International Journal of Applied Science and Engineering
2019. 16, 1: 1-13

Effect of Aggregate Type and Polymer Modification on the Performance of Bituminous Concrete Mixes

Harpreet Singh[a], Tanuj Chopra[b*], Sambhav Jain[c], Amandeep Kaur[d] and Sahil Kamotra[e]

[a]*Ministry of Road Transport & Highway-IIT Roorkee, India*
[b]*Civil Engineering Department,Thapar University, Patiala, India*
[c]*Amity University, Haryana, India*
[d]*Military Engineering Service, Shimla, India*
[e]*Himalayan Institute of Engineering & Technology, India*

Abstract: In this study, bitumen was modified with different percentages of SBS polymer and Zycotherm additive. Effect of SBS modification and Zycotherm additive in the bituminous concrete mixture was evaluated by Marshall Stability test and Indirect tensile strength test. Comparisons were made between different bituminous mixtures prepared by base bitumen, SBS modified bitumen and Zycotherm modified bitumen. SBS dosage in bitumen was kept 3, 5 and 7%. The Zycotherm additive dosage was kept same for all mixes i.e. 0.1%. Two types of aggregate i.e. limestone and riverbed were used for this study. Marshall Stability for 5% SBS modification has shown better results. Indirect tensile strength for the mixture containing 5% SBS has shown maximum tensile strength as compared to other mixes. Limestone aggregate has shown maximum stability and maximum tensile strength as compared to riverbed aggregate. Zycotherm additive has shown no effect on mechanical properties of bituminous concrete mixtures. It was finally concluded that best results were obtained by using 5% SBS in bitumen and limestone aggregate in bituminous concrete mixtures.

Keywords: VG30 bitumen; SBS modified bitumen; Zycotherm; limestone aggregate; riverbed aggregate; Marshall Stability; ITS.

1. Introduction

Bituminous concrete surface mainly consist of aggregate, binder and filler material. In India, about 95% of roads are flexible roads which consist approximately 93-95% of aggregate and 5- 7% of binder material. Until now these conventional materials were performing satisfactory. However, increase in traffic level, larger and heavier trucks with new axle designs and high tyre pressures requires construction of durable roads with higher quality standards. Adverse climatic condition also causes the bituminous material to fail and with repeated traffic loading, there is permanent deformation of pavement surface [1, 2, 3]. To overcome the failure associated with bituminous mixes, better mixes with durable material is required, so as to achieve better performance from the pavement. This can be achieved by two methods:

i. By improving the properties of conventional bitumen and
ii. By selection of better aggregate for the bituminous mix.

Various researches have shown that introduction of polymer in bitumen offers better solution to overcome the deficiencies in properties of conventional bitumen and improves the performance of the pavement [4, 5, 6]. Addition of polymer in bitumen can improve the performance of pavement by increasing its resistance towards a wide range of temperature

Corresponding author; e-mail: tchopra@thapar.edu
doi: 10.6703/IJASE.201906_16(1).001

Received 27 July 2017
Revised 11 February 2019
Accepted 17 May 2019

variation [7, 8, 9]. Polymer modified bitumen reduces rutting and fatigue failure in the pavement which reduces the maintenance required for pavement structure [10].

In bituminous mix, maximum traffic load imposed on pavement is resisted by aggregates. Aggregate provides a strong material to resist deformation caused by repeated load application. Properties and characteristic of aggregates plays an important role in influencing bituminous mix properties [11]. Aggregate gradation, shape, texture, and chemical composition play an important role in influencing bituminous mix properties [12, 13, 14]. Generally angular and rough textured aggregate provide more shear strength than the rounded aggregate [15]. Therefore, knowledge of aggregate properties is crucial in designing a high-quality pavement [16].

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 performance and butadiene part makes bitumen more rubbery which increases the thermal cracking resistance of modified bitumen [17]. SBS polymer enhances the strength and elastic properties of asphalt binders under wide range of temperature variation; it becomes one of the most widely used polymer modifiers for asphalt binders [18, 19, 5]. However, SBS modified asphalt also has disadvantages such as higher viscosity which requires elevated temperature for pumping and mixing on site [20]. Therefore, various warm-mix-additives are also used in bituminous mixes to provide better workability at low temperatures [21, 22].WMA reduces the mixing and compaction temperature of bituminous mixes by reducing the binder's viscosity, which will further decrease the energy required to makehot mix asphalt, reduce odour emission from plants, and improve the working conditions at plants and paving sites [20, 21]. In this study Zycotherm additive is used as warm mix additive in bituminous mix. Zycotherm additive is an odourless nano organo-silane additive for bituminous mixes which increases moisture resistance and decreases mixing temperature for bituminous mixes [23, 24, 25, 26].

To overcome the failure associated with flexible pavement, performance of different bituminous mixes prepared using limestone and riverbed aggregate are evaluated in this study. The objective is to study the effect of different dosages of SBS polymer and Zycotherm additive on mechanical properties of bituminous concrete mixes prepared using two different aggregates. To evaluate the mechanical property of bituminous mixes, Marshall Stability and Indirect tensile strength test is performed on bituminous mixes.

2. Materials

VG 30 bitumen is used as a base binder for all bituminous mixes. Zycotherm additive percentage is kept same for all mixtures as recommended by manufacturer i.e. 0.1% by weight of the binder. Properties of Zycotherm additive is shown in Table 1. Different percentages of SBS are added in base binder i.e. 3, 5 and 7% by weight of the base binder. Properties of SBS polymer are given in Table 2. SBS modified bitumen is prepared using a laboratory blender capable of maintaining constant temperature and constant blending speed for long duration. Base bitumen is heated to a temperature of 160 ˚C and then SBS is added slowly. Mixing was done at a temperature of 170- 180 ˚C for 2 hrs at 4000 rpm. Zycotherm additive is mixed at a temperature of 120 ˚C for 5 min at 100 rpm.

Table 1. Properties of Zycotherm additive.

Property	**Results**
Specific gravity	0.97 g/cm^3
Viscosity	1 – 5 pas
Flash point	>80 ˚C
Colour	Pale yellow
Physical state	Liquid
Solubility	Soluble in water

Table 2. Properties of SBS polymer.

Property	**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

To evaluate the effect of aggregate on performance of bituminous mixes, two types of aggregates are used in this study i.e. limestone aggregate and riverbed aggregate. Aggregate gradation was chosen as per MoRT&H specification [26] for the bituminous concrete layer of thickness 30-45 mm with nominal aggregate size of 13 mm. Midpoint gradation was selected for preparation of bituminous mix. Limestone aggregate was procured from Shillai (Himachal Pradesh) and riverbed aggregates were procured from Paonta Sahib (Himachal Pradesh). The difference in physical properties of aggregates was determined by performing various tests on aggregates. Aggregate physical property is given in Table 4. Both aggregates used in this study satisfied the minimum criteria given in MoRT&H Specification [26].

Table 3. Adopted aggregate gradation.

Layer thickness	**30-45 mm**	
IS Sieve size, mm	**Percentage passing by weight**	
	Specified gradation limit	**Adopted gradation**
19	100	100
13.2	79-100	89.5
9.5	70-88	79
4.75	53-71	62
2.36	42-58	50
1.18	34-48	41
0.6	26-38	32
0.3	18-28	23
0.15	12-20	16
0.075	4-10	7

Table 4. 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 [27]	-
Specific gravity coarse aggregate	2.62	2.69	ASTM C127 [28]	-
Impact value (%)	22.33	19.66	IS:2386 Part 4 [29]	Max 24%
Crushing value (%)	22	20		
Abrasion value (%)	23	19	ASTM C131 [30]	Max 30%
Water absorption (%)	0.91	0.50	ASTM C127 [28]	Max 2%

3. Experimental

Marshall Method of mix design was used to determine the optimum binder content for VG30 bitumen and both aggregates conforming to ASTM D6927 [32] specifications. Binder content of 5 – 7% by total weight of mix is allowed as per MoRT&H specification [27] for the bituminous concrete layer. In this study binder content was varied from 4.5 – 6.5% with increment of 0.5% i.e. 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%. Three samples were prepared for single binder content. Volumetric analysis and stability-flow analysis was done for all the samples. The average value for three samples at single binder content is measured and recorded. Recorded results were evaluated to calculate the optimum binder content for both aggregates i.e. limestone aggregate and riverbed aggregate.

For the preparation of Marshall Specimen, aggregate and binder mixing temperature were kept 160-170 ˚C for all specimens. The sample was compacted using a rammer by applying 75 blows on either side of the specimen. Marshall Stability and flow value are recorded for all specimens. ITS test is also performed on Marshall Specimens to evaluate the tensile strength of bituminous mixtures prepared with different binder. ITS test is performed as per standard specification conforming to ASTM D6931-17 [33].

4. Results and discussion

4.1 Effect of modification on conventional properties of bitumen

With an increase in SBS percentage in bitumen, decrease in penetration value and increase in softening point of bitumen was observed. This is due to the elastomeric phase of the SBS copolymer, which absorbs the maltenes from the bitumen and swells up to nine times its initial volume [34]. This swelling causes the SBS rubber phase to dominate the asphalt phase, resultingin a new modified asphalt binder possessing the principal characteristics of rubber [17]. For pure VG30 binder addition of Zycotherm decreased the penetration value and slightly increased the softening point. A slight increase in penetration value was observed in case of addition of Zycotherm to SBS modified bitumen. There is no significant increase in softening point for Zycotherm addition in SBS modified bitumen. Effect of modification on penetration value is shown in Figure 1 and effect of the modification on softening point is shown in Figure 2.

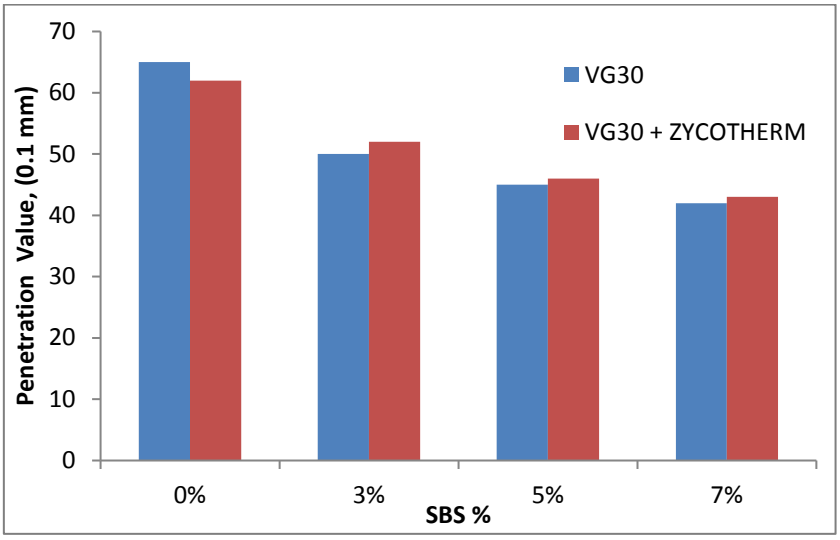

Figure 1. Effect of modification on penetration value.

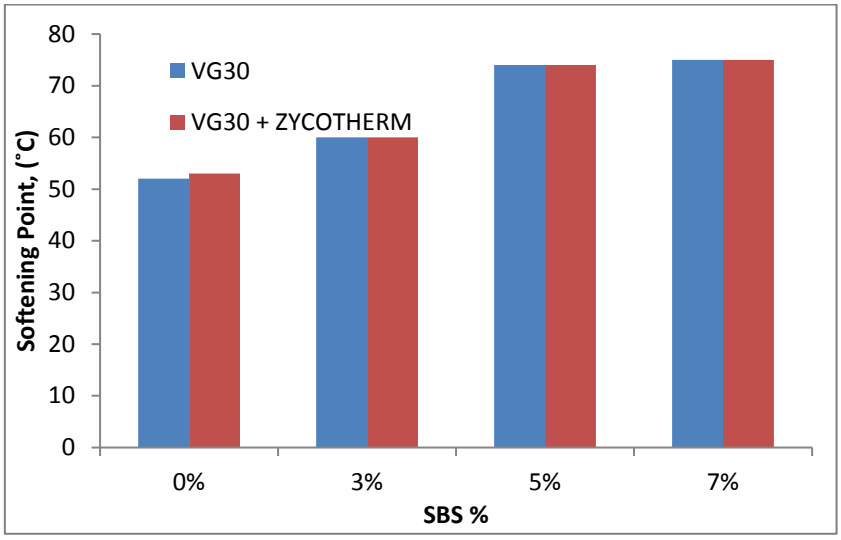

Figure 2. Effect of modification of bitumen on softening point.

4.2 Marshall Method of Mix Design

As per Marshall Method of mix design, different graphs were plotted for both aggregates [Figure 3 – Figure 7]. 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%. The difference in optimum binder content is due to the difference in absorption capacity of aggregate. Studies has also shown that limestone aggregate tends to have higher Optimum Binder content [34].

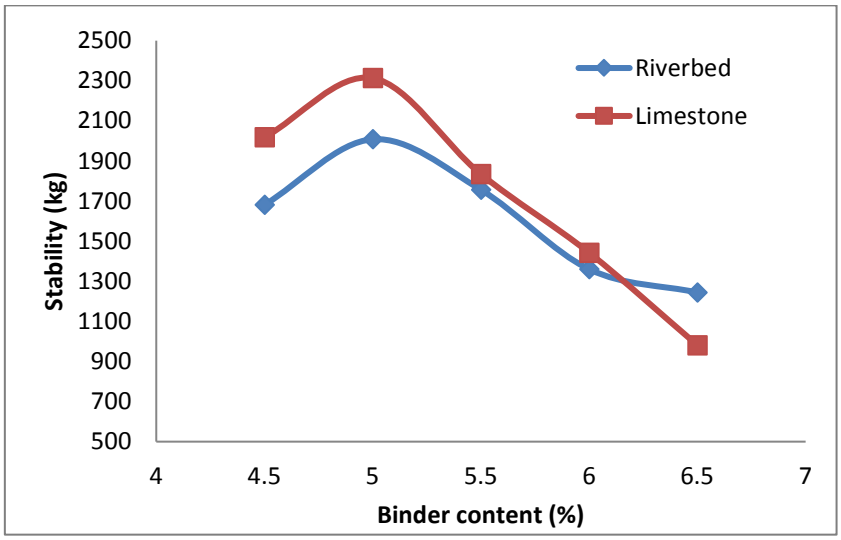

Figure 3. Marshall Stability Vs binder content.

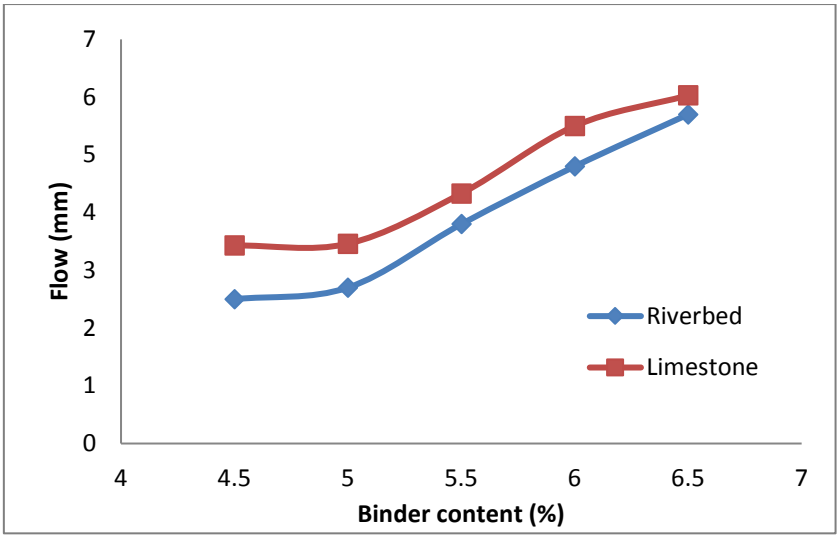

Figure 4. Flow Vs binder content.

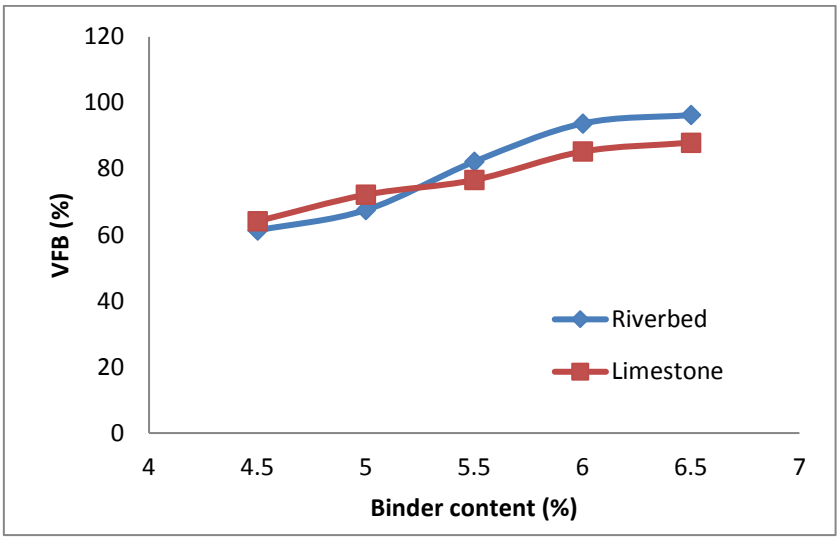

Figure 5. VFB (%) Vs binder content.

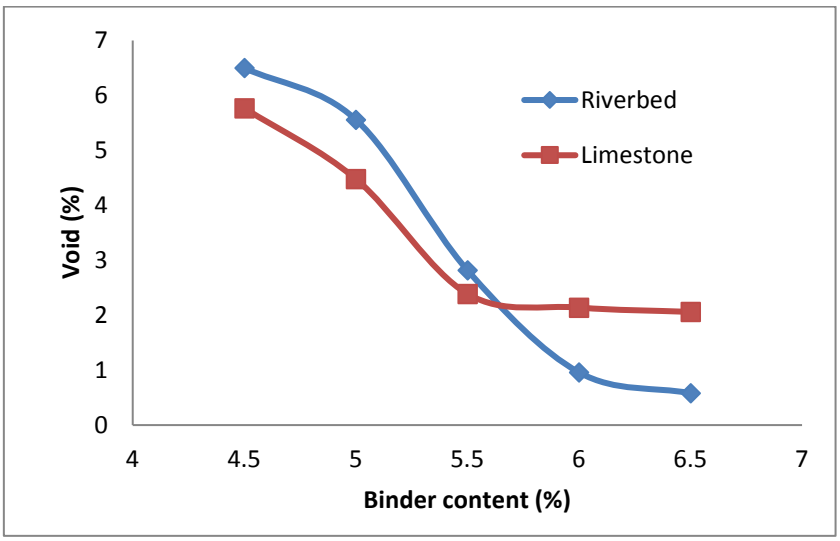

Figure 6. Void (%) Vs binder content.

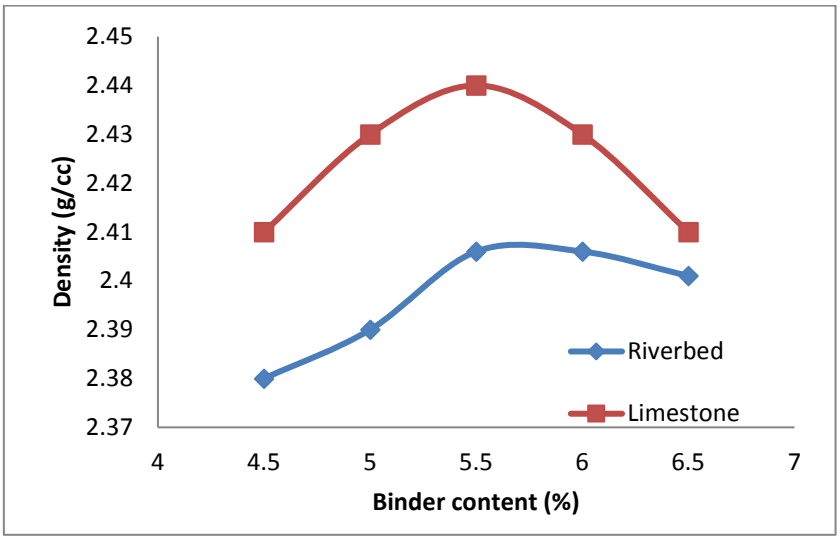

Figure 7. Density Vs binder content.

It was seen that with an 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 an 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 8 and Figure 9 for riverbed aggregate and limestone aggregate respectively.

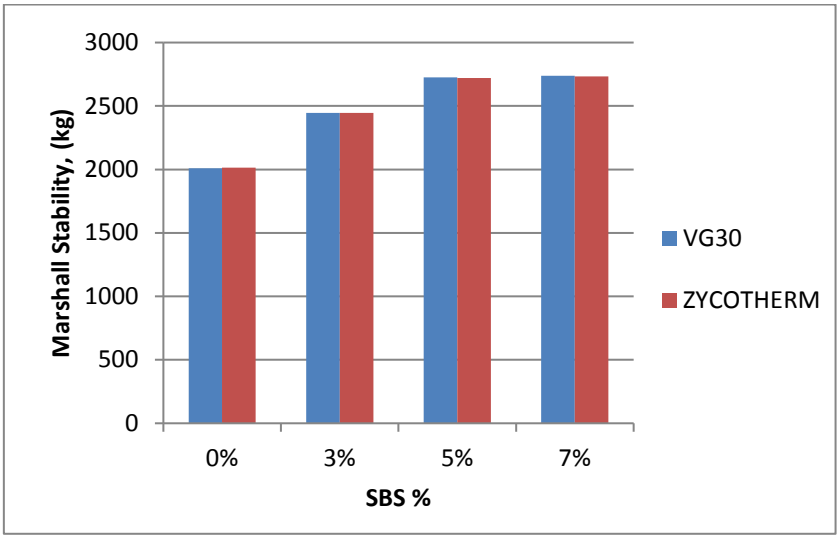

Figure 8. Effect of SBS% on Marshall Stability for Riverbed Aggregate.

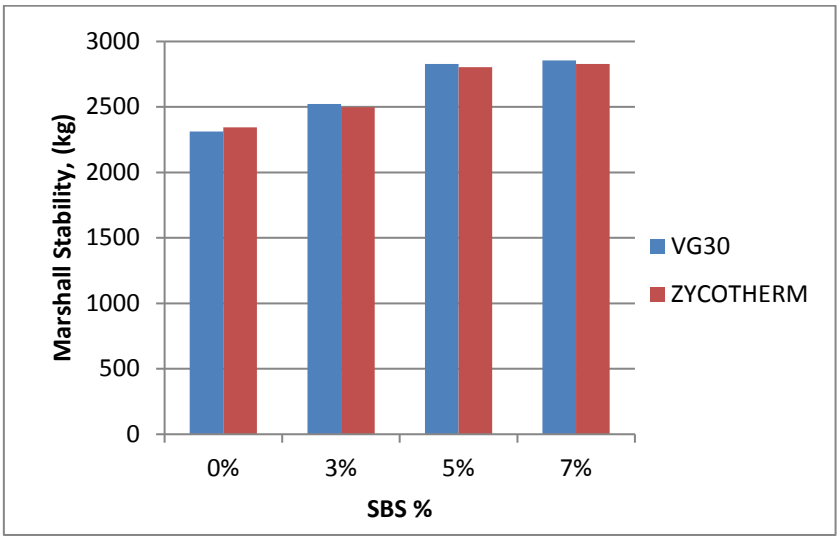

Figure 9. Effect of SBS% on Marshall Stability for Limestone aggregate.

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 [34, 35].The difference in stability value for both the aggregate is shown in Figure 10.

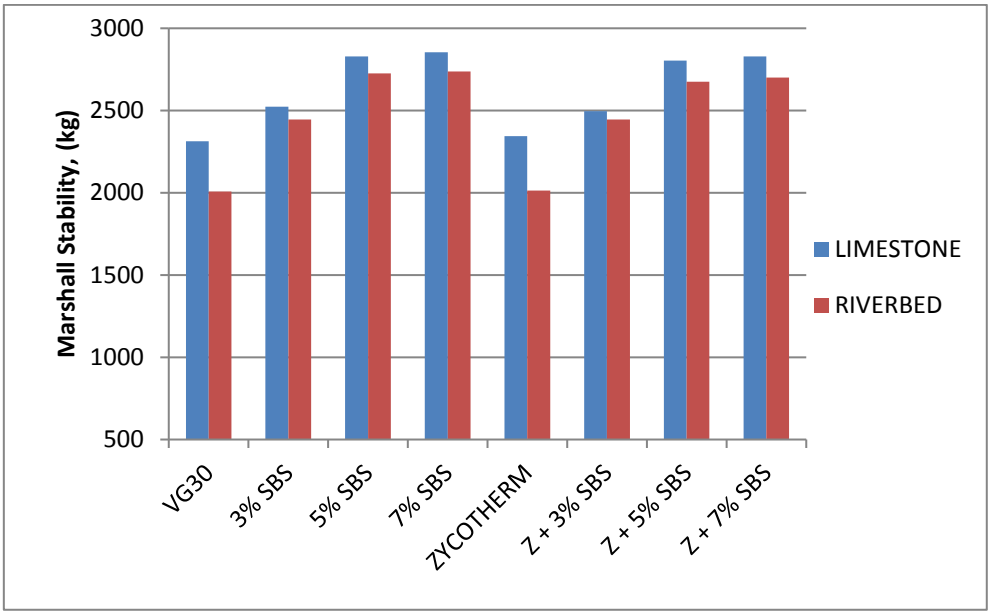

Figure 10. Effect of Aggregate on Marshall Stability for different binder.

4.3 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. ITS test was performed as perstandard specification conforming to ASTM D6931-17 [32].

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 an 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.

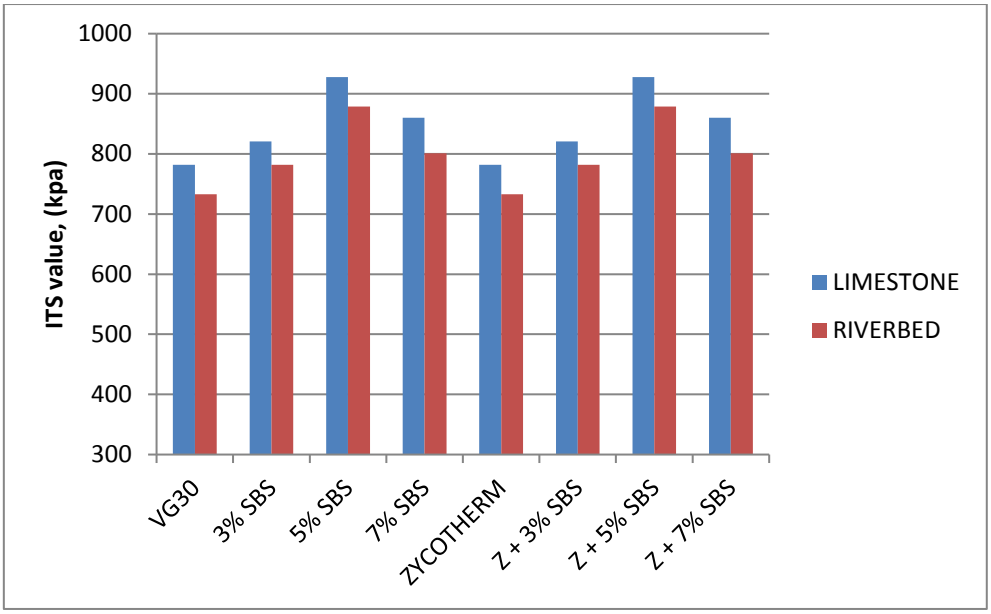

Figure 11. Effect of Aggregate on ITS value for different binder.

5. Conclusion

In this study, various tests were conducted on the mechanical properties of mixes prepared with different binders and different aggregate. Based on the results of these tests following conclusion were made:

i. Conventional test on different binders shows that SBS polymer modification in bitumen decreases penetration value and increases softening point. Zycotherm additive decreases the penetration value for neat VG30 bitumen. Zycotherm additive has the negligible effect on the conventional properties of SBS modified bitumen.

ii. Optimum binder content for limestone aggregate was more as compared to riverbed aggregate due to the difference in absorption capacity of aggregate. Using Limestone aggregate in bituminous mix resulted in 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.

iii. SBS polymer showed an increase in performance of bituminous mixes at all polymer content. However, with an 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.
iv. 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 an increase in SBS percentage from 5 to 7% there was a decrease in ITS value.
v. Zycotherm additive has not shown any effect on the mechanical properties of bituminous mixes.

References

[1] Bodin, D., Chupin, O. and Denneman, E. 2016 *Effect of Temperature and Traffic Speed on the Asphalt Moduli for Fatigue Cracking and Pavement Structural Design Considerations* 8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements, vol, 13, Springer, Dordrecht.

[2] Mandula, J. and Olexa, T. 2017 *High temperature impact on fatigue life of asphalt mixture in Slovakia,* IOP Conference Series: Materials Science and Engineering, 236, doi:10.1088/1757-899X/236/1/012023.

[3] Steiner, D., Hofko, B., Dimitrov, M. and Blab, R. 2016. *Impact of Loading Rate and Temperature on Tensile Strength of Asphalt Mixtures at Low Temperatures* 8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements, 13, doi 10.1007/978-94-024-0867-6-10.

[4] Singh, M., Kumar, P. and Anupam, A. K. 2015. *Effect of type of aggregate on perma nent deformation of bituminous concrete mixes*, Road Materials and Pavement Desig n, doi: 10.1080/14680629.2015.1091374.

[5] Kök, B. V. and Çolak, H. 2011 *Laboratory comparison of the crumb-rubber and SBS modified bitumen and hot mix asphalt*, Construction and Building Materials, 25: 3204–3212.

[6] Airey, G. D. 2003. *Rheological properties of styrene butadiene styrene polymer modified road bitumen, Elsevier*, Fuel, 82: 1709–1719.

[7] Garcıa, M. M., Partal, P., Navarro, F. J. and Gallegos, C. 2006. *Effect of waste polymer addition on the rheology of modified bitumen*, Fuel, 85: 936–943.

[8] Munera, J. C. and Ossa, E. A. 2014. *Polymer Modified Bitumen: Optimization and Selection,* Materials and Design, Doi: 10.1016/2014.05.009.

[9] Keymanesh, M. R., Ziari, H., Damyar, B. and Shahriari, N. 2017. *Effect of waste EVA (Ethylene Vinyl Acetate) and Waste CR(Crumb Rubber) on characteristics of Bitumen,* Petroleum Science and Technology, doi: 10.1080/10916466.2017.1384840.

[10] Singh, M., Kumar, P. and Maurya, M. R. 2013. *Effect of aggregate types on the performance of neat and EVA-modified asphalt mixtures*, International Journal of Pavement Engineering, 15, 2: 163-173, doi: 10.1080/10298436.2013.812211.

[11] Apeagyei, A. K., Grenfell, J. R. A. and Airey, G. D. 2015. *Influence of aggregate ab sorption and diffusion properties on moisture damage in asphalt mixtures*, Road Mat erials and Pavement Design, 16, 1: 404-422, doi: 10.1080/14680629.2015.1030827.

[12] Bagampadde, U., Isacsson, U. and Kiggundu, B. M. 2005. *Influence of aggregate chemical and mineralogical composition on stripping in bituminous mixtures,* International Journal of Pavement Engineering, 6, 4: 229-239.

[13] Al, S. A. S. 1995. *Effect of Aggregate Properties on Asphalt Concrete Mixes*, JKAU: Eng. Sci., vol, 7: 93-110.

[14] Singh, D., Zaman, M. and Commuri, S. 2013. *Effect of production and sample preparation methods on aggregate shape parameters*, International Journal of Pavement Engineering, 14, 2: 154-175, doi: 10.1080/10298436.2011.635792

[15] Huang, B., Chen, X. W., Shu, X., Masad, E. and Mahmoud, E. 2009. *Effects of coarse aggregate angularity and asphalt binder on laboratory-measured permanent deformation properties of HMA*, International Journal of Pavement Engineering, 10, 1: 19-28, doi: 10.1080/10298430802068915.

[16] Golalipour, A., Jamshidi, E., Niazi, Y., Afsharikia, Z. and Khadem, M. 2012. *Effect of aggregate gradation on rutting of asphalt pavements. Procedia*, Social and Behavioral Sciences, 53: 440–449. doi:10.1016/j.sbspro.2012.09.895.

[17] Ahmedzade, P., Tigdemir, M. and Kalyoncuoglu, S. F. 2007. *Laboratory investigation of the properties of asphalt concrete mixture modified with TOP-SBS, Elsevier*, Construction and building material, 21: 626-633.

[18] Ahmedzade, P. 2013. *The investigation and comparison effects of SBS and SBS with new reactive terpolymer on the rheological properties of bitumen*, Elsevier, Construction and building materials, 38: 285-291.

[19] Kumar, K., Singh, A., Maity, S. K., Srivastava, M., Sahai, M., Singh, R. K. and Garg, M. O. 2016. *Rheological studies of performance grade bitumens prepared by blending elastomeric SBS (styrene butadiene styrene) co-polymer in base bitumens*, Journal of Industrial and Engineering Chemistry, doi: 10.1016.

[20] Shang, L., Wang, S., Zhang, Y. and Zhang, Y. 2011. *Pyrolyzed wax from recycled cross-linked polyethylene as warm mix asphalt (WMA) additive for SBS modified asphalt*, Construction and Building Materials, 25: 886–891.

[21] Baha, V. K., Yilmaz, M. and Akpolat, M. 2014. *Evaluation of the conventional and rheological properties of SBS + Sasobit modified binder*, Elsevier, Construction and building materials, 63: 174-179.

[22] Bheemashankar and Amarnath, M. S. *laboratory studies on effect of Zycotherm additive on bituminous concrete mix*.

[23] Ziari, H., Mirzababae, P. and Babagoli, R. 2016. *Properties of bituminous mixtures modified with a nano - organosilane additive*, Taylor & Francis, Petroleum Science and technology, Vol, 34: 386-393.

[24] Ziari, H., Naghavi, M and Imaninasab, R. 2016. *Performance evaluation of rubberised asphalt mixes containing WMA additives*, Taylor & Francis, International Journal of pavement engineering, ISSN: 1029-8436.

[25] Harpreet, S., Tanuj, C., Neena, G. and Maninder, S. *Effect of Zycotherm Additive on Performance of Neat Bitumen and Bituminous Concrete.*

[26] Mirzababaei, P. 2016. *Effect of Zycotherm on moisture susceptibility of Warm mix asphalt mixtures prepared with different aggregate types and gradation*, Elsevier, Construction and building material, 116: 403-412.

[27] Ministry of Road Transport and Highway, *Specification for Roads and bridge work, 5th revision*, Indian Road Congress.

[28] *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*, ASTM, C128: 15.

[29] *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate*, ASTM, C127: 15.

[30] *Methods of test for aggregates for concrete part 4, Mechanical properties*, IS, 2386: 4.

[31] *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*, ASTM, C131, C131M: 14.

[32] *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*, ASTM, D6927: 15.

[33] *Standard Test Method for Indirect Tensile (IDT) Strength of Asphalt Mixtures*, ASTM, D6931: 17.

[34] Isacsson, U., Lu, X. 1995. *Testing and appraisal of polymer modified road bitumens: state of the art. Mater Struct*, 28:139–59.

[35] Behiry, A. E. A. E. 2015. *Optimisation of hot mix asphalt performance based on agg regate selection*, International Journal of Pavement Engineering, doi: 10.1080/10298 436.2015.1043634.

[36] Kanitpong, K., Charoentham, N. and Likitlersuang, S. 2011. *Investigation of effect of gradation and aggregate type to moisture damage of warm mix asphalt modified with Sasobit*, Taylor & Francis, International Journal of pavement engineering, Vol, 13, 5: 451-458.