherm	43	75

With an increase in SBS percentage in bitumen an increase in viscosity of bitumen was observed as shown in Figure 2. This was due to the reason that elastomeric phase of SBS polymer absorbs the oil fraction from the bitumen binder and swells up to nine times as much as its initial volume [40]. This swelling causes the SBS rubber phase to dominate the asphalt phase, resulting in a new modified asphalt binder possessing the principal characteristics of rubber.

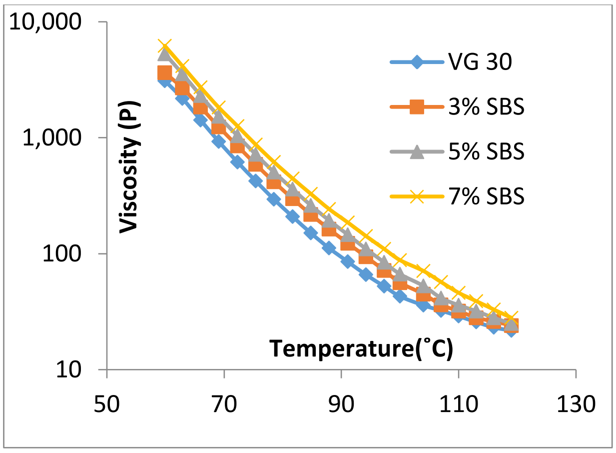

Figure 2: Effect of SBS modification on viscosity of bitumen

With addition of Zycotherm additive in pure VG30 bitumen, an increase in viscosity was observed when temperature was between 60 and 100˚C then afterwards there was a significant decrease in viscosity of binder [Figure 3]. For SBS modified bitumen, addition of Zycotherm has slightly lowered the viscosity of binder but the difference in viscosity is not much [Figure 4 - 6]. This decrease in viscosity of binder at high temperature will reduce Mixing and compaction temperature of bituminous mixes by making binder less viscous, such that optimum mixing of bituminous mixes can be achieved at a low temperature.

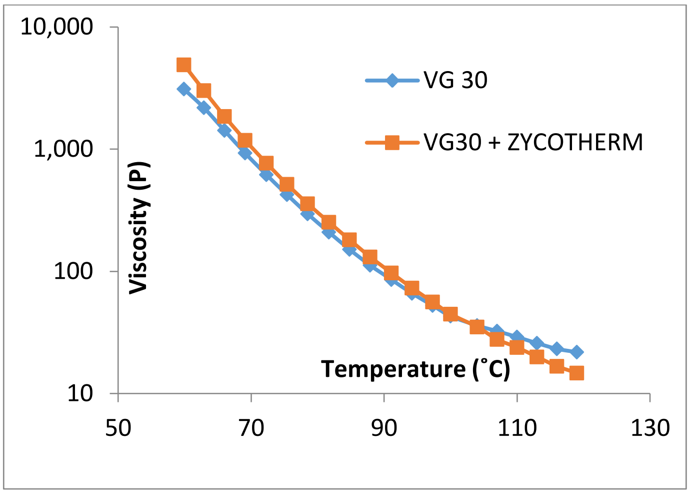

Figure 3: Effect of Zycotherm additive on viscosity of VG30 bitumen

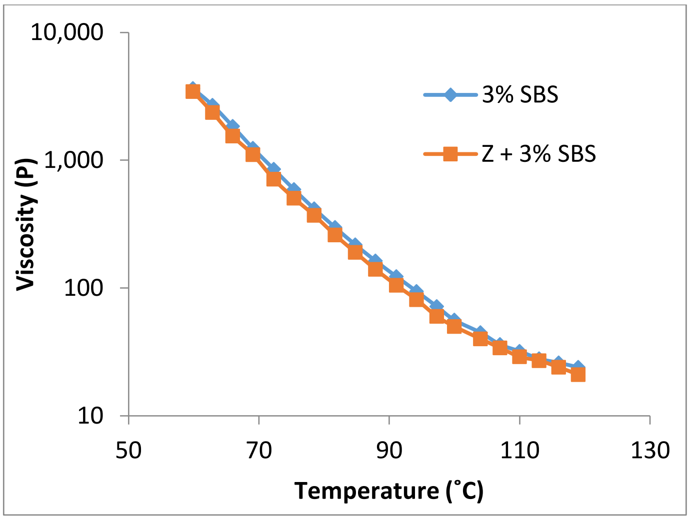

Figure 4: Effect of Zycotherm additive on viscosity of 3% SBS modified bitumen

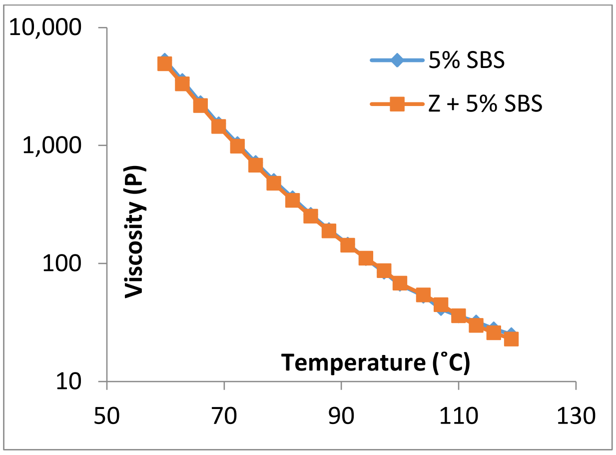

Figure 5: Effect of Zycotherm additive on viscosity of 5% SBS modified bitumen

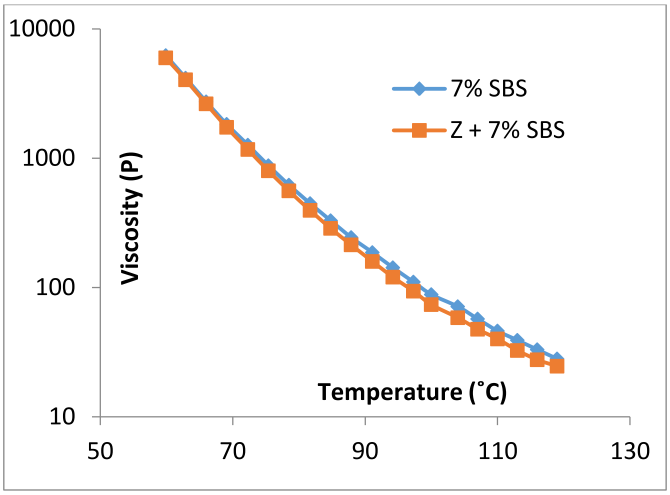

Figure 6: Effect of Zycotherm additive on viscosity of 7% SBS modified bitumen

B. Effect of modification in bitumen on rheological properties of binder

There was an increase in G*/Sinδ value with gradual increase in SBS polymer concentration in bitumen as shown in Figure no. 7. This increase in G*/Sinδ value signifies an increase in rutting resistance performance of bituminous binder with gradual increase in polymer modification. Maximum rutting resistance performance was achieved with 7% SBS modification in bitumen

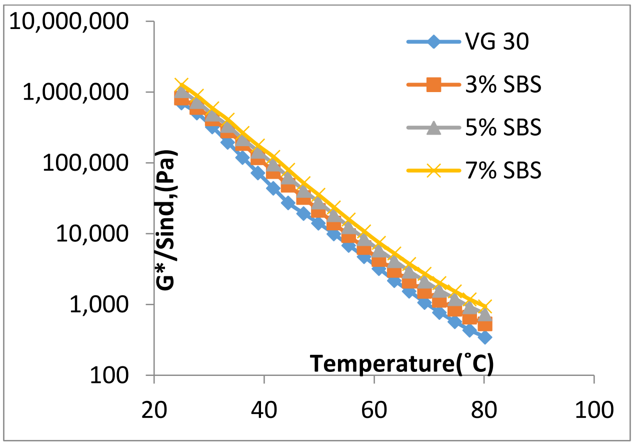

Figure 7: Effect of SBS modification on G*/Sinδ

Temperature corresponding to G*/Sin δ= 1kPa for VG30, VG30 + 3% SBS, VG30 + 5% SBS and VG30 + 7% SBS was 69.7, 73.3, 76.6, 79.4 ˚C respectively.

Zycotherm additive has shown no significant increase in rutting resistance potential for VG30 binder. Temperature corresponding to G*/Sin δ= 1kPa for VG30 + Zycotherm additive was 69.07˚C.

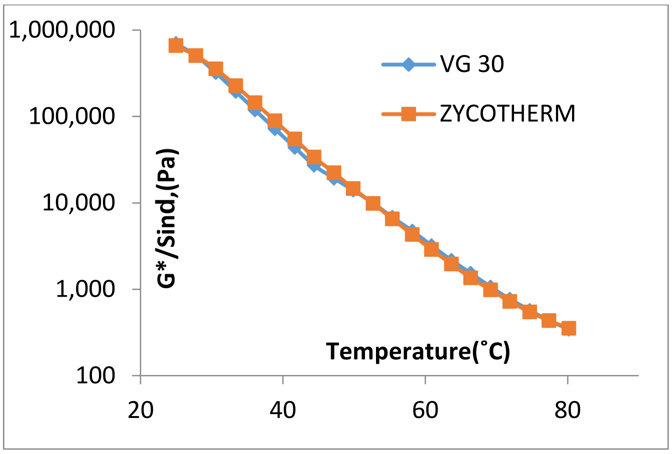

Figure 8: Effect of Zycotherm on VG30 bitumen

Zycotherm addition in SBS modified bitumen does not have any significant increase in performance of binder. Temperature corresponding to G*/Sin δ= 1kPa for VG30 + 3% SBS + Z, VG30 + 5% SBS+ Z and VG30 + 7% + SBS + Z was 69.7, 72.8, 76.4, 76.9 ˚C respectively.

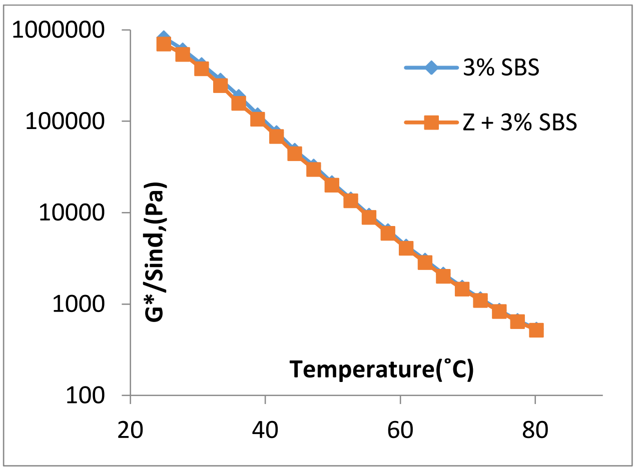

Figure 9: Effect of Zycotherm on 3% SBS Modified bitumen

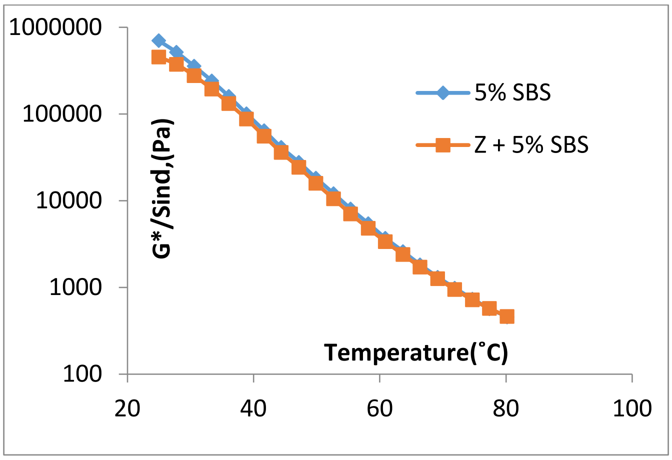

Figure 10: Effect of Zycotherm additive in 5% SBS modified bitumen

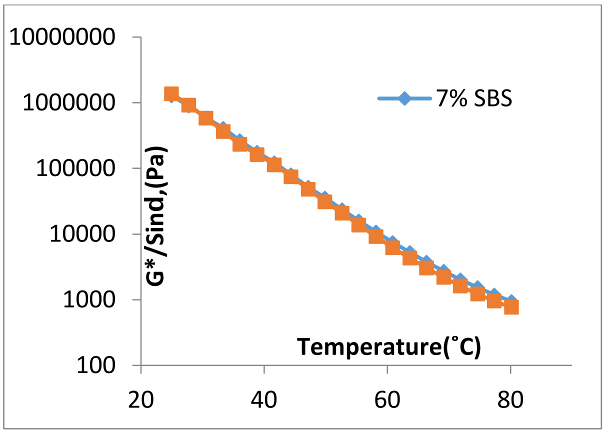

Figure 11: Effect of Zycotherm in 7% SBS modified bitumen

C. Effect of different binder on mechanical properties of bituminous concrete mix

(i) Marshall Method of Mix Design

As per Marshall Method of mix design, different graphs were plotted for both aggregate. It was observed that for same gradation the optimum binder content for limestone aggregate is more as compared to riverbed aggregate. For riverbed aggregate optimum binder content is 5.26 % and for limestone aggregate optimum binder content is 5.3%. Difference in optimum binder content is due to difference in absorption capacity of aggregate.

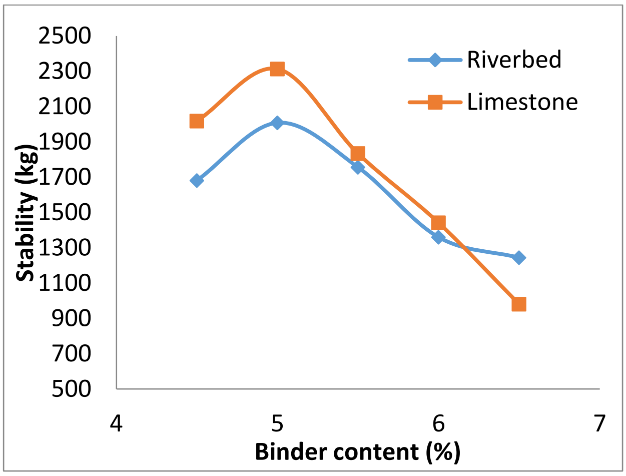

Figure 12: Marshall Stability Vs binder content

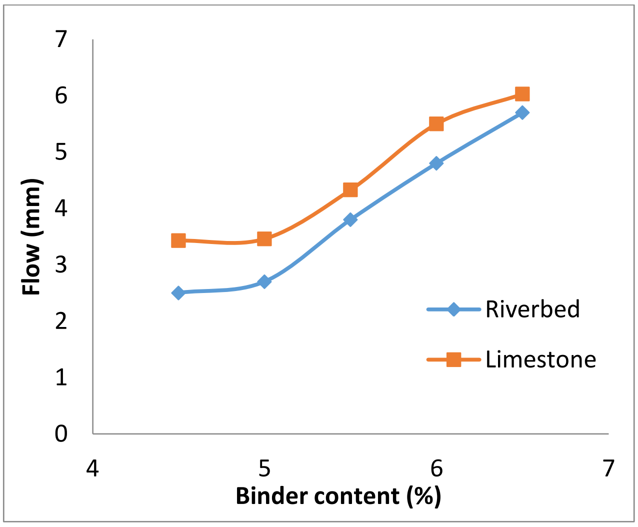

Figure 13: Flow Vs binder content

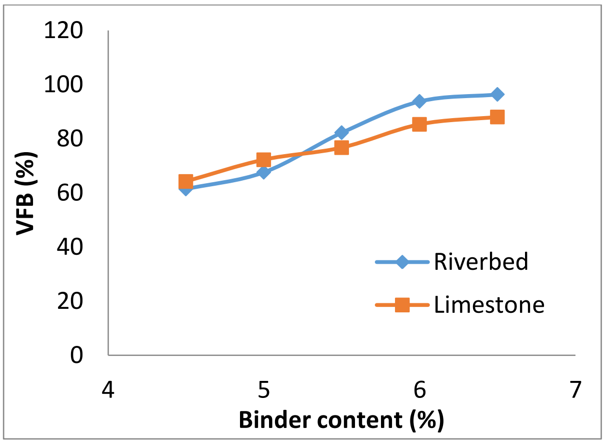

Figure 14: VFB (%) Vs binder content

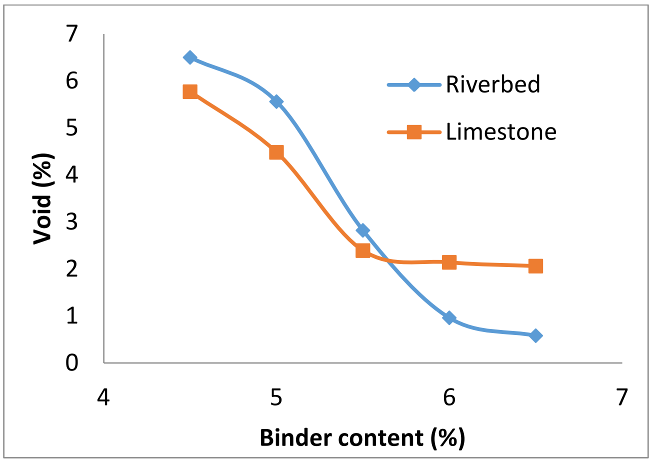

Figure 15: Void (%) Vs binder content

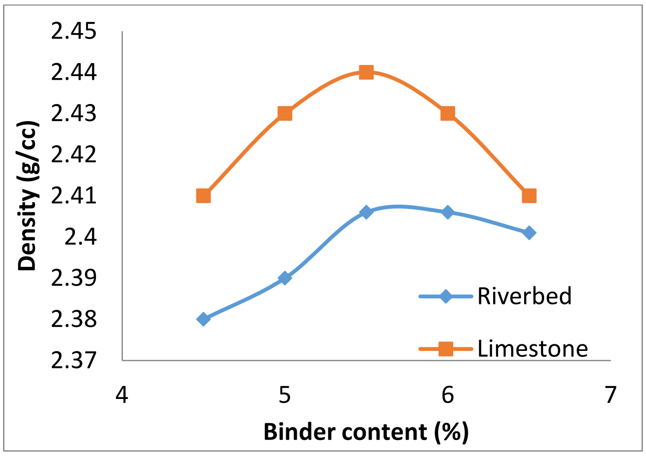

Figure 16: Density Vs binder content

It was seen that with increase in SBS percentage from 3, 5 and 7% there was an increase in stability value and there was a decrease in flow value. It was also seen that with increase in SBS percentage from 5 to 7% there was not much significant increase in stability value. Addition of Zycotherm additive on neat VG30 binder does not have any significant increase in stability value. Zycotherm additive in SBS modified binder does not have any effect on stability value. Zycotherm additive has negligible effect on stability and flow value. Effect of SBS and Zycotherm additive in bitumen is shown in Figure 17 and Figure 18 for riverbed aggregate and limestone aggregate respectively.

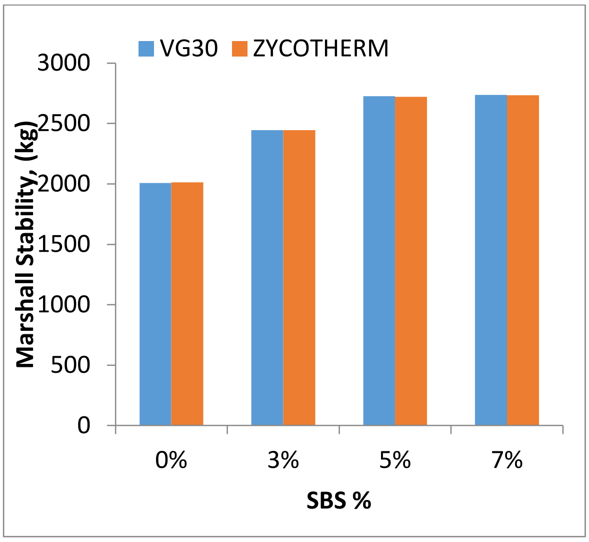

Figure 17: Effect of SBS% on Marshall Stability for Riverbed Aggregate

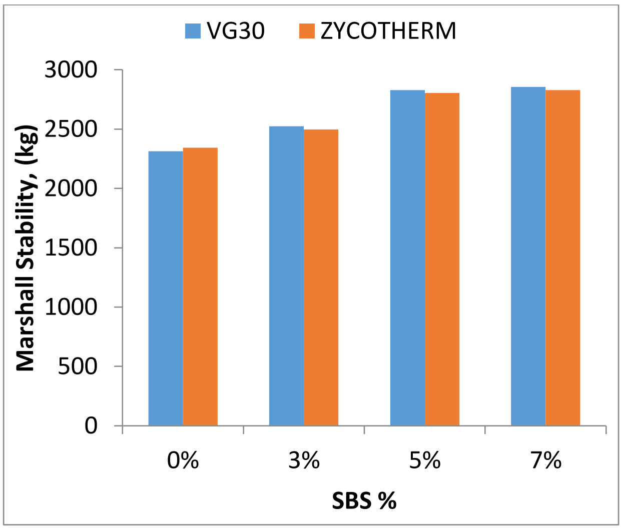

Figure 18: Effect of SBS% on Marshall Stability for Limestone aggregate

It was seen that limestone aggregate has much more Marshall Stability value as compared to riverbed aggregates at all binder type. Limestone aggregate has more flow value as compared to riverbed aggregate. This increase in stability value for limestone aggregate is due to the difference in physical and mineralogical properties of limestone aggregate and riverbed aggregate. Bitumen normally tends to bond better to some aggregates, such as limestone, than to siliceous ones such as gravel [41, 42].The difference in stability value for both the aggregate is shown in Figure 19.

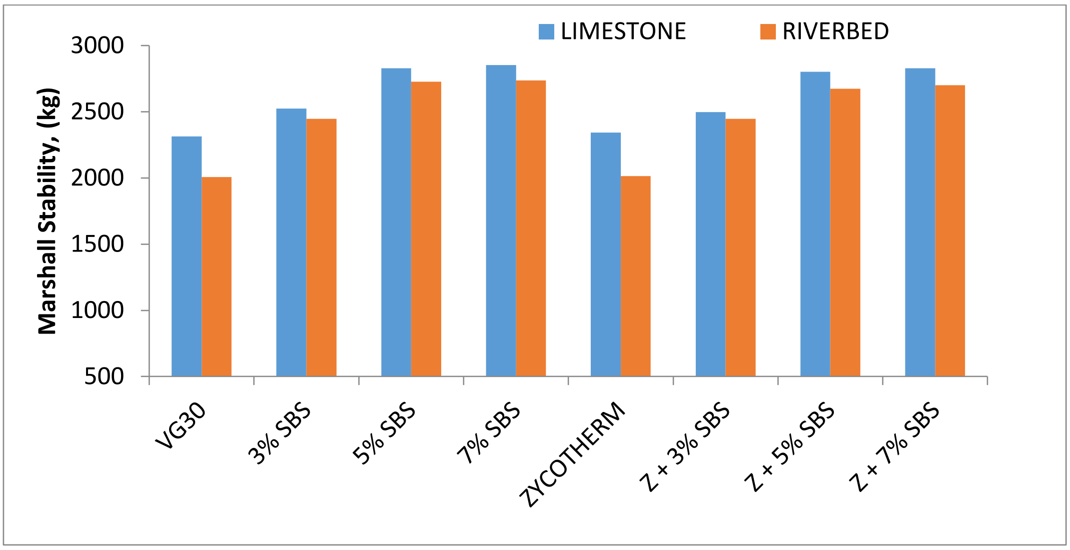

Figure19: Effect of Aggregate on Marshall Stability for different binder

(ii) Indirect Tensile Strength Test

Indirect tensile strength is used in this study to evaluate the tensile properties of bituminous mixes prepared with different type of binder i.e. VG30, VG30 + 3% SBS, VG30 + 5% SBS, VG30 + 7% SBS, VG30 + Zycotherm, VG30 + 3% SBS+ Zycotherm, VG30 + 5% SBS+ Zycotherm, VG30 + 7% SBS+ Zycotherm. ITS test is conducted on both type aggregates i.e. Riverbed and Limestone. Results of ITS test were evaluated and compared with different binder type and different aggregates.

Table 5: Effect of different binder on ITS value

Binder	Limestone	Riverbed
	ITS (kPa)	ITS (kPa)
VG30	782	733
VG30 + 3% SBS	821	782
VG30 + 5% SBS	928	879
VG30 + 7% SBS	860	801
VG30 + Zycotherm	782	733
VG30 + 3% SBS + Z	821	782
VG30 + 5% SBS + Z	928	879
VG30 + 7% SBS + Z	860	801

It was found that SBS modified bitumen has more tensile strength than neat VG30 binder at all concentration of SBS percentage. Maximum ITS value was achieved at 5% SBS concentration and with increase in SBS percentage from 5 to 7% there was a decrease in ITS value. Zycotherm additive has no effect on ITS value for neat VG30 binder and SBS modified binder. It was found that limestone aggregate has more ITS value than riverbed aggregate for same aggregate gradation.

V. CONCLUSION

In this study various conventional and rheological tests were conducted on different binders and their effect on the mechanical properties of mixes prepared with limestone and river bed aggregate were evaluated. Based on the results from these tests following conclusion were made:

- Conventional test on different binders shows that SBS polymer tends to decrease penetration value and increase the softening point of bituminous binder, however the effect of SBS polymer begin to stabilize when SBS dosage was increased to 7%. 5% SBS modification is selected to be the optimum dosage in bitumen. Zycotherm additive does not show any significant increase in performance of binder as per conventional test.
- SBS polymer has increased the viscosity of bitumen and with increase in SBS percentage in bitumen there was increase in viscosity. Zycotherm additive tends to decrease the viscosity of all binder at high temperature. Decrease in viscosity of binder will help reduce compaction temperature of mixes by providing proper coating of binder on aggregate at lower temperature.
- Rheological test on SBS bitumen shows that SBS modification increases the rutting resistance parameter. With increase in SBS dosage in bitumen there was an increase in rutting resistance performance of bituminous binder. Zycotherm showed no significant affect on rutting resistance of normal bitumen and SBS modified bitumen.

- Optimum binder content for limestone aggregate was more as compared to riverbed aggregate due to difference in absorption capacity of aggregate. Using Limestone aggregate in bituminous mix resulted 15% increase in stability value as compared to riverbed aggregate. Flow value for limestone aggregate was more in case of limestone aggregate which signifies more deformation at load application in case of limestone aggregate.
- SBS polymer showed an increase in performance of bituminous mixes at all polymer content. However with increase in SBS percentage from 5 to 7% there was not much significant increase in stability value for both the aggregate used in this study.
- It was found that SBS modified bitumen has more tensile strength than neat VG30 binder at all concentration of SBS percentage. Maximum ITS value was achieved at 5% SBS concentration and with increase in SBS percentage from 5 to 7% there was a decrease in ITS value.
- Zycotherm additive has not shown any effect on the mechanical properties of bituminous mixes.

Recommendations

5% SBS modification in bitumen showed better performance in rutting resistance potential of bituminous mixes. However the viscosity of 5% SBS modified bitumen is more which will require more mixing temperature to properly coat the aggregate with binder, so Zycotherm additive can be used which will reduce the viscosity of SBS binder at high temperature. Addition of Zycotherm will result in lower mixing and compaction temperature without compromising the performance of bituminous mix.

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