EFFECT OF ADDITION OF SBS POLYMER AND ZYCOTHERM ON BITUMEN AND BITUMINOUS CONCRETE MIX PREPARED WITH RIVERBED & LIMESTONE AGGREGATE

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DECLARATION

I, Harpreet Singh, hereby declare that this thesis entitled **"Effect of addition of SBS polymer and Zycotherm on bitumen and bituminous concrete mix prepared with riverbed & limestone aggregate"** is an authentic record of my study carried out as requirements for the award of degree of **Master of Engineering** in **Civil Infrastructure Engineering** in the Civil Engineering Department, Thapar University, Patiala, under the supervision of **Mrs. Neena Garg,** Assistant Professor and **Mr. Tanuj Chopra,** Assistant Professor, Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2017. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

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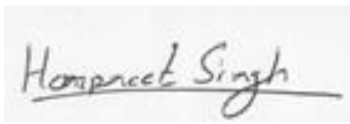

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“I am thankful to those who have said no to me, it’s because of them I did it myself” ***- Albert Einstein***

ABSTRACT

In this study, the bitumen was doped with various percentages of SBS polymer and Zycotherm additive. Comparison was made between Base bitumen, SBS modified bitumen and Zycotherm modified bitumen. The dosages of SBS polymer were taken as 3, 5 and 7%, which were added to the optimum binder content and the Marshall Stability and the flow of the mixes were determined. Zycotherm additive dosage was kept 0.1% for all mixes. The effects of SBS content and Zycotherm additive on bitumen were examined by using Marshall Stability, Indirect Tensile Strength (ITS) test and rheological test. Marshall Stability of the SBS modified bitumen at 5% dosage of SBS polymer was found to be optimum as compared to 3% and 7% polymer content. The Indirect Tensile Strength of SBS modified bitumen was higher at 5% SBS content as compared to 3% and 7%.

Zycotherm additive has not shown any significant effect on properties of mix. It observed that best results were obtained by using 5% of SBS polymer and Zycotherm additive has no effect on mechanical properties of mix. Rheological test on different binders has shown that Zycotherm additive has very less affect on rutting resistance of modified bitumen.

5% SBS modification in bitumen showed better performance in rutting resistance potential of bituminous mixes. However the viscosity of SBS modified bitumen is higher 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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CHAPTER 1

INTRODUCTION

1.1 General

In India majority of the roads are flexible pavements. Flexible pavements generally contain mixture of bitumen as a binder and mineral aggregate. If designed and constructed properly these pavements can perform better but performance of bituminous mixes is very limited and they cannot perform better in each and every condition. India is a developing country and for its development efficient road network is necessary. Traffic intensity is increasing every year and with increasing traffic intensity there is a need of quality roads which can perform better in any condition and can withstand heavy traffic loads without any failure. Conventional bituminous mixes are not able to withstand the adverse climatic conditions and heavy loads imposed upon it. There is a need of better raw material for bituminous mixes which can perform better in adverse conditions. Considering these facts many researchers have been carried out to get best performance from bituminous mixes. Many researchers have indicated better performance of bituminous mixes with addition of polymer in bitumen. Type of aggregate also plays a vital role in influencing the performance of bituminous layer. Additive which is to be used for modification of bitumen should satisfy strength requirements and economical aspects.

1.2 Bituminous Concrete

Bituminous concrete layer of a flexible pavement is a thin top most layer of the pavement which is directly in contact with the vehicles. Bituminous concrete layer is generally referred as surface course or wearing course. Thickness of bituminous concrete layer varies from 30 - 70 mm and it consists of crushed aggregate and bituminous binder. Maximum size of aggregate for bituminous concrete layer is 19 mm. Wearing course surface is more prone to failure because this surface is in direct contact with vehicular loads. Type of binder and type of aggregate mainly influence the quality of pavement. Bituminous concrete layer prevents the seepage of moisture to the surface below and provides a smooth surface for quiet riding quality.

Base course surface is below the surface of wearing course which helps in distribution of traffic load. This surface helps in sub surface drainage. Thickness of base course surface varies from 100 to 300 mm as per design requirement. This surface consists of crushed stone, slag and other material. Sometimes binder course layer is provided in between surface course and wearing course layer. Binder course layer thickness varies from 50 to 100 mm thickness. Binder course layer generally consists of crushed aggregate with less bitumen content and this layer does not require quality as high as surface course.

Below base course surface of flexible pavement is sub base course. This layer provides structural support to the pavement and is provided as per design requirement. If the quality of sub grade layer is not good then sub base layer is provided. Subgrade layer is the bottom most layer of a pavement and whole traffic load is imposed on this layer. This layer is properly compacted so as achieve best performance. Typical cross-section of flexible pavement is shown in Figure 1.1.

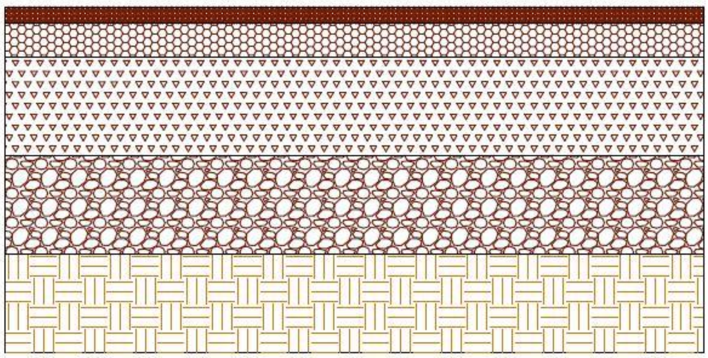


Figure 1.1: Typical cross section of flexible pavement

1.3 Failures in Bituminous Concrete

Failure in pavement can occur generally due to improper construction of pavement or due to inadequate quality of pavement material. Inadequate quality of pavement material makes bituminous concrete layer more prone to rutting and fatigue failure.

1.3.1 Rutting

Rutting is generally referred as permanent deformation causing surface depression on bituminous pavement. When a load is applied on bituminous pavement then there is small deflection in pavement. After the load is removed from the pavement the pavement tends to regain its original position. But after repeated loading on pavement there is a permanent deformation on the pavement due to inadequate binder or due to other structural factors. Rutting can cause due to mix failure or due to subgrade failure. Rutting causes a major problem because these ruts can create bad riding surface for vehicles moreover these ruts will fill up with water when there is rainfall which will cause skidding of vehicles. Rheologically, Rutting due to mix is associated to plastic or viscous behaviour of bitumen at high temperatures. More viscous binder will make the surface more stiff and hence resisting deformation. Thermoplastic polymers are added to bitumen making improvements on rutting resistance and hardening effect of these polymers at high temperatures.

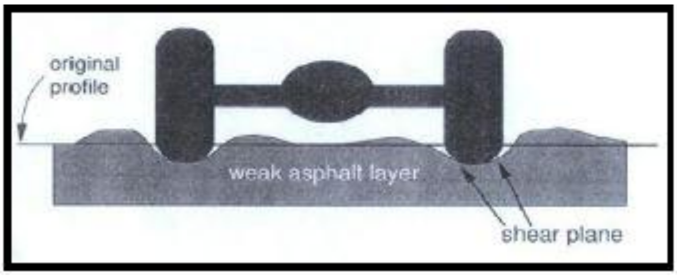


Figure 1.2: Failure due to weak bituminous layer

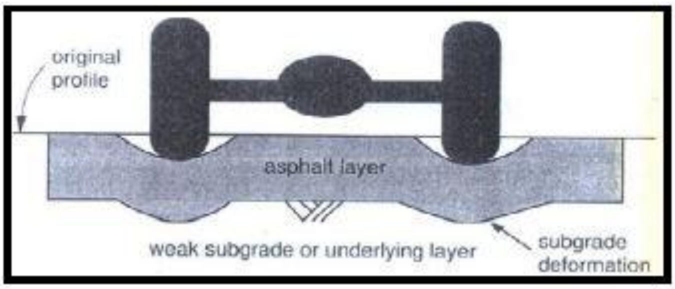


Figure 1.3: Failure due to weak subgrade

1.3.2 Fatigue Failure

Fatigue cracking is characterised by series of interconnected cracks on the surface of bituminous pavement due to fatigue failure of the pavement under repeated traffic load. Cracking generates under the surface of bituminous surface and then reaches on the surface. These cracks allows moisture infiltration and this may further deteriorate to a pothole. Fatigue cracking is generally associated to brittle fracture of bitumen at low temperatures. In order to reduce cracking, bitumen has been modified by elastomeric polymers which increases elasticity of the bitumen and reduce cracking.

1.4 Polymer Modified Bitumen (PMB)

PMB is normal bitumen with added polymer, which gives it extra strength, high cohesiveness and resistance to fatigue, stripping and deformations, making it a favourable material for infrastructure. PMB is specially designed and engineered bitumen grades that are used in making pavement, roads for heavy duty traffic to withstand extreme weather conditions. Properties of normal bitumen are enhanced with addition of polymer in bitumen.

Table 1.1: Different types of polymer used in bitumen

Types of modifiers	Examples
Plastomeric Thermoplastics	Polyethylene (PE), Ethylene Vinyl Acetate(EVA), Ethylene Butyl Acrylate (EBA), Ethylene-Methyl-Acrylate copolymers (EMA)
Elastomeric Thermoplastics	Styrene Isoprene Styrene (SIS), styrene-butadiene-styrene (SBS), Styrene-Butadiene Rubber, and Ethylene Ter polymer (ETP) etc.
Synthetic Rubber Latex	Styrene Butadiene Rubber (SBR) latex and other suitable synthetic rubber
Natural Rubber	Latex or Rubber Powder
Crumb Rubber Or Treated Crumb Rubber	Crumb Rubber, Treated Crumb Rubber

1.4.1 Need of Modified Bitumen

Conventional bituminous binder has various limitations and it does not have capability to withstand high traffic load and extreme weather condition. This causes the pavement to fail, so better binder material is required to fulfil the required performance level. Binder modification aims in making binder material better in terms of rheological characteristic and mechanical characteristic. To fulfil the demand of increasing traffic loads on pavement, better binder is required to provide the desired quality. Pavement should be less susceptible to temperature variations. Addition of polymer in bitumen provides a better alternative to fulfil demands of traffic. Moreover polymer modified bitumen pavement are less prone to failures so it also reduces maintenance cost of pavement and reduces life cycle cost of pavement. Plastomeric polymer makes bitumen more stiff which minimises rutting and elastomeric polymer makes bitumen more elastic and thereby reducing fatigue cracking on pavement surface. Polymer also improves bitumen aggregate bonding and provides better water resistance properties to pavement.

1.4.2 General Requirement of Modifier

- Modifier should be compatible with bitumen.
- It should resist degradation at mixing temperature.
- Modifier should be easily processed by conventional mixing and laying machinery.
- It should be capable of providing coating viscosity at application temperature.
- Should be able to provide homogeneous blend with bitumen
- Modified bitumen should be able to maintain its properties during storage and during application.

1.5 Problem Statement

Bituminous concrete surface generally consists of aggregate, binder material and filler material. In India about 95% of roads are flexible pavement which consists approximately 93-95% of aggregate and 5- 7% of binder material. Until now these conventional materials were performing satisfactory but with an increase in traffic loads on roads the performance of these conventional materials tends to deteriorate. Increase in traffic loads and severe climatic conditions have resulted in demand for a better pavement material. Adverse climatic conditions cause the bituminous material to fail and with an increase in traffic loads there is permanent deformation in pavement surface. To overcome these types of failure, better mixes with more durable material are required so as to achieve improved performance from the pavement. This can be achieved by two methods:

- By improving the properties of conventional bitumen.
- By selection of better aggregate for bituminous mix.

Introduction of polymer in bitumen offers a better provision to overcome the deficiency in properties of conventional binder which may improve the performance of pavement. Addition of polymer in bitumen can improve the performance of pavement by increasing its resistance to a wide range of temperature variation. This can reduce rutting and fatigue failure in pavement and result in lower less maintenance required to pavement. Selection of good quality aggregate can also offer a good solution to overcome failure in pavement. The physical and chemical properties of aggregate largely influence the performance of pavement. So selection of better aggregate material is essential factor to achieve improved performance from bituminous mix.

1.6 Goals and Objective

The primary objective of this study is to determine the effect of polymer and additive on the characteristic of bituminous concrete mixes. Mixes were prepared using SBS polymer and Zycotherm additive. Different percentages of SBS were added in bitumen and its influence was observed on the properties of binder and the mixes prepared with these binders. The following are the major objective of the study:

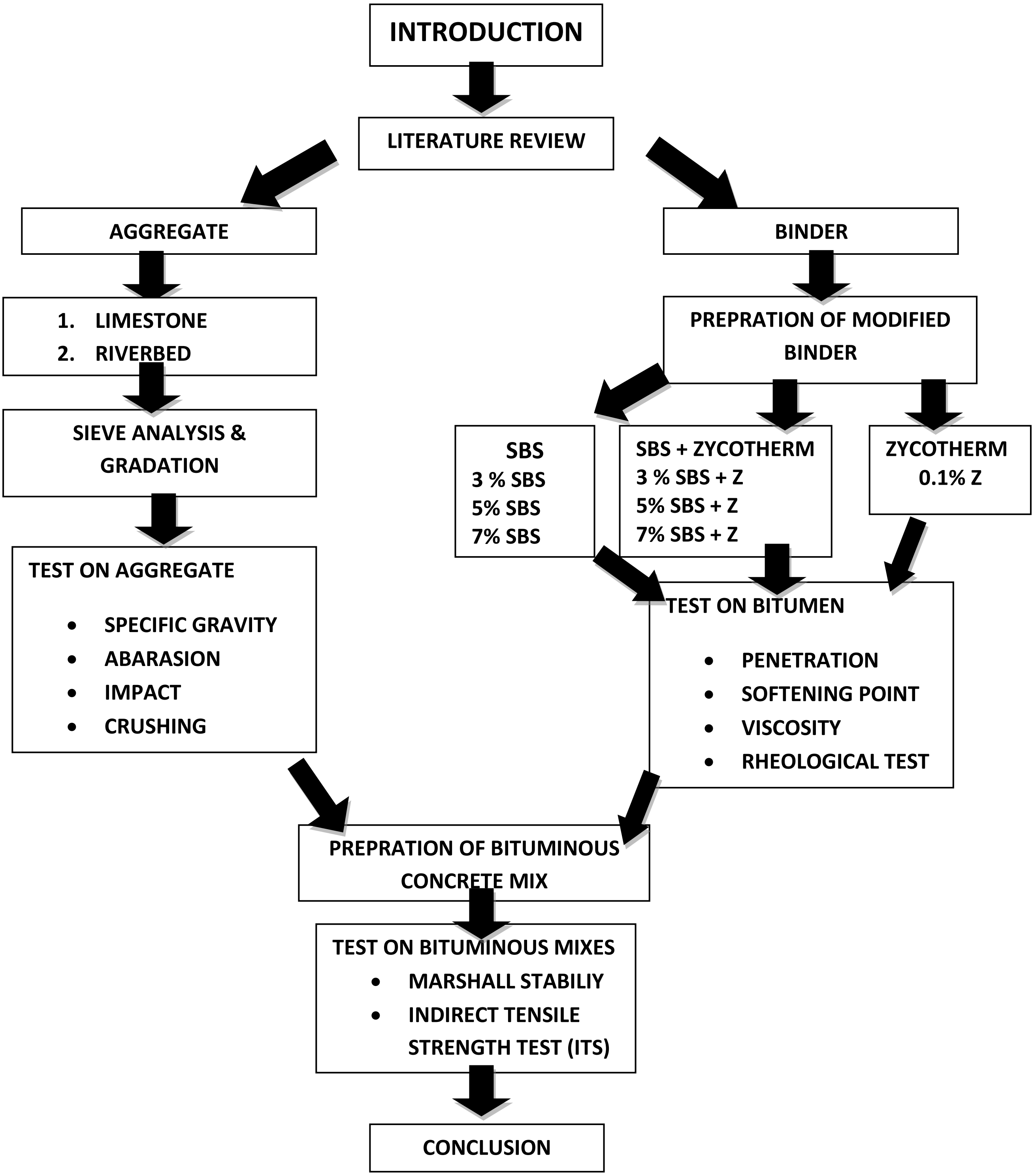
- To determine the physical properties of both aggregates i.e. limestone and riverbed aggregate.
- To determine the effect of different percentages of SBS polymer in bitumen.
- To determine the effect of Zycotherm additive on the properties of normal bitumen and SBS modified bitumen.
- To compare different binders based on their rheological and physical properties.
- To determine the optimum binder content for each of the aggregate for VG30 bitumen.
- To evaluate the effect of different binder and different aggregate on the properties of bituminous mixes using Marshall test and ITS test.

1.7 Organization of Thesis

This research work has been divided into 6 chapters

- Chapter 1 introduces and outlines problem statement and the need of polymer modification in bitumen.
- Chapter 2 presents literature review on use of SBS modification in bitumen and the effect of Zycotherm additive in bitumen. Previous research on the effect of both additives in bitumen on rheological properties and mix properties is studied in this chapter.
- Chapter 3 deals with the material characterization, which includes properties of aggregate used and properties of SBS polymer and Zycotherm additive. Preparation of modified bitumen is described in this chapter. Further the effect of modification of binder on rheological properties is also discussed in this chapter.
- Chapter 4 includes experimental programme and explains the test procedure for bituminous mixes. Marshall Test and ITS test procedure are explained in this chapter.
- Chapter 5 includes results and findings of the various tests performed on bituminous mixes. Discussion of results is also included in this chapter.

- Chapter 6 shows the significant conclusion drawn from different parts of chapter in this thesis. It also gives recommendations for future research studies in this field.



CHAPTER 2

LITERATURE REVIEW

2.1 General

Many researchers have been carried out to study the effect of various additives in bitumen. Effect of different aggregates and different binder material in bituminous mix has been studied in various researches. Addition of polymer in bitumen results in modification of the conventional and rheological properties of bitumen. Similarly effect of aggregates properties can influence the performance of bituminous mix. This chapter gives a literature on the effect of various additives used in bitumen and effect of different aggregate on properties of bituminous mix.

2.2 Styrene Butadiene Styrene (SBS)

SBS is a thermoplastic elastomer consisting of two monomers i.e. styrene and butadiene. Styrene is a hard plastic and this gives SBS its durability. Butadiene is rubber type material and it gives rubber like properties. Styrene part of SBS polymer provide bitumen its hardness which increases its rutting resistance and butadiene part makes bitumen more rubbery which increases thermal cracking resistance of modified bitumen.SBS polymer is the most widely used polymer for modification in bitumen and it has become the most appropriate polymer used for modification in bitumen. The use of SBS in bitumen modification was developed by Shell Chemical Company in 1960. Modification of bitumen with SBS polymer improves the mechanical and rheological properties of bitumen.

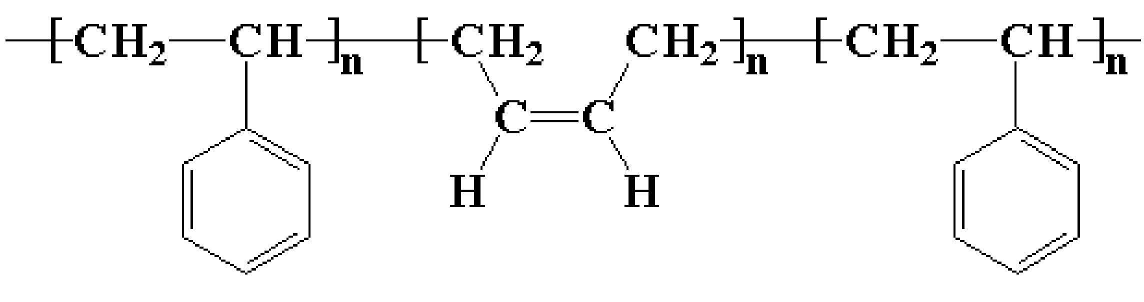


Figure 2.1: Structure of SBS polymer

2.2.1 Effect of SBS on Properties of Bitumen

P. Ahmedzade et al. [2005] investigated benefits of adding Tall oil pitch (TOP), Styrene-butadiene-styrene (SBS) and TOP + SBS to bitumen. Seven different bitumen binder blend were prepared with 3% SBS, 6% SBS and 9% SBS, 8% TOP, 8%TOP + 3% SBS, 8%TOP + 6% SBS and 8%TOP + 9% SBS by total weight of binder. There was an improvement in penetration, softening point and viscosity with addition of modifier in base bitumen. Marshall Stability test and compression test showed best result for the binder containing 8% TOP + 6% SBS than all other mixtures. They also concluded that modification of bitumen with TOP and SBS gives longest fatigue life. Effect of modification with different additive is shown in table 2.1 and table 2.2.

Table 2.1: Effect of modification on properties of bitumen

Binder	Penetration	Softening point(˚C)	Kinematic viscosity
AC-10	84	46	354
AC-10 + 8% TOP	58	53	1080
AC-10 + 8%TOP +3% SBS	67	51.3	1490
AC-10 + 8%TOP +6% SBS	67	68.5	1860
AC-10 + 8% TOP + 9% SBS	44	77.7	3950
AC-10 + 3% SBS	70	50.6	793
AC-10 + 6% SBS	54	71.3	1935
AC-10 + 9% SBS	41	81.2	4585

Table 2.2: Effect of modification on mechanical properties of mix

Property	AC-10	AC-10 + 8% SBS	AC-10 + 8%TOP + 6%SBS	AC-10 + 6% SBS
Compressive strength (25˚C)	3.10	3.70	3.95	3.50
Compressive strength (50˚C)	1.66	1.84	1.96	1.78
Compressive strength(water absorbed)	2.48	2.98	3.64	3.13
Compressive strength (25 freeze- thaw cycles)	2.23	2.79	3.60	2.86

Sengoz Burak and Giray Isikyakar [2007] analysed and compared the effect of adding SBS and EVA polymer in bitumen. SBS concentrations in bitumen were chosen as 2-6% and EVA concentrations in bitumen were chosen as 3-7%. Modified bitumen and base bitumen were subjected to conventional bitumen tests like penetration, softening point, TFOT and storage stability test. Effect of SBS and EVA modified PMB on mechanical properties of bitumen mixture was determined using Marshall Method. With increase in polymer content there is a decrease in penetration value and an increase in softening point. Storage stability test indicates that EVA modified PMB is less affected by storage as compared to SBS modified PMB. The viscosity values are higher in case of EVA modified PMB as compared to SBS modified PMB. SBS modified PMB increased the Marshall Stability value of mix as compared to control mix. In case of EVA modified PMB there is a decrease in Marshall Stability value. Flow value in both the PMB was more than the flow value of control mix but flow value is more in case of SBS modified PMB. Conventional test on PMB and base bitumen demonstrated the improvement in viscosity and improved temperature susceptibility of SBS and EVA modified PMB.

Y. Cong et al. [2008] investigated the compatibility between SBS and bitumen. Their result indicated that SBS modified bitumen has different compatibility in different SBS content at different temperature. SBS content in bitumen less than 4% show good compatibility between bitumen and SBS but SBS content at 8% showed poor compatibility of SBS and bitumen.

Baha vural kok and hakan colak [2011] compared crumb rubber modified bitumen and SBS modified bitumen with HMA. Modified bitumen's were evaluated by rotational viscometer, dynamic shear Rheometer and conventional binder tests. Crumb rubber content ranged from 3% to 15 %. Modified binder was prepared using a laboratory mixer with 1000 rpm at 180 c for 1 hour. SBS modified binder was prepared by varying the SBS content ranging from 2 – 5%. Marshall Stability test is performed to evaluate the mechanical properties of mix. For 4, 6, 8, 10% of CRMB stability value was 17.3, 18.4, 19 and 19.2 kn respectively and for 2, 3, 4, 5% of SBS MB stability value was 17.6, 18.2, 19.3 and 21.3 kn respectively. Complex modulus graph showed similar behaviour trend of SBS and CRM bitumen. SBS showed higher performance than CRMB and to satisfy the same performance level as that of SBS, CRMB must be used at much higher content than SBS. Same value of G* at 3% SBS content was obtained at 6.9% and 7.1% CRMB. 12% CR modification provides same temperature susceptibility as that of 4% SBS modification. Dynamic creep test showed same performance value of 5% SBS modified bitumen at 10% CR modified bitumen.

Overall 8% CR content was determined as the most suitable content and CR is preferred over SBS due to high price of SBS.

Table 2.3: Comparison in properties of SBSMB and CRMB

Binder type	Penetration	Softening point	PI
Base	190	41.5	0.365
2% SBS	128	47.8	0.922
3% SBS	97	53.8	1.576
4% SBS	82	58.2	2.047
5% SBS	64	62.7	2.219
3% CR	116	46.4	0.130
6% CR	100	52.0	1.222
9% CR	81	56.3	1.585
12% CR	62	62.2	2.032
15% CR	53	67.9	2.637

S. Sadeghpour Galooyak et al.[2011] investigated the effect of addition of Nanoclay on rheological properties and storage stability of SBS modified bitumen. Organophilic montmorillonite is used as Nanoclay in this research. OMMT was mixed to SBS modified bitumen using a high shear mixer rotating at 4000 rpm for 30 min at 180˚C. Conventional tests were conducted on all the modifiers. Different SBS/OMMT blends were prepared i.e. 100/0, 100/35, 100/50 and 100/65. There is an increase in softening point of SBS modified bitumen by adding OMMT in blend. Similarly there is a decrease in penetration value by addition of OMMT in blend. Viscosity of base binder increases by addition of SBS and OMMT. Decrease in phase angle, increase in complex modulus and increase in rut factor was observed by addition of SBS and OMMT. Moreover OMMT enhanced the storage stability of the SBS modified bitumen.

Table 2.4: Effect of addition of OMMT in SBS Modified bitumen

Properties	Base bitumen	SBS/OMMT ratio			
		100/0	100/35	100/50	100/65
Penetration (mm)	85	62	58.5	57.5	56.6
Softening point(˚C)	47.2	62.5	66	67.5	70.2
Ductility at 4 C (cm)	4.1	28	30	32	29
Viscosity at 135 C (Pa s)	0.287	1.15	1.437	1.489	1.700
Softening point top		67.7	66.8	69	70.9
Softening point bottom		62.5	66	68.6	71
Difference in softening point		5.2	0.8	0.4	0.1

Perviz Ahmedzade [2012] investigated and compared the effect of SBS modified bitumen and SBS + Entire bond 8 modifications on rheological properties of bitumen. Conventional test method like penetration, softening point, viscosity and dynamic shear Rheometer were used to analyse the effect of modification. 5 different binder concentration was compared i.e. B (base bitumen), B-3S (B + 3% SBS), B-1.5S-1E (B + 1.5% SBS + 1% Entira Bond 8), B-4.5S (B + 4.5% SBS), B-2.25S-1E (B+ 2.25% SBS + 1% Entira Bond 8). Base bitumen with 100/150 penetration grade was used. Modification of bitumen with SBS decreased the penetration value and there is an increase in softening point as compared to base bitumen and with addition of Entira Bond 8 the penetration value further decreases and softening point increases as shown in Table 2.6. Viscosity of bitumen also gets increased with addition of SBS polymer and it further increases with addition of Entira Bond 8. Results from DSR exhibits that bitumen modified with SBS and Entira Bond 8 together showed better result than bitumen modified with SBS alone.

Table 2.5: Effect of modification on conventional properties of bitumen

Properties	Binder type				
	B	B-3S	B-1.5S-1E	B-4.5S	B-2.25S-1E
Penetration (25 ˚C ,0.1mm)	130	71	69	54	51
Softening point (˚C)	45.7	53.6	55	58	60
Penetration index	0.32	0.56	0.81	0.81	1.08
Rotational viscosity at 135 ˚C	375	1110	1115	1775	1790

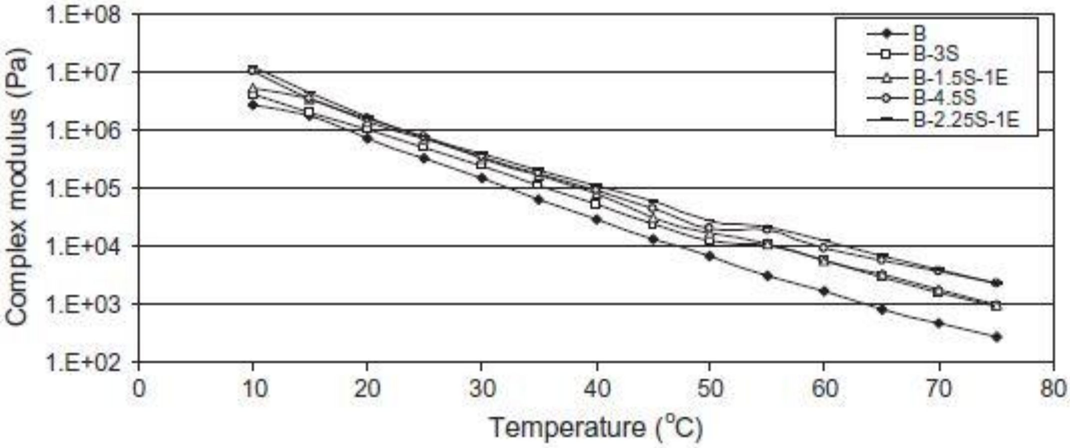


Figure 2.2: Comparison of Complex modulus value with different modifier percentage

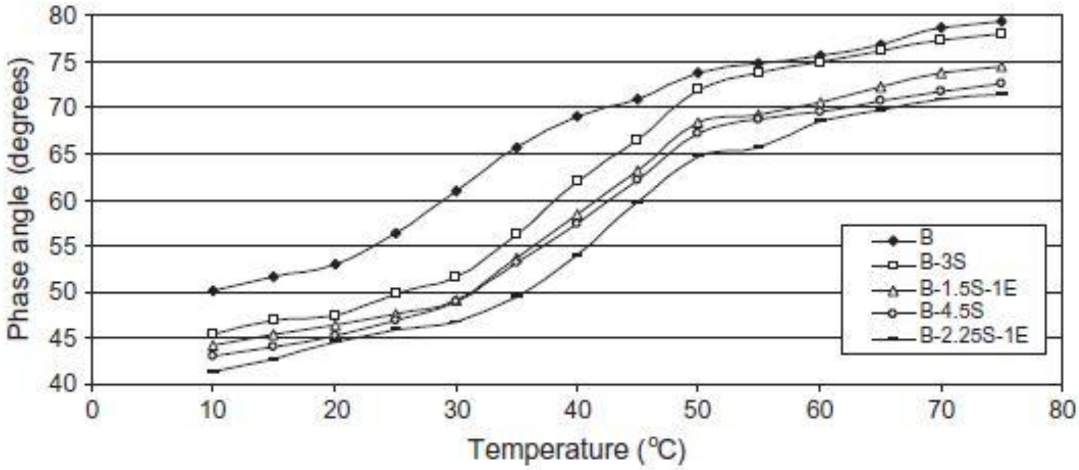


Figure 2.3: Effect of Modification on Phase angle

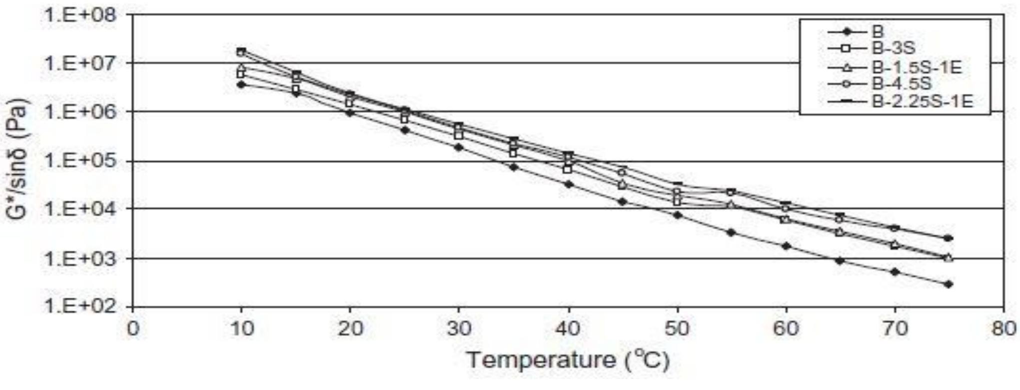


Figure 2.4: Effect of modification on G*/Sinδ value

Behnam golestani et al. [2015] investigated the effect of addition of Nanoclay and SBS with bitumen. They conclude from their study that Nanoclay enhances the physical and rheological properties of SBS modified bitumen. SBS modified bitumen and Nanoclay modified bitumen are more resistant to moisture damage and are less susceptible to temperature changes.

Mahmoud ameri et. al. [2016] investigated the impact of Nanoclay on moisture damage and rutting resistance of base binder and SBS modified binder. 2% Nanoclay was blended with 4% SBS and 6% Nanoclay was blended alone with bitumen. Nanoclay used in this research is Cloisite 15A. Effect of addition of Nanoclay and SBS was analysed using rotational viscosity, dynamic shear Rheometer and indirect tensile strength. Nanoclay blending was done using mixer at fixed power of 6 watt at 150 ˚C for 20 min. It was seen that Nanoclay improves the thermal stability of SBS modified bitumen. Combination of Nanoclay and SBS showed highest viscosity value. Dynamic shear Rheometer indicates that addition of Nanoclay in SBS modified bitumen showed improved rutting performance of mix. Moreover repeated creep and recovery test indicates that addition of Nanoclay in SBS modified bitumen has positive effect on rutting resistance of asphalt pavement. Nanoclay enhances the moisture susceptibility of asphalt mix better as compared to SBS modified bitumen.

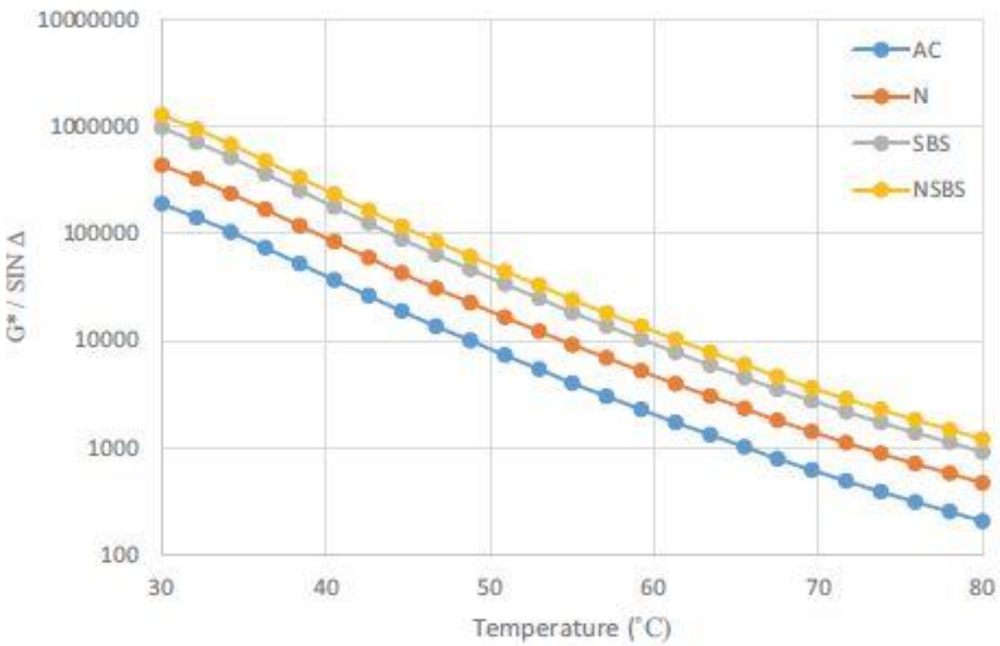


Figure 2.5: Effect of nano clay on rheological properties of bitumen

Kamal kumar et al. [2016] investigated the rheological properties of performance grade bitumen prepared by addition of SBS polymer. 3 different SBS concentration as 0.5%, 1.0%

and 1.5% were blended in two different base bitumen. SBS was blended at 800 rpm for 90 min at 170 c. There was an improvement in rheological properties of base bitumen with addition of SBS polymer. Increase in Softening point value with increase in polymer concentration and decrease in penetration values with increase in polymer concentration was observed. Increase in G* value and decrease in δ value was observed with addition of SBS content. They concluded that modified bitumen is more elastic than base bitumen at same temperature.

2.2.2 Preparation of SBS Modified Bitumen

Burak sengoz and Giray Isikyakar [2007] prepared SBS modified bitumen by means of a high shear laboratory mixer rotating at 1100rpm. Base bitumen was heated to a temperature of 180-185 ˚C and then temperature is kept constant. SBS is slowly added to bitumen and mixing process is continued for 2 hrs using mixer.

Kumar P et al. [2005] prepared SBS modified bitumen by initially heating the bitumen to a temperature of 150 ˚C and then mixer was operated at a constant speed of 100 rpm so as to attain uniform mixing temperature. Polymer was then added slowly to the bitumen so as to avoid agglomeration of polymer and frequency of stirrer was increased to 150 rpm. Mixing of SBS was done for 2 hrs.

J. S. Chen et al. [2002] prepared SBS modified bitumen by melt blending. Mixing was done using a laboratory preparation method that maximised rheological properties and minimizing bitumen degradation. Mixer was operated at 150 rpm. Initially bitumen was heated to a temperature of 180 ˚C and then polymer was added slowly. Mixing was then continued for 2 hrs at 180 ˚C so as to produce a homogeneous blend of SBS and bitumen.

Ali khodaii and amir mehrara [2009] prepared SBS bitumen blend using a mechanical mixer with adjustable rpm between 30 rpm and 1200 rpm. Mixing of SBS in bitumen was carried out at 1200 rpm for 1 hrs at 180 ˚C.

H. Fu et al. [2006] heated the bitumen to 160 ˚C and then added SBS polymer in bitumen. Initial Mixing was done under high speed stirring for 40 minutes and after that mixing was continued with low speed stirring for 30 min at 160 ˚C.

2.3 Zycotherm

Zycotherm is an odourless nano organosilane additive for bituminous mix. It increases moisture resistance and lowers the mixing temperature.

2.3.1 Effect of Zycotherm additive in bitumen

Hassan ziari et al. [2016] investigated the effect of different WMA additives on asphalt mixture. Sasobit, Rheoflat and Zycotherm additive were added into CRM bitumen and neat bitumen. With addition of Sasobit, Rheoflat and Zycotherm compaction level of mixtures at lower temperature is improved. Zycotherm and Rheoflat additive improves moisture damage resistance of asphalt mix. All the additives have improved the rutting resistance and resilient modulus of asphalt binder.

Peyman mirzababaei et al. [2016] evaluated the permanent deformation of pure binder and binder containing Zycotherm. Different blend of Zycotherm modified binder containing 0.1%, 0.3% and 0.5% of Zycotherm was added to base binder with the help of mechanical mixer at 120 ˚C for 10 min. Conventional test on modified bitumen showed that all binders has ductility value more than 100 cm. Penetration value decreased with addition of Zycotherm and there is an increase in softening point with addition of Zycotherm. However it was seen that addition of Zycotherm has decreased the viscosity of modified blend. 0.1% of Zycotherm concentration has highest potential of improving binder resistance against permanent deformation. Zycotherm modified bitumen has improved the performance of binder against rutting. Multistress creep recovery test and DSR test result showed that 0.1% of Zycotherm concentration has best performance against permanent deformation.

Bheemashankar and Amarnath.M.S [2016] investigated the effect of Zycotherm additive on bituminous concrete mix. It was found that ITS value at all temperature is greater in case of Zycotherm modified bitumen. TSR value is also found to be greater in case of Zycotherm modified bitumen.

Hassan Ziari et al. [2016] determined the properties of bitumen modified with liquid nano organosilane additive namely Zycotherm.0.1% of Zycotherm was added in bitumen. There was a decrease in penetration value from 43 to 54 and increase in softening point from 49 to 51 with addition of Zycotherm. Penetration index value increased from -0.915 to -0.780 with addition of Zycotherm. FTIR test shows that Zycotherm produces a hydrophobic layer over the surface. It was seen that addition of Zycotherm has inconsiderable effect on elastic response and viscosity as compared to neat bitumen. Addition of Zycotherm improved rutting performance for unaged binder but in case of aged binder there is negligible improvement in rutting performance

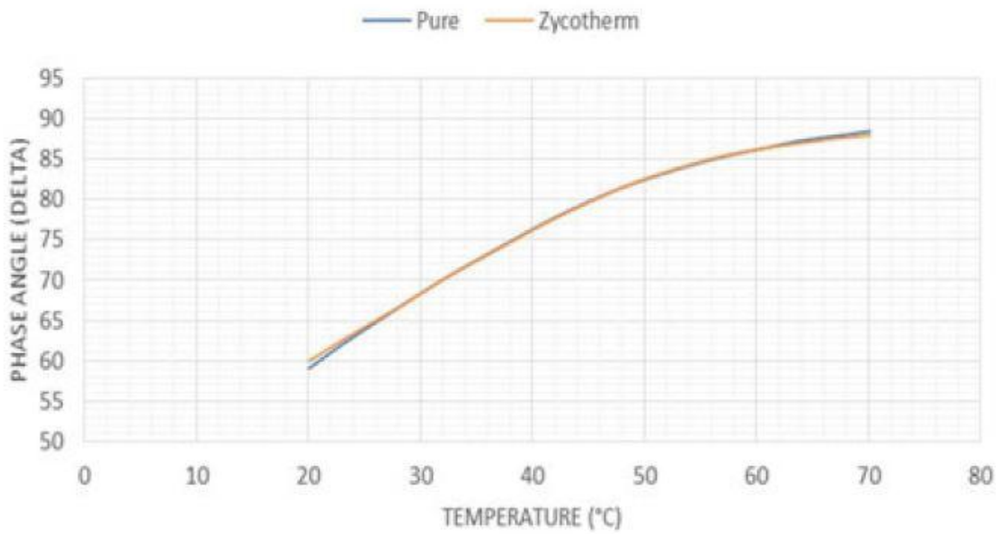


Figure 2.6: Effect of Zycotherm on phase angle for neat bitumen

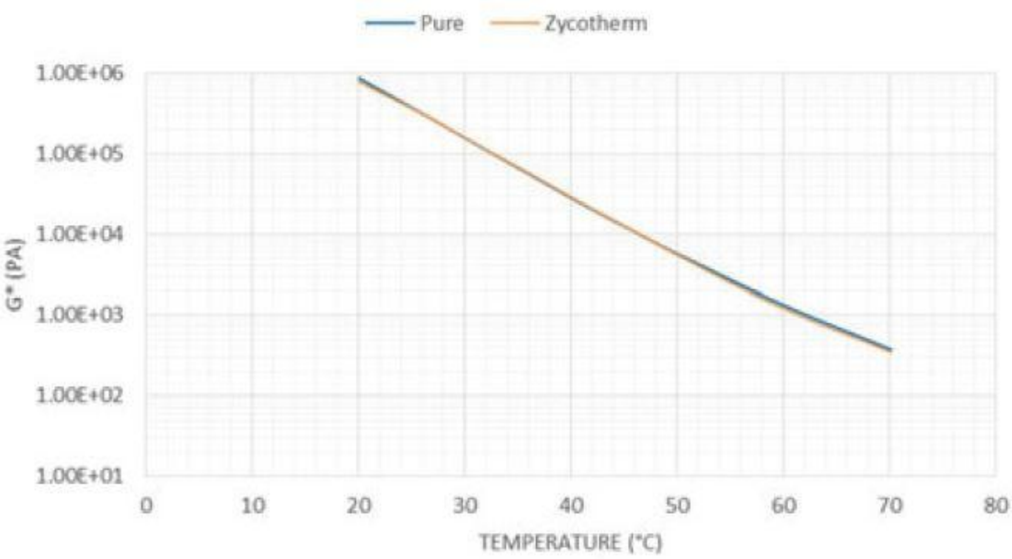


Figure 2.7: Effect of Zycotherm on complex modulus for neat bitumen

Rohith N and J. Ranjitha [] studied the effect of addition of Zycotherm on Marshall Stability properties of WMA and HMA. It was seen that with addition of Zycotherm on WMA mix there is an increase in stability value because Zycotherm lowers the mixing temperature and compaction temperature for mix. When compared with HMA specimen, stability value for WMA at 130 ˚C and 115 ˚C with addition of Zycotherm showed better results.

2.4 Effect of Aggregate Properties on Bituminous Mixes

Ahmed ebrahim abu el-maaty behiry [2015] studied the effect of aggregate morphological properties on mechanical properties of HMA. Two different aggregate i.e. limestone and basalt were used in this study. Limestone showed lower optimum binder content for HMA mixture. Stability value for limestone aggregate was more than that of basalt aggregate and flow value was also more for limestone aggregate. Mixture prepared with limestone aggregate has shown best results in moisture susceptibility test and basalt aggregate showed better performance in rutting potential.

Eyad Masad et.al [2011] analysed the effect of aggregate shape characteristic on HMA performance. Results showed that aggregate shape play an important role in affecting performance of HMA. With increase in percentage of flat particles in mixture, there was an increase in resistance to permanent deformation in vertical direction. Elongated aggregates tend to orient themselves in such a way that the longest axis of particles is inclined toward horizontal plane. This causes an increase in aggregate contacts in vertical direction and causes higher stiffness in vertical direction.

Kunnawee Kanitpong et.al [2011] investigated the effect of gradation and aggregate type on moisture damage of WMA mixes. Two different aggregates were used i.e. granite and slag and two gradation were used i.e. fine and coarse. It was concluded that WMA is more prone to moisture damage than HMA. Fine graded aggregate showed better resistance to moisture damage than coarse graded aggregate. For coarse graded mixture granite aggregate showed lower permanent deformation than slag mixes. Slag mixes showed poor abrasion value which results in less durable aggregates which makes aggregate less sufficient to transfer loads through stone contact points.

U.Bagam padde et.at [2007] studied the influence of aggregate chemical and mineralogical composition on bituminous mix. Aggregate containing sodium and potassium elements exhibit high moisture sensitivity for bituminous mixes. Aggregate with 100% quartz showed high resistance to moisture damage. Aggregate containing calcium, magnesium and iron showed no indication for moisture sensitivity.

CHAPTER 3

MATERIAL CHARACTERIZATION

3.1 Introduction

Hot mix bitumen generally consists of combination of different sizes of aggregate with filler material, which are mixed together with bituminous binder. Each material used in hot mix bitumen pavement has its own particular characteristic and is suitable for a specific construction purpose as per its properties. Each material is chosen as per design requirement so as to achieve best quality. For this study two different type of aggregates i.e. limestone and riverbed aggregate is used. Moreover bitumen is also modified with SBS polymer and Zycotherm additive.

3.2 Aggregate

In a bituminous mix, maximum traffic load imposed on pavement is resisted by primarily aggregates. Aggregates provide a strong material to resist deformation caused by repeated load application. Properties and characteristic of an aggregate plays an important role in influencing bituminous mix properties. Generally angular particles and rough textured aggregate provide more shear strength as compared to rounded aggregate.

In this study two types of aggregate were chosen i.e. limestone and riverbed aggregate. Both aggregates are compared with each other using normal bituminous binder and polymer modified binder. Limestone aggregate was procured from Shillai (Himachal Pradesh) and riverbed aggregates were procured from Paonta sahib (Himachal Pradesh). Difference in physical properties of aggregates was determined by performing various tests on aggregates. The physical properties of the aggregates are given in Table 3.1.

Table 3.1: Physical Properties of Aggregates

Test description	Aggregate		Standard	Recommended value
	Limestone	Riverbed		
Specific gravity fine aggregate	2.7	2.7	ASTM C128	-
Specific gravity coarse aggregate	2.62	2.69	ASTM C127	-
Impact value (%)	22.33	19.66	IS:2386 Part 4	Max 24%
Crushing value (%)	22	20		
Abrasion value (%)	22	18	ASTM C131	Max 30%

Water absorption (%)	0.91	0.50	ASTM C127	Max 2%

3.2.1 Aggregate Gradation and Size

Size and gradation of aggregate is chosen as per design requirement i.e. maximum load imposed on it and design thickness of pavement. Maximum size of aggregate in pavement surface is dependent on design pavement thickness. In this study aggregate gradation is chosen for bituminous concrete layer of thickness 30-45mm having nominal aggregate size of 13 mm. Midpoint gradation of aggregate is adopted for this study. Table 3.2 represents the aggregate gradation limits and adopted aggregate gradation for bituminous concrete layer. Identical gradation is used for all the bituminous mixes in this study as shown in Figure 3.1.

Table 3.2: Specified Aggregate gradation and Adopted gradation

Layer thickness	**30-45mm**	
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

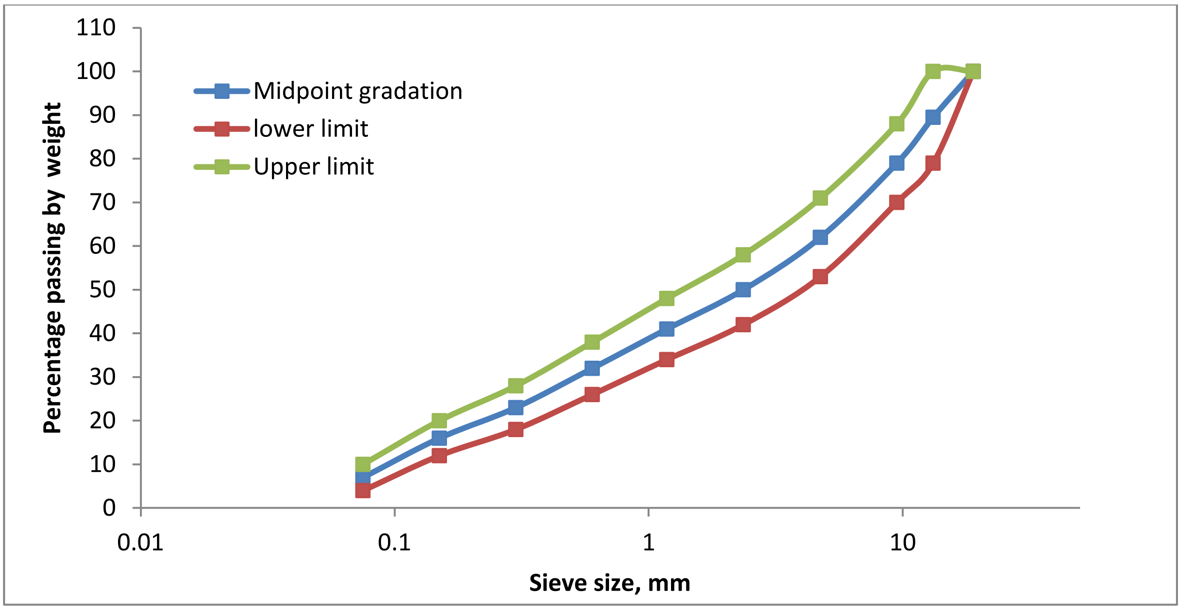


Figure 3.1: Aggregate Gradation Limits and Adopted Gradation

Figure 3.2: Riverbed aggregate (left) and limestone aggregate (right)

3.3 Bituminous Binder

Bitumen is the main binder material in a pavement that holds aggregate and filler particles together with each other. Bitumen is a thermoplastic material so it has a tendency to liquefy when heated. Bitumen is mainly classified on the basis of its consistency and its ability to flow at variable temperature. Consistency of bituminous binder is generally measured by penetration test and viscosity test. Softening point test is also performed so as to check the temperature susceptibility of bituminous binder.

In this research VG30 bitumen is used as a base binder and it has been further modified with SBS polymer and Zycotherm additive. Three different percentages of SBS were added in base bitumen i.e. 3, 5, 7%. The Zycotherm additive percentage is kept constant i.e. 0.1%. Different bituminous binder is compared with each other and the effect of Zycotherm additive was studied on SBS modified bitumen and base binder. The properties of VG30 bitumen are shown in Table 3.3.

Table 3.3: Properties of VG30 bitumen

Properties	Results	Standard
Penetration (25˚C)	65	ASTM D5
Softening point (˚C)	52	ASTM D36
Specific gravity	1.02	ASTM D70
Ductility	100 +	ASTM D113

3.4 Styrene Butadiene Styrene

SBS is a thermoplastic elastomer that is used in this study to modify the base bitumen. Three different percentages of SBS are added in base bitumen i.e. 3, 5, 7 % by weight. SBS used in this study was supplied by LG Chem. and grade of SBS was 411. SBS used was in the form of porous pellets. The properties of SBS polymer are given in Table 3.4.

Table 3.4: Properties of SBS polymer

Properties	Results	Test method
Styrene content	31 %	LSY-QB-SD015
Density	0.94 g/cm^3	ISO 2781
Toluene solution viscosity	28.2 cSt	ASTM D445
Melt index	<1 g/10min	ASTM D1238
Hardness	84 Shore A	ASTM D2240
Volatile matter	0.3 %	ASTM D1416
Yellow index	1	ASTM D1925
Flash point	288 ˚C	-
Solubility	Insoluble in water	-

Figure 3.3: SBS polymer

3.4.1 Preparation of SBS Modified Bitumen (MB)

Mixing of SBS polymer was done using a high shear mixer capable of maintaining constant temperature and constant blending speed for long duration. Bitumen was heated to a temperature of 160˚C for 30 min at 500 rpm so as to attain uniform mixing. When mixing temperature of 170 -180˚C was reached, the SBS was added slowly in bitumen so as to avoid agglomeration of polymer. Then mixing was continued for 2 hrs at 4000 rpm so as to achieve a homogeneous blend of SBS modified bitumen. Table 3.5 shows conventional properties of SBS modified bitumen.

Table 3.5: Conventional properties of SBS modified binder

Properties	**Test method**	**3% SBS MB**	**5% SBS MB**	**7%SBS MB**
Penetration (25˚C)	ASTM D5	50	45	42
Softening point	ASTM D36	60	74	75
Ductility	ASTM D113	100 +	100 +	100+

3.5 Zycotherm

Zycotherm is an odourless nano- organosilane additive for bituminous mix. Zycotherm gives better chemical bonding for extended moisture resistance and ensures 100 % coating of bitumen at low temperatures. In this study 0.1% (by weight of bitumen) of Zycotherm is added in base binder and SBS modified binder. Table 3.6 presents properties of Zycotherm.

Table 3.6: Properties of Zycotherm additive

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

Figure 3.4: Zycotherm additive

3.5.1 Preparation of Zycotherm Modified Bitumen

Zycotherm modified bitumen was prepared using a mechanical mixer rotating at 100 rpm for 5 min at 120˚C. Dosage of Zycotherm was kept 0.1 % by weight of bitumen for all the mixes.

For polymer modified bitumen, Zycotherm was added first to bitumen then blending for SBS was done as per blending procedure for SBS modified bitumen.

Table 3.7: Conventional properties of Zycotherm modified bitumen

Properties	Test method	Zycotherm MB
Penetration (25˚C)	ASTM D5	62
Softening point (˚C)	ASTM D36	53
Ductility	ASTM D113	100+

3.6 Effect of Modification on Conventional Properties of Bitumen

3.6.1 Penetration Value

Penetration test is used to measure the consistency or hardness of bitumen or bituminous binder so as to classify bitumen binder into different grades based on the penetration value. Penetration value is the vertical distance penetrated by standard needle into bituminous binder under specified conditions of time, loading and temperature. Test is carried at a standard temperature of 25˚ C and penetration duration is 5 sec. Bitumen with penetration value in range of 60 -70 is referred as 60/70 grade bitumen. Higher penetration value corresponds to softer bitumen with lower viscosity and vice versa. Generally higher penetration grade bitumen is recommended for cold climate region and lower penetration grade bitumen is recommended for hot climate region. Penetration test was conducted for different binders and results are shown in Table 3.8.

Table 3.8: Penetration values for different binders

Binder	Penetration Value(0.1 mm)
VG30	65
VG30 + 3% SBS	50
VG30 + 5% SBS	45
VG30 + 7% SBS	42
VG30 + Zycotherm	62
VG30 + 3% SBS + Z	52
VG30 + 5% SBS + Z	46
VG30 + 7% SBS + Z	43

3.6.1.1 Effect of SBS modification on penetration value

The Figure 3.5 shows a decrease in penetration value of bitumen with increase in addition of SBS percentage in bitumen from 3 to 5 and 7%. Penetration value decreased from 62 to 50 with addition of 3% SBS which further decreased to 45 and 42 with addition of 5 and 7% SBS respectively. It was seen that with increase in SBS percentage to 7%, there was a formation of continuous film of tiny droplet around the surface of bitumen, moreover penetration value begin to stabilize. Hence 5% SBS modification is suggested as the optimum dosage for VG30 bitumen so as to avoid phase separation of polymer in bitumen.

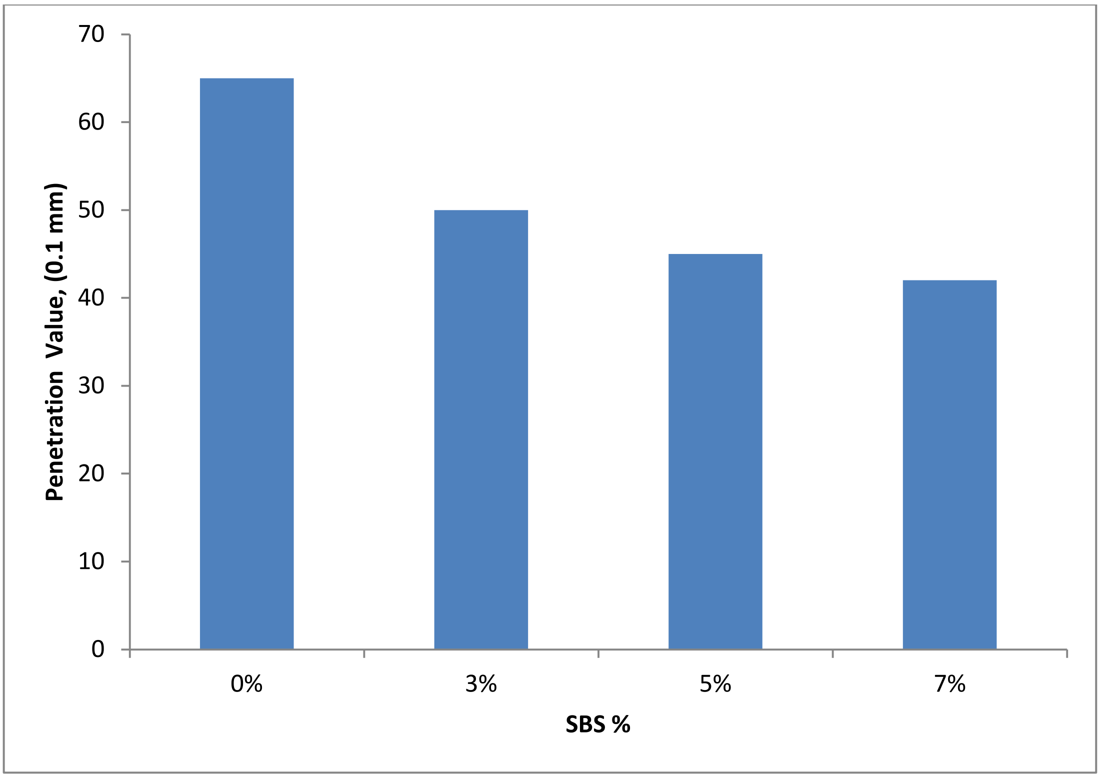


Figure 3.5: Effect of SBS content on penetration value

3.6.1.2 Effect of Zycotherm additive on penetration value

For pure VG30 binder, addition of Zycotherm decreased the penetration value of binder from 65 to 62. An increase in penetration value was observed in case of addition of Zycotherm to SBS modified bitumen. The effect of Zycotherm for different binder is shown in Figure 3.6

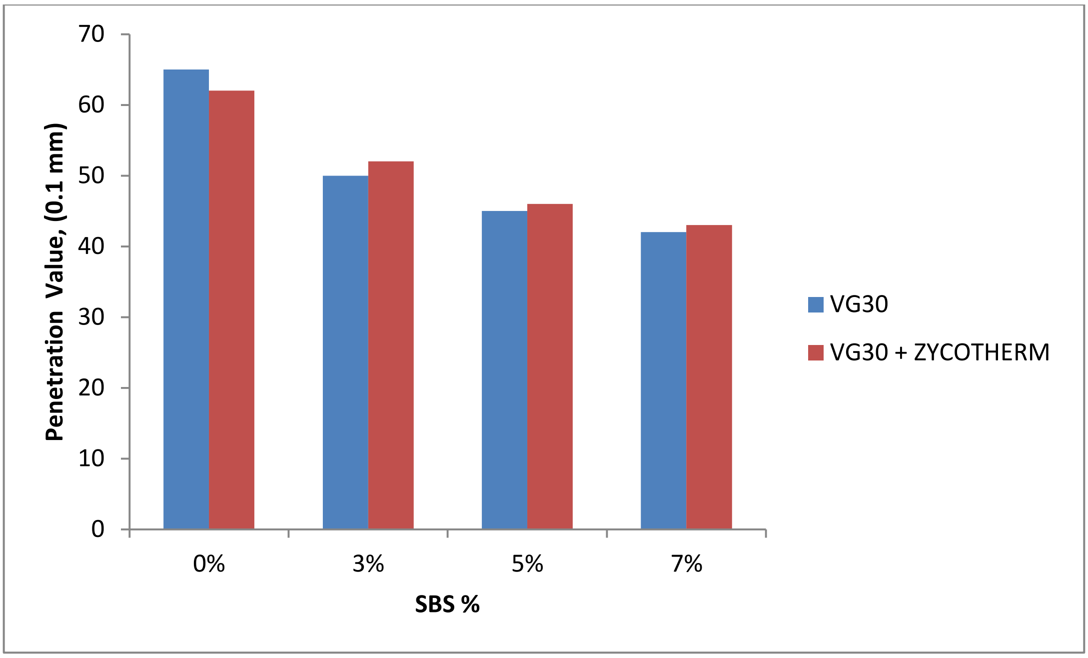


Figure 3.6: Effect of Zycotherm on penetration value

3.6.2 Softening Test

Softening point is the temperature at which bitumen or bituminous binder attains a particular degree of softening under specified conditions. For bitumen binder softening value is determined by ring and ball test. Softening test was conducted on all the binders. The results are shown in Table 3.9.

Table 3.9: Softening point values for different binder

Binder	**Softening point (˚C)**
VG30	52
VG30 + 3% SBS	60
VG30 + 5% SBS	74
VG30 + 7% SBS	75
VG30 + Zycotherm	53
VG30 + 3% SBS + Z	60
VG30 + 5% SBS + Z	74
VG30 + 7% SBS + Z	75

3.6.2.1 Effect of SBS modification on softening point

It was observed that there was an increase in softening point, with an increase in SBS percentage from 3, 5 and 7% in bitumen. Softening point of pure VG30 binder increased from 52 ˚C to 75 ˚C for 7% SBS modification. Further 5 and 7% SBS modification in bitumen showed the nearly same value for softening point. The Effect of SBS modification is shown in Figure 3.7.

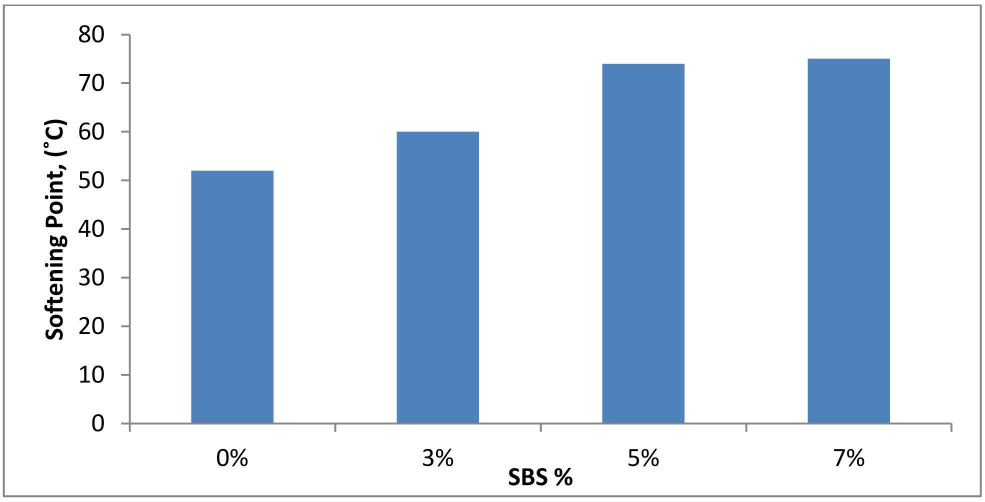


Figure 3.7: Effect of SBS content on softening point

3.6.2.2 Effect of Zycotherm additive on softening point

From Figure 3.8 it is clear that Zycotherm does not have any significant effect on the softening point of bitumen. For SBS modified bitumen there was no effect of Zycotherm additive on softening point.

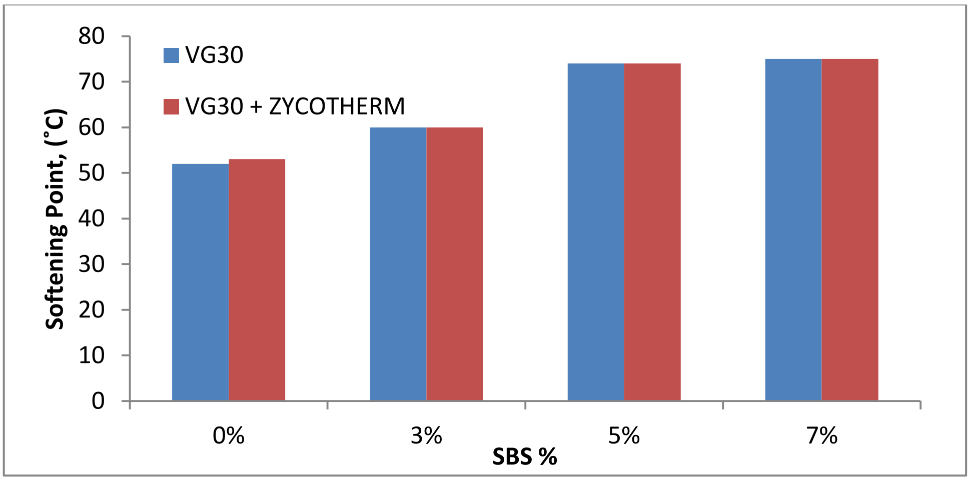


Figure 3.8: Effect of Zycotherm additive on softening point

3.7 Effect of Modification on Rheological Properties of Bitumen

3.7.1 Viscosity Test

Viscosity is the property of any fluid to retard its flow due to internal friction. Viscosity of bitumen binder is the measure of its flow characteristic. Performance of bitumen binder is mainly dependent on its viscosity. If viscosity of bitumen binder is too low then bitumen will just lubricate the aggregate and this will give lower stability value and if viscosity is too high then bitumen will not coat the surface of aggregate properly therefore give lower stability value. Therefore measurement of bitumen binder viscosity is an important parameter. Viscosity of bitumen was measured using DSR at a temperature ranging from 60 to 120 ˚C at a shear rate of 4 (1/sec).

3.7.1.1 Effect of SBS modification on viscosity

With increase in SBS percentage in bitumen there was an increase in viscosity of bitumen. At 60 ˚C the viscosity of neat VG30 binder is 3100 P and with addition of SBS viscosity value changes to 3640, 5290, 6204 P for 3, 5 and 7% SBS respectively. Effect of SBS modification on viscosity is shown in figure 3.9.

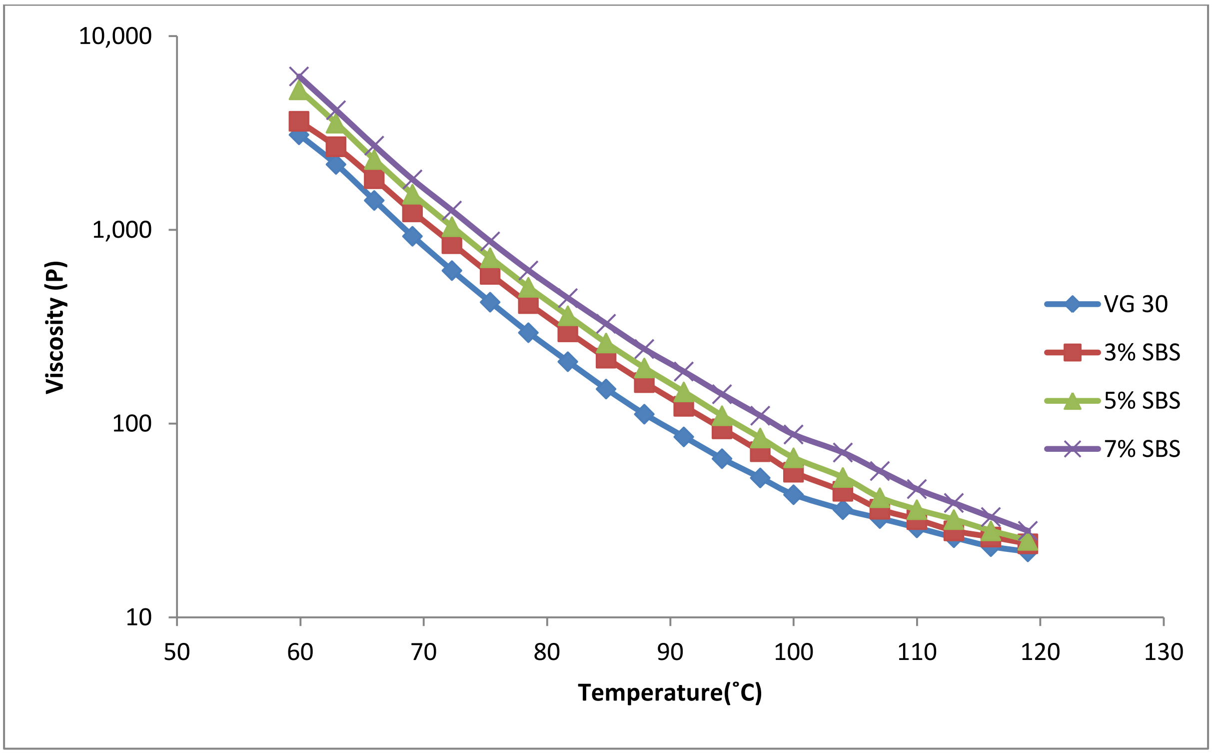


Figure 3.9: Effect of SBS modification on viscosity of binder

3.7.1.2 Effect of Zycotherm additive on viscosity of bitumen

Figure 3.10 shows that with addition of Zycotherm additive in neat VG30 bitumen the viscosity value increased when the temperature range was between 60 and 100 ˚C and the viscosity value started decreasing after 100 ˚C. Decrease in viscosity of bitumen after 100 ˚C can help better coating of bitumen over aggregate which could result in better moisture susceptibility of mix.

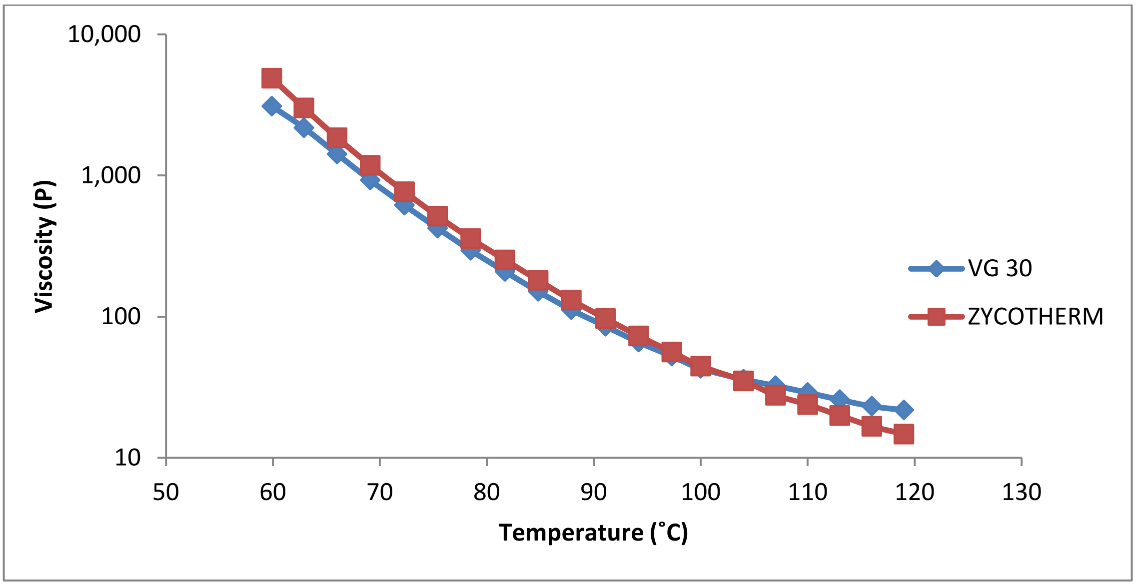


Figure 3.10: Effect of Zycotherm additive on VG30 binder

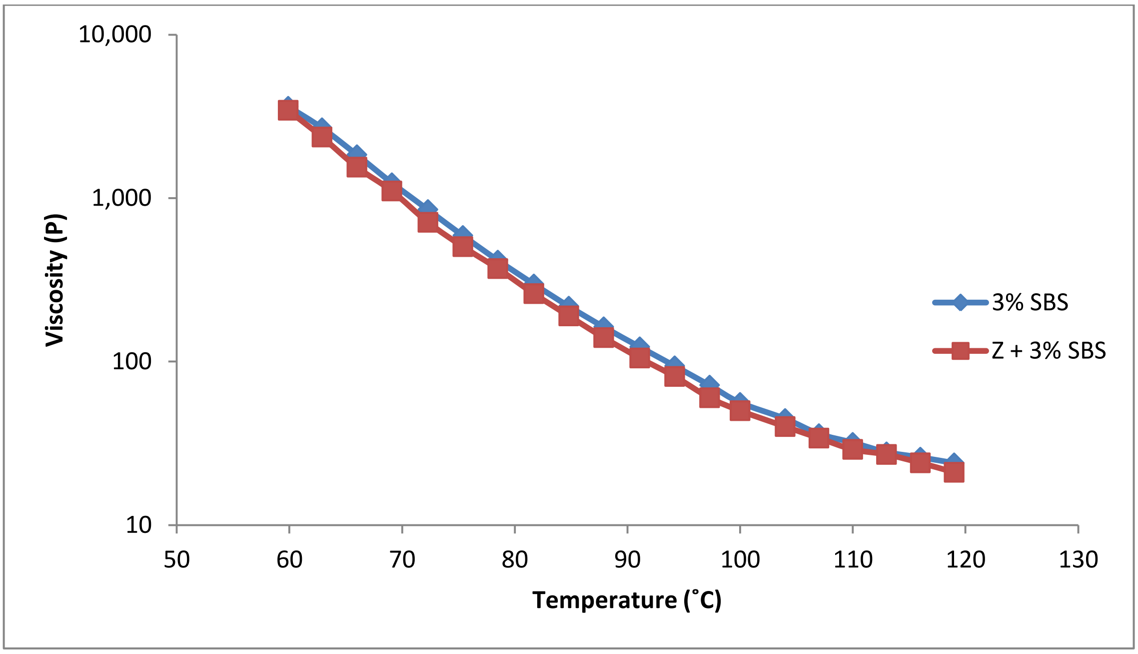


Figure 3.11: Effect of Zycotherm on viscosity for 3% SBS modified binder

Addition of Zycotherm in SBS modified bitumen has slightly lowered the viscosity of binder for all dosages of SBS polymer 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.

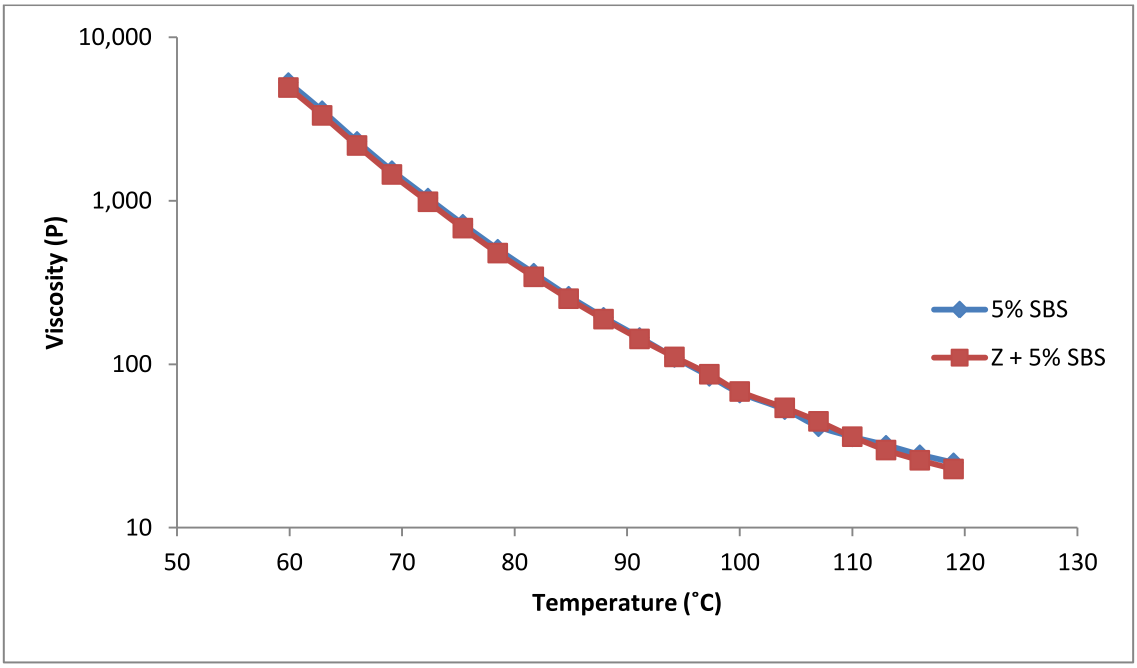


Figure 3.12: Effect of Zycotherm on viscosity for 5% SBS modified bitumen

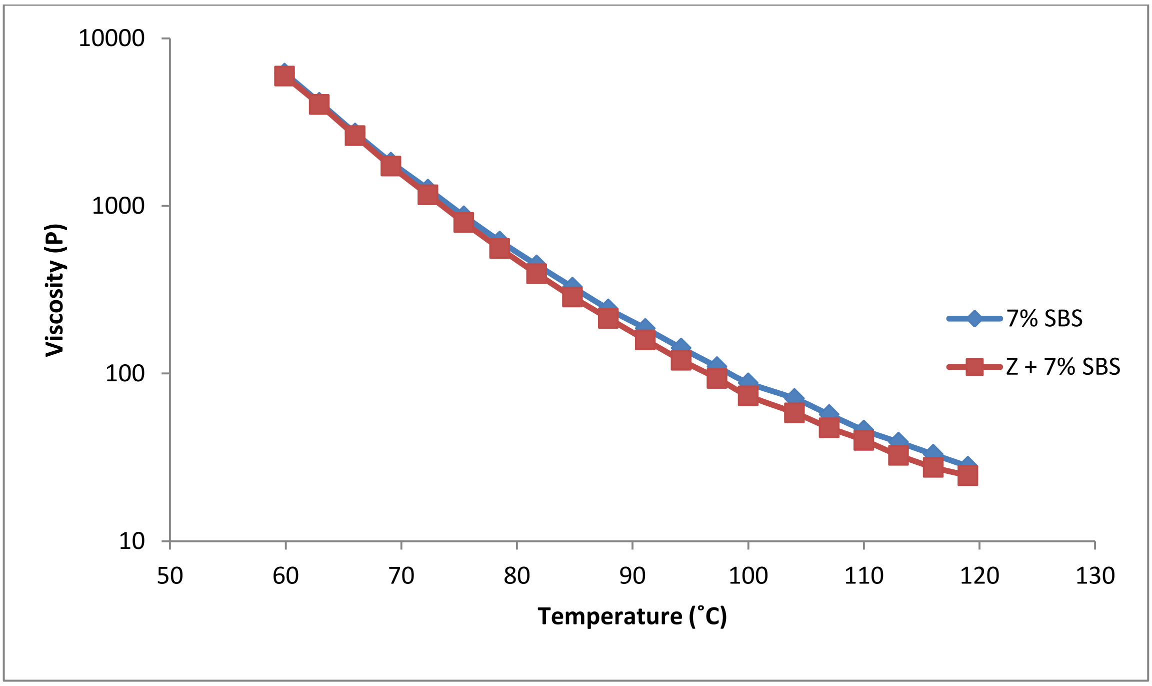


Figure 3.13: Effect of Zycotherm on viscosity for 7% SBS modified bitumen

3.7.2 Dynamic Shear Rheometer

Dynamic shear Rheometer (DSR) is used to characterise the viscous and elastic behaviour of bituminous binder at different temperatures. Bituminous binders are viscoelastic in nature i.e. they behave partly like elastic solid in which deformation due to loading is recoverable and they partly behave like viscous liquid in which deformation due to loading is non recoverable. 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*/sinδ 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*.sinδ value should be less.

DSR can characterise 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 specimen were subjected to sinusoidal loading at a frequency of 10 rad/sec which corresponds to a traffic speed of 80Km/hr. The testing for determination of complex modulus is conducted as per IRC: SP: 53-2010.

25 mm parallel plate geometry is used with a gap of 1.00 mm for conducting the entire test in dynamic shear Rheometer.

Figure 3.14: Dynamic Shear Rheometer

3.7.2.1 Effect of SBS modification on rheological properties

It can be observed from the Figure 3.15 and Figure 3.16 that with an increase in SBS percentage in bitumen there is a decrease in phase angle and increase in complex modulus respectively. Decrease in phase angle shows more elastic nature of modified binder. For rutting resistance of pavement, higher value of complex modulus and lower value of phase angle is desirable. Higher value of complex modulus indicates stiffer binder and lower phase angle indicates more elastic behaviour of binder. Therefore $G^*/\sin\delta$ value should be high to avoid rutting of pavement.

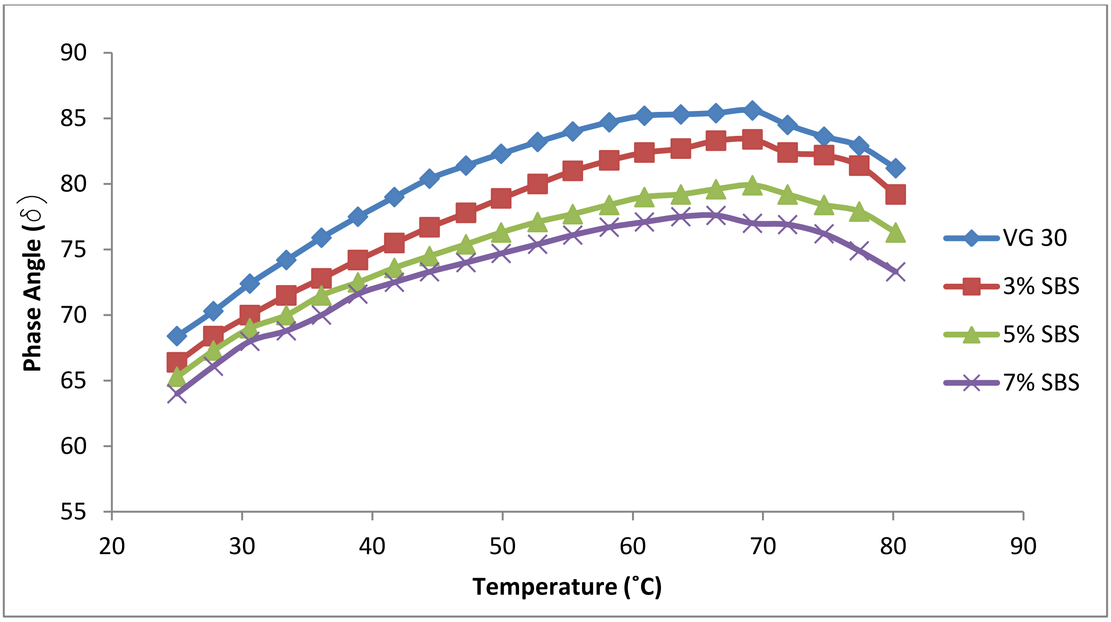


Figure 3.15: Effect of SBS content on Phase angle

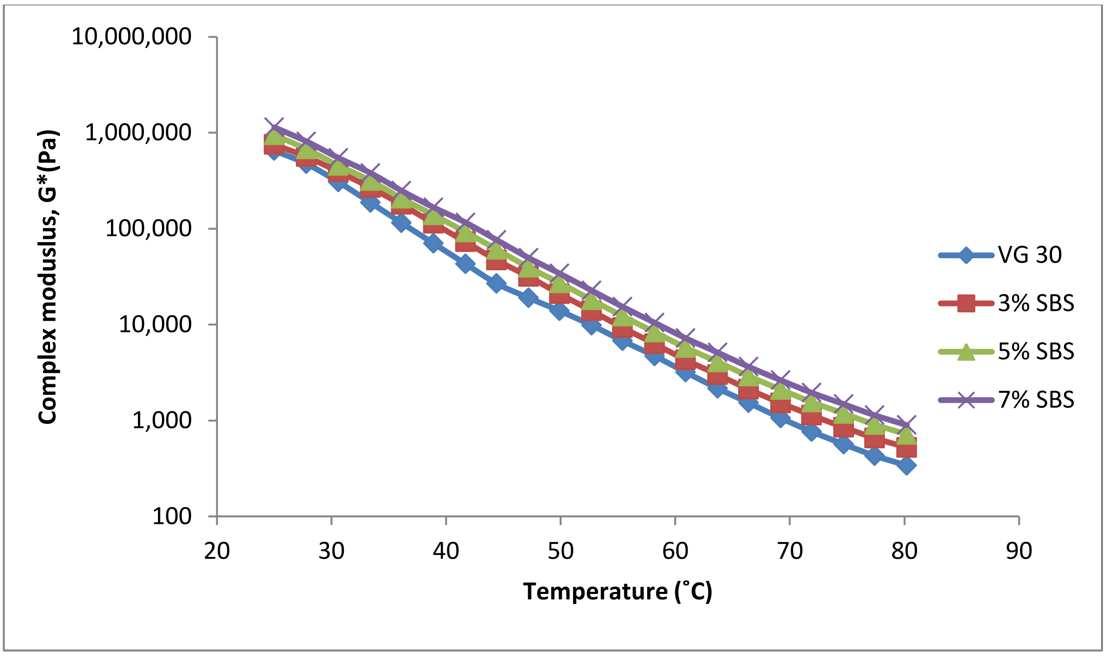


Figure 3.16: Effect of SBS content on Complex modulus value

Figure 3.17 indicates that with addition of SBS in bitumen there is an increase in G*/Sinδ which results in higher rutting resistance potential of SBS modified bitumen. All dosages of SBS polymer in bitumen showed better rutting resistance performance as compared to base bitumen. However 7% SBS modification in bitumen shows best performance in rutting resistance potential as compared to 3 and 5% SBS .

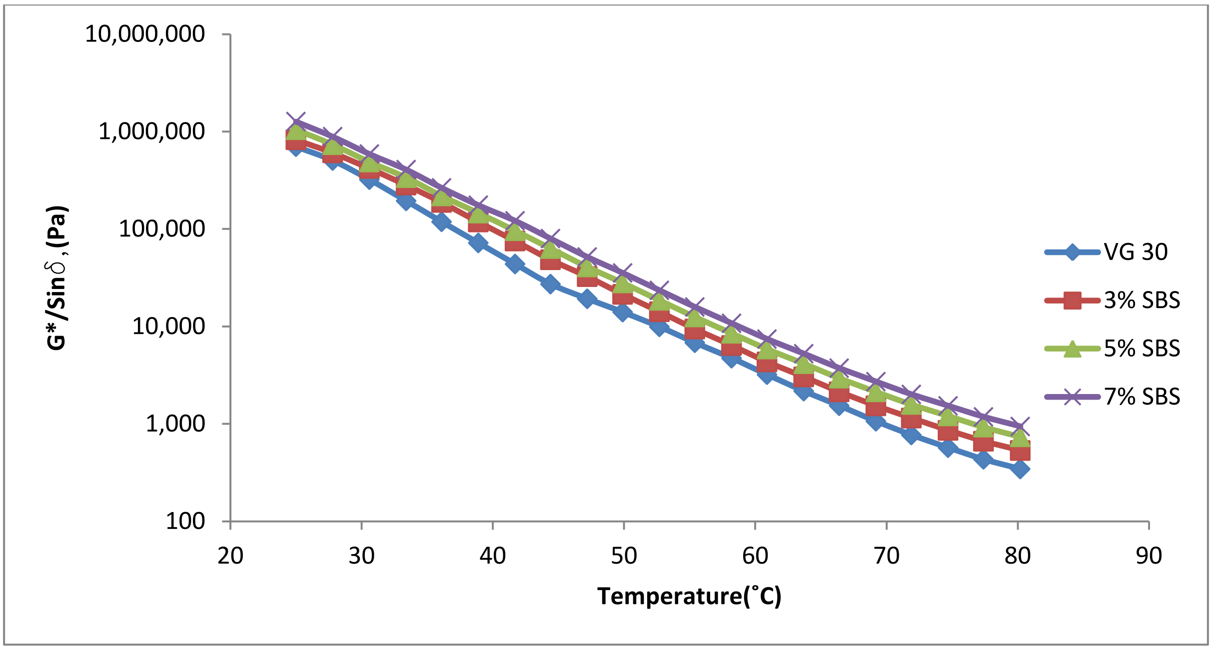


Figure 3.17: Effect of SBS content on G*/Sinδ value

3.7.2.2 Effect of Zycotherm additive on rheological properties of bitumen

It was observed from Figure 3.18 that with addition of Zycotherm to neat VG30, the phase angle slightly tends to decrease which signifies higher elastic nature of Zycotherm modified bitumen. There was not much significant change in complex modulus value, which signifies that Zycotherm additive in base bitumen does not increase the stiffness of binder as shown in Figure 3.19

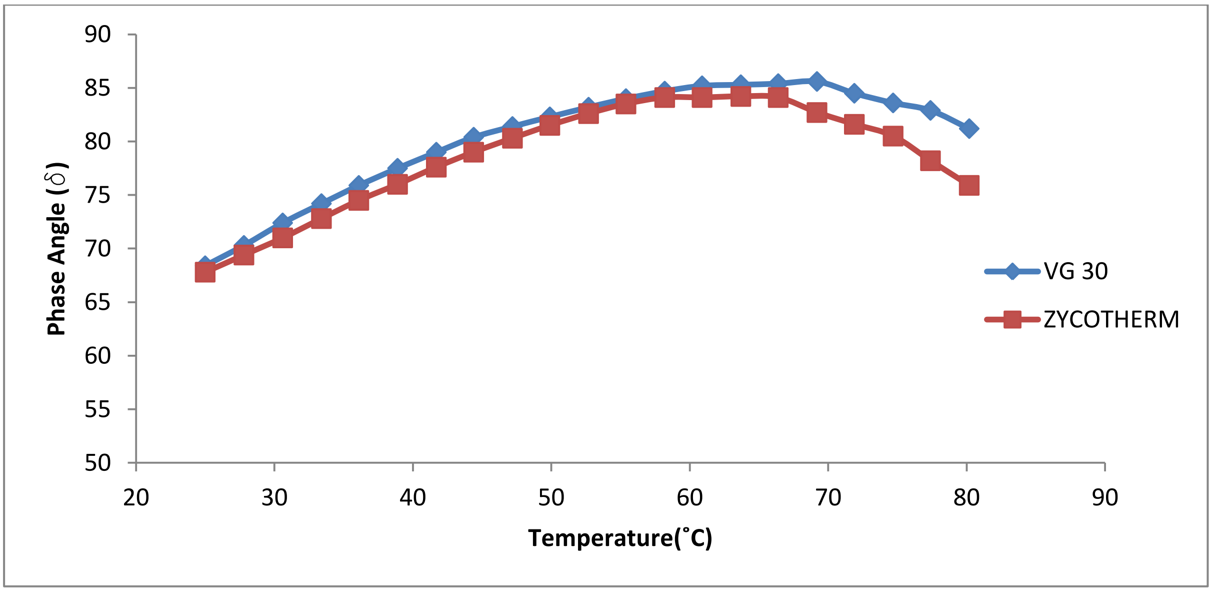


Figure 3.18: Effect of Zycotherm on phase angle for VG30 binder

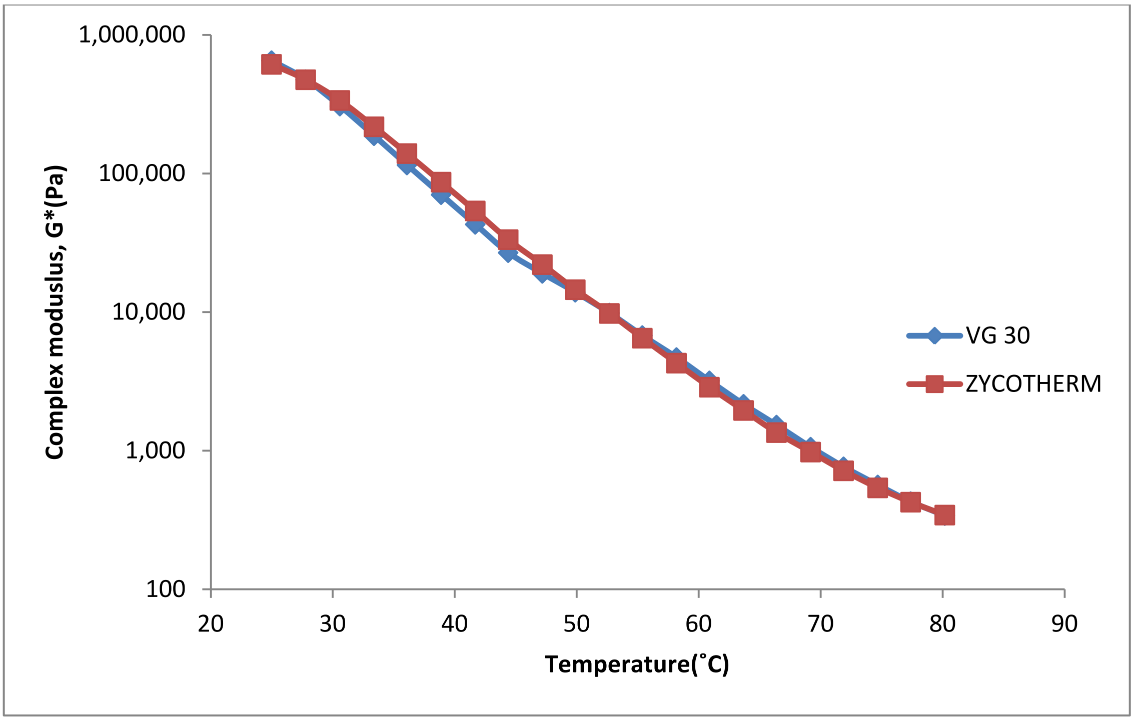


Figure 3.19: Effect of Zycotherm on Complex modulus value for VG30 binder

There was no significant change in G*/Sinδ value with addition of Zycotherm in bitumen as shown in Figure 3.20. This signifies that Zycotherm additive in base bitumen does not improve the rutting resistance performance of mix.

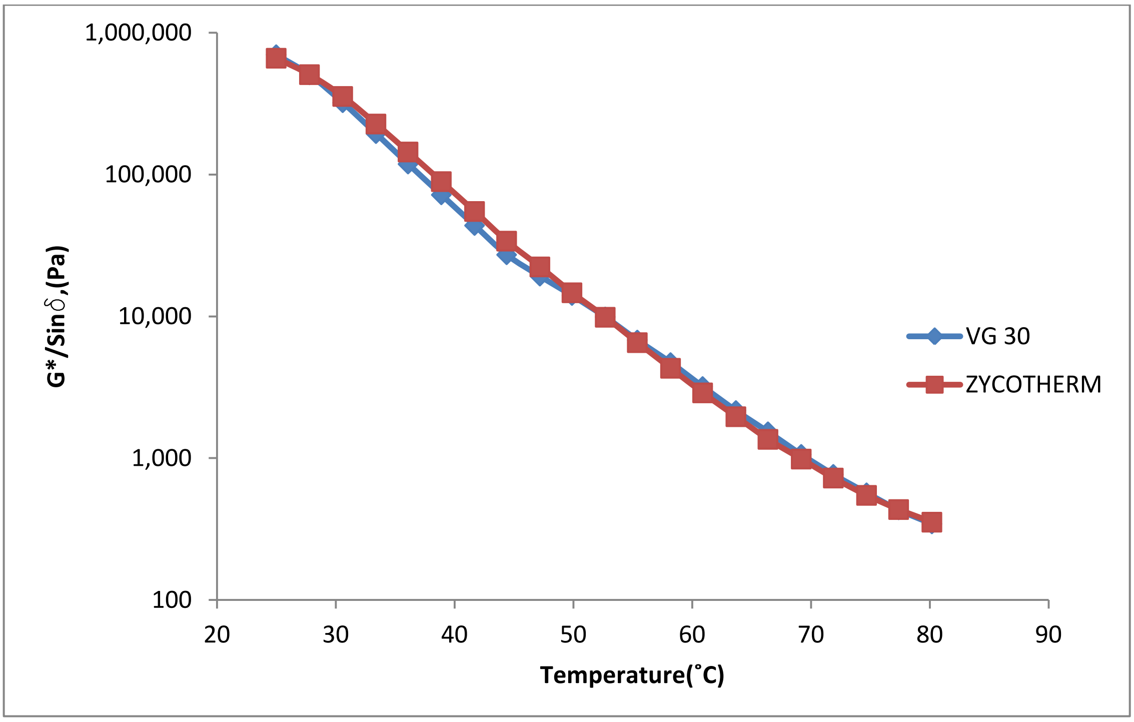


Figure 3.20: Effect of Zycotherm on G*/Sinδ value for VG30 binder

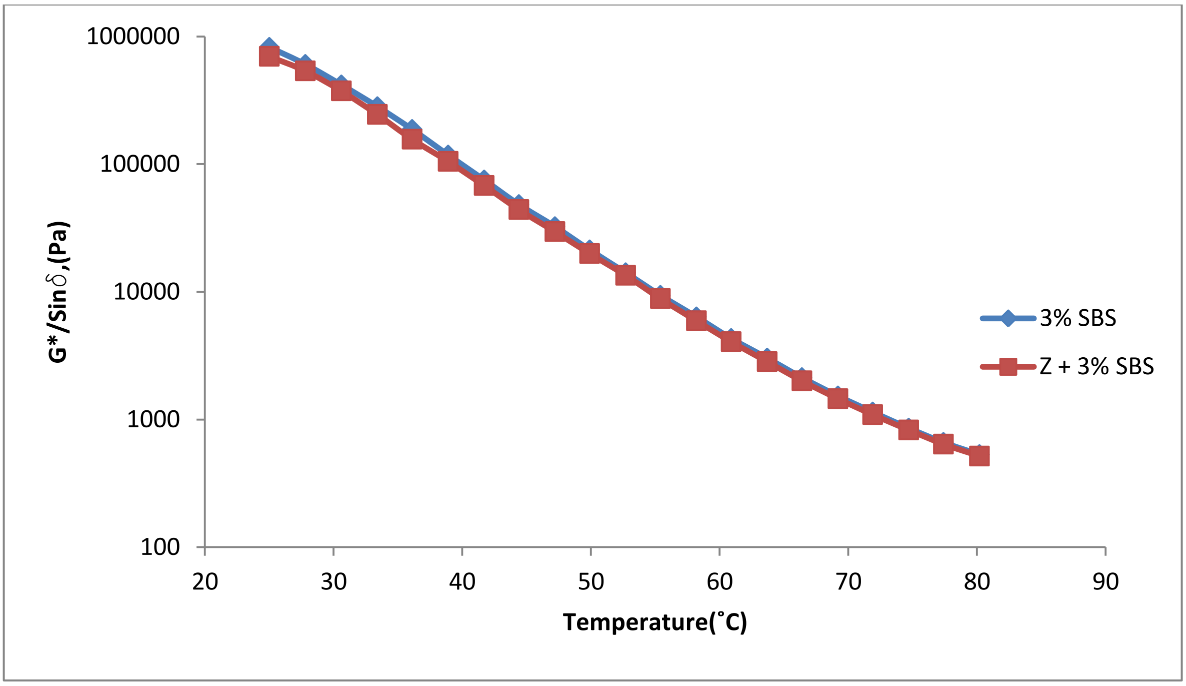


Figure 3.21: Effect of Zycotherm on G*/Sin𝛿 for 3% SBS modified bitumen

It was observed from Figure 3.21, 3.22 and 3.23 that Zycotherm additive in SBS modified bitumen at all dosages of SBS, does not have any significant change in G*/Sin𝛿 value of binder. Zycotherm additive in SBS modified bitumen does not alter the rutting resistance performance of binder.

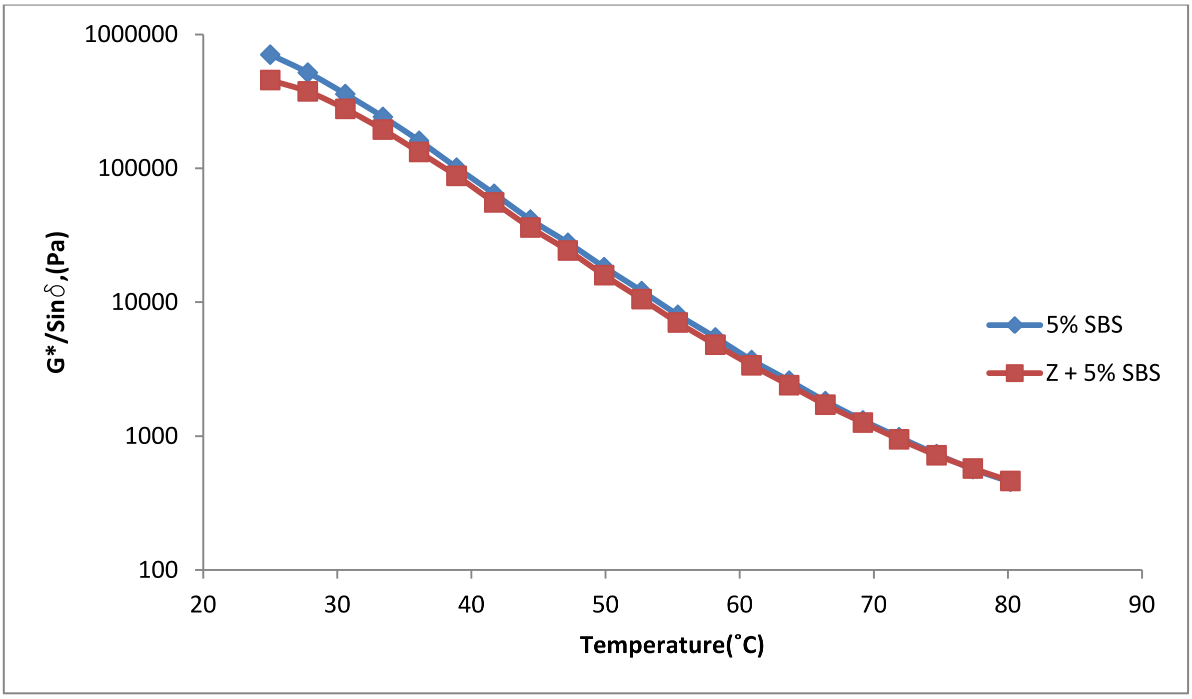


Figure 3.22: Effect of Zycotherm on G*/Sin𝛿 for 5% SBS modified bitumen

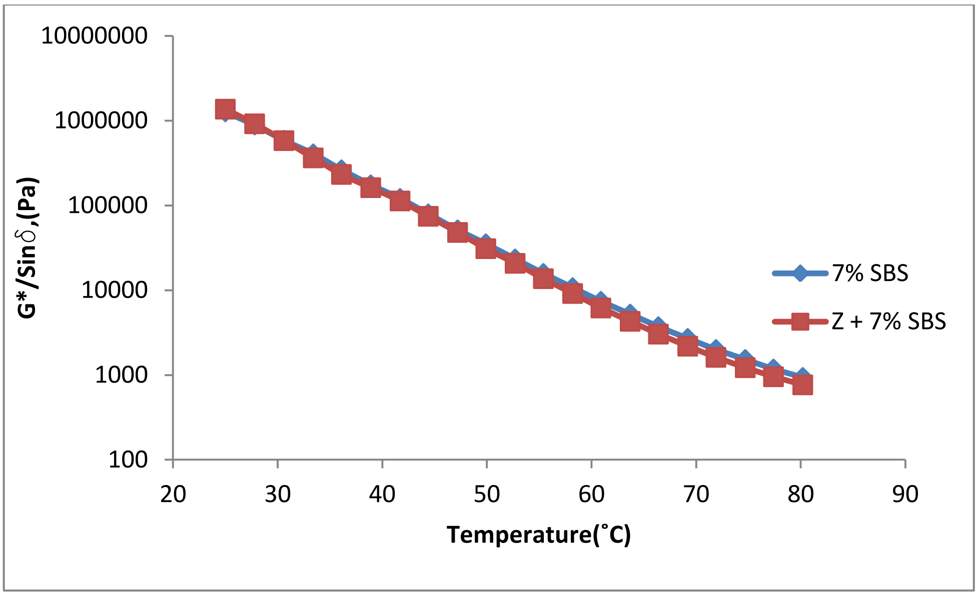


Figure 3.23: Effect of Zycotherm on G*/Sinδ for 7% SBS modified bitumen

Table 3.10: Temperature corresponding to G*/Sinδ = 1kpa

Binder	Temperature Corresponding To G*/Sinδ=1kpa
VG30	69.7
VG30 + Zycotherm	69.07
3% SBS	73.3
5% SBS	76.6
7% SBS	79.4
3% SBS + Z	72.8
5% SBS + Z	76.4
7% SBS + Z	76.9

Table 3.10 shows temperature values corresponding to G*/Sinδ= 1kpa. With increase in SBS concentration in bitumen there is an increase in temperatures values corresponding to G*/Sin**d=** 1kpa. SBS tends to increase performance grade of binder. Addition of Zycotherm in VG30 bitumen has not altered the values of temperature values corresponding to G*/Sinδ = 1kpa however for SBS modified bitumen at 7% SBS modification, Zycotherm has slightly decreased the temperature values which shows decrease in performance grade of binder.

CHAPTER 4

EVALUATION FOR BITUMINOUS CONCRETE MIX

4.1 General

Various tests are conducted on bituminous mixes so as to check the effect of various binders and aggregate on the mechanical properties of bituminous mix. 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. These tests help in determining better material for bituminous layer.

4.2 Marshall Mix Design

Marshall Mix design is performed to determine the optimum binder content for the bituminous mixes. The basic principle of Marshall mix design is to achieve maximum durability from bituminous pavement by achieving the impermeability of mix through fully coating the aggregates with bitumen and sealing all voids within the bituminous material. A minimum amount of binder is essential to bind particles of aggregate together when load is applied to it. However, high binder content could result in the instability of the bituminous pavement and could cause bleeding of bitumen under high traffic load. Therefore optimum binder content needs to be determined.

In Marshall Method load is applied at the loading rate of 50.8 mm/minute on prepared standard cylindrical sample of bituminous mix till its failure as specified in ASTM D6927. Load is applied perpendicular to the axis of cylindrical sample through a testing head consisting of a pair of cylindrical segments. Marshal stability is defined as the maximum load carried by the compacted specimen at 60˚C. Flow value is the total deformation of Marshall Specimen corresponding to maximum stability value.

4.2.2 Apparatus

1. Compaction mould assembly:
   i) Cylindrical mould of 101.6mm diameter and height of 75mm consisting of collar ring and base plate.
   ii) Compaction hammer with flat circular plate of 98.4mm diameter and a hammer of 4.5 kg which can be lifted and released upto a height of 457mm

2. Sample extruder: sample extruder preferable fitted with a hydraulic jack for extraction of sample from the mould.
3. Testing head: it consist of upper and lower cylindrical segments as shown in figure 4.1 with inside radius of 51mm.
4. Testing machine: It consists of a motorised loading unit provided with gear system so as to apply a loading rate of 50.8 mm/min. A calibrated proving ring of 10 tons capacity is also fixed with testing machine so as to measure the stability value.
5. Flow meter.
6. Thermostatically controlled water bath.
7. Thermometer.

4.2.1 Steps for Marshall Design

1. Select the grading of aggregate as per requirement
2. Determine the quantity of each aggregate as per selected specification so as to achieve required grading
3. Determine specific gravity of aggregate and binder
4. Prepare the trial samples by varying the quantity of bitumen.
5. Determine specific gravity of compacted specimen
6. Calculate percentage of void present and percentage void filled with bitumen in each sample.
7. Determine stability value and flow value
8. Select optimum binder content from the data obtained.

Figure 4.1: Testing head of Marshall Machine

Figure 4.2: Motorised testing machine for Marshall Test

4.2.3 Sample Preparation

In Marshall Method three compacted samples of bituminous mix are prepared for each trial binder content. Trial Binder content is varied with an increment of 0.5%. Approximately 1200 gm of aggregate sample containing fine aggregate, coarse aggregate and filler is weighted correctly and then heated to a temperature of 160 to 180 ˚C. Simultaneously, bituminous binder is heated to a temperature of 120 to 165 ˚C depending on the type and grade of binder used.

The calculated quantity of bitumen is added to the heated aggregate and then mixture is mixed thoroughly at specified mixing temperature. For VG10 grade bitumen mixing temperature is about 154 ˚C and for VG30 grade bitumen mixing temperature is around 160 ˚C. After mixing the mixture is placed in preheated mould and then compacted by hammer having weight of 4.75kg. A total of 75 numbers of blows are applied on either side of specimen at specified temperature. After this sample is allowed to cool down and then sample is extracted from the mould using sample extruder. After extraction of sample the dimensions of sample, weight of sample in air / water and saturated weight of sample is taken for void analysis.

Figure 4.3: Compacted bituminous concrete samples

4.2.4 Volumetric Analysis

The volumetric properties of specimen help in determining the optimum binder content for the bituminous mix. Durability and performance of bituminous mixes are determined by analysing compacted specimen for:

- Theoretical specific gravity
- Bulk specific gravity
- Percentage air void
- Percentage volume of binder
- Voids in mineral aggregate
- And voids filled with bitumen

4.2.4.1 Specific gravity of mix (Theoretical), G_t

It is the specific gravity of bituminous mix excluding the influence of air voids and is given by:

$$Gt = \frac{W1+W2+W3+Wb}{\frac{W1}{G1}+\frac{W2}{G2}+\frac{W3}{G3}+\frac{Wb}{Gb}} \quad (4.1)$$

Where, W1 = Weight of aggregate (Coarse).

W2 = Weight of aggregate (fine).

W3 = Weight of filler.

Wb = Weight of bitumen.

G1 = Specific gravity of coarse aggregate.

G2 = Specific gravity of coarse aggregate.

G3 = Specific gravity of filler.

Gb = Specific gravity of bitumen.

4.2.4.2 Bulk specific gravity, G_m

Bulk specific gravity is the actual specific gravity of mix considering air voids in the specimen and is given by

$$Gm = \frac{Wm}{Wm - Ww} \tag{4.2}$$

Where, Wm = Weight of mix in air.

Ww = Weight of mix in water.

and (Wm-Ww) = Volume of mix.

4.2.4.3 Percentage of air void, V_v

Air void is the percentage of air voids (by volume) in the compacted specimen given by:

$$Vv = \frac{(Gt - Gm)100}{Gt} \tag{4.3}$$

Where, Gt = Theoretical specific gravity of bituminous mix.

Gm = Actual specific gravity of bituminous mix.

4.2.4.4 Percentage volume of bitumen, V_b

Volume of bitumen is the percent of volume of bitumen in bituminous mix that is given by:

$$Vb = \frac{\frac{Wb}{Gb}}{\frac{W1+W2+W3+Wb}{Gm}} \tag{4.4}$$

Where, W1 = Weight of coarse aggregate.

W2 = Weight of fine aggregate.

W3 = Weight of filler.

Wb = Weight of bitumen.

G1 = Specific gravity of coarse aggregate.

G2 = Specific gravity of coarse aggregate.

G3 = Specific gravity of filler.

Gb = Specific gravity of bitumen.

Gm = Bulk specific gravity of mix.

4.2.4.5 Voids in mineral aggregate, VMA

According to Asphalt Institute (2003), voids in mineral aggregate are the inter-granular void space between the aggregate particles in compacted mixture. VMA is the sum of total air voids and the volume of bituminous binder and is given by:

$$VMA = Vv + Vb \tag{4.5}$$

4.2.4.6 Voids filled with bitumen, VFB

According to Asphalt institute (2003), VMA is the percentage of the volume of inter-granular void space between the aggregate particles that is occupied by the bituminous binder. It is the percentage of void space between the aggregate particles that is filled with bitumen and is given by:

$$VFB = \frac{Vb\ x\ 100}{VMA} \tag{4.6}$$

4.2.5 Marshall Stability and Flow Value

Prior to testing of sample in Marshall Machine, the samples are kept in water bath at a constant temperature of 60˚C for a period of 30 minutes. The samples are placed in Marshall testing head for evaluation of Marshall Stability and flow value. Load is applied on the sample at loading rate of 50.8 mm/minute. The maximum load carried by the specimen till its failure and corresponding deformation are recorded as Marshall Stability and flow value respectively.

Figure 4.4: Hot water bath for Marshall Specimen

4.2.5.1 Stability correction

During preparation of Marshall Specimen the thickness and volume of sample can vary from the standard specification of 63.5 mm. Therefore, the measured Marshall Stability values need to be corrected to those values which would have been obtained if the specimen was of standard specimen thickness of 63.5 mm. This is done by multiplying the each Marshall Stability value by appropriate correction factor as given in Table 4.1.

Table 4.1: Marshall Stability correction factor

Volume of Specimen (cm^3)	Thickness of Specimen (mm)	Correction Factor
457 – 470	57.1	1.19
471 – 482	68.7	1.14
483 – 495	60.3	1.09
496 – 508	61.9	1.04
509 – 522	63.5	1
523 – 535	65.1	0.96
536 – 546	66.7	0.93
547 – 559	68.3	0.89
560 – 573	69.9	0.86

4.2.6 Preparation of Graphical Plots

The average value of various volumetric properties (as specified in Section 4.2.4) is determined for each mix with different bituminous binder content and following graphs are plotted:

1. Bituminous binder content Vs Marshall Stability.
2. Bituminous binder content Vs Marshall Flow.
3. Bituminous binder content Vs Percentage of void in mix.
4. Bituminous binder content Vs Void filled with bitumen (VFB).
5. Bituminous binder content Vs Bulk specific gravity.

4.2.7 Determination of Optimum Binder Content

Optimum binder content is determined by taking the average value of following three parameters:

1. Bituminous binder content corresponding to maximum stability.
2. Bituminous binder content corresponding to maximum bulk specific gravity.
3. Bituminous binder content corresponding to middle value of specified limits of percent air void in total mix i.e. 4%.

The stability value, flow value and VFB are checked with Marshall Mix design specifications for the specified grading as given below in Table 4.2.

Table 4.2: Specified value for Marshall Test

Test Property	Specified Value
Marshall Stability, Kg	900 kg
Flow value, 0.25 mm units	2-4
Percentage air void, Vv (%)	3-6
Void filled with bitumen, VFB (%)	65-75

4.3 Indirect Tensile Strength Test (ITS)

The indirect tensile strength test is used to determine the tensile properties of the bituminous mixture. 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. Indirect tensile strength test indicates strength, temperature cracking and rutting potential of bituminous mixes. ITS test is more popular because this test can be done using the Marshall samples. The indirect tensile strength test is done in accordance with ASTM D6931-17.

The tensile strength of the bituminous mixes is evaluated by loading the Marshall specimen along the vertical diameter plane of the specimen through two opposite loading strips. A 13 mm wide strip loading is used to apply uniform loading to the Marshall specimen at the loading rate of 50.8mm/minute. 13 mm wide strips on both the ends cause tensile failure of specimen rather than compressive failure. Continuous load is then applied on sample perpendicular to the diameter of sample throughout the length of sample till peak load is reached. By measuring the ultimate load and by knowing the dimension of the specimen, the indirect tensile strength of the mixture can be calculated. Ultimate load of the specimen is recorded and tensile strength value is calculated using following expression.

$$St = \frac{2000\,P}{3.14\,D\,t} \tag{4.7}$$

Where, St is indirect tensile strength, kPa

P is the maximum load on proving ring, N

t is the height of specimen before test, mm

D is the diameter of specimen, mm

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Figure 4.5: ITS sample for SBS modified bitumen

Figure 4.6: SBS modified samples after tensile failure

Figure 4.7: ITS samples for Zycotherm modified bitumen

Figure 4.8: Zycotherm modified bitumen samples after tensile failure

CHAPTER 5

RESULTS AND DISCUSSION OF BITUMINOUS MIX

5.1 Introduction

In this study Marshall Method of mix design is used for designing and comparing various types of mixes. Bituminous mixes were prepared using two different types of aggregate i.e. limestone and riverbed aggregates. There were 8 different types of binder used in this study 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. In addition to Marshall Test, Indirect Tensile Strength test is also performed so as to differentiate different material with different binder based on its tensile strength value.

5.2 Optimum Binder Content

Marshall Method of mix design is used to determine the optimum binder content for VG30 bitumen and both aggregates. Binder content of 5 – 7% by total weight of mix is allowed as per MoRTH specification for 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%, 5.5%, 6%, and 6.5%. Three samples were prepared for each binder content. Volumetric analysis and stability-flow analysis was done for all the samples. Average value for three samples at single binder content was measured and recorded. Recorded results were evaluated to calculate the optimum binder content for both aggregates i.e. limestone aggregate and riverbed aggregate.

5.2.1 Riverbed Aggregate

Table 5.1 presents the results of various tested Marshall Properties for riverbed aggregates. Maximum stability value for riverbed aggregate was attained at 5% binder content for VG30 bitumen. Maximum density was achieved at 5.5% binder content and binder content corresponding to 4% void was 5.3%. As per Marshall Method of mix design, optimum binder content is average of these three bitumen content. Therefore optimum binder content for river bed aggregate is 5.26% by total weight of mix. Further the value for flow, air void, void filled with bitumen is observed corresponding to the value of optimum binder content from the graphs plotted in Figure 5.2, 5.3 and 5.4 and the values are checked with standard MoRTH Specification.

Table 5.1: Marshall Test data for riverbed aggregate

Binder content. (%)	Bulk density, (gm/cc)	Air void, (%)	Void filled with bitumen, (%)	Corrected stability, (kg)	Flow, (mm)	Marshall quotient, (kg/mm)
4.5	2.38	6.5	61.4	1681	2.5	672
5.0	2.39	5.56	67.58	2008	2.7	735
5.5	2.406	2.82	82.21	1756	4.6	381
6.0	2.406	0.96	93.77	1360	5.6	242
6.5	2.401	0.58	96.34	1244	5.7	210

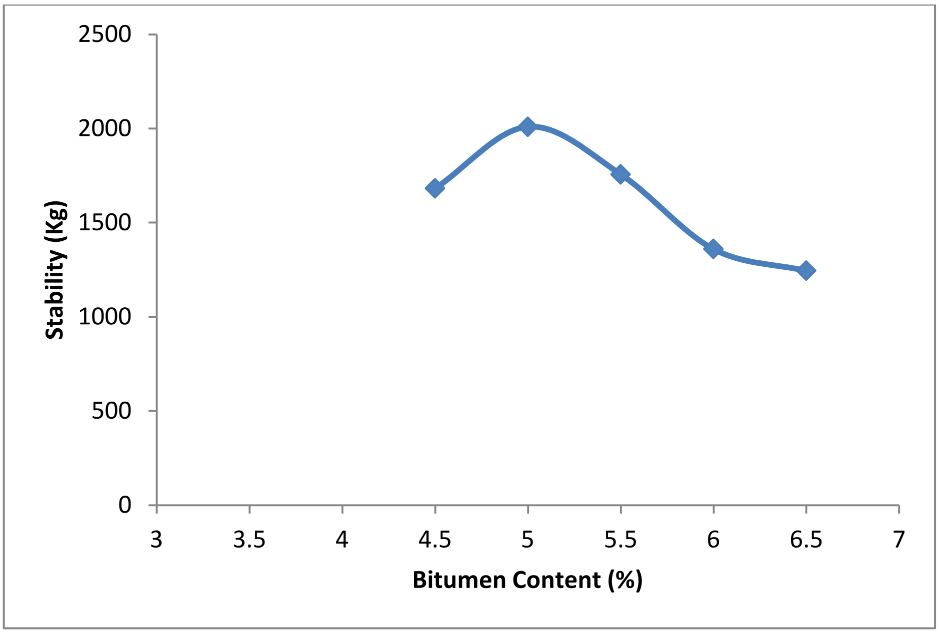

Figure 5.1: Stability Vs bitumen content for riverbed aggregate

It can be observed from the Figure 5.1 that when 4.5% bitumen (by weight of mix) was added in bituminous mix then the stability value was 1681 kg. With increase in bitumen content to 5% there was an increase in stability value to 2008 kg and with further increase in bitumen content there was a gradual decrease in stability value. At lower binder content of 4.5%, there was not enough binder content to bind aggregate efficiently together so the stability value was less. At higher binder content of 5.5 to 6.5%, binder quantity was more which cause a gradual decrease in stability value.

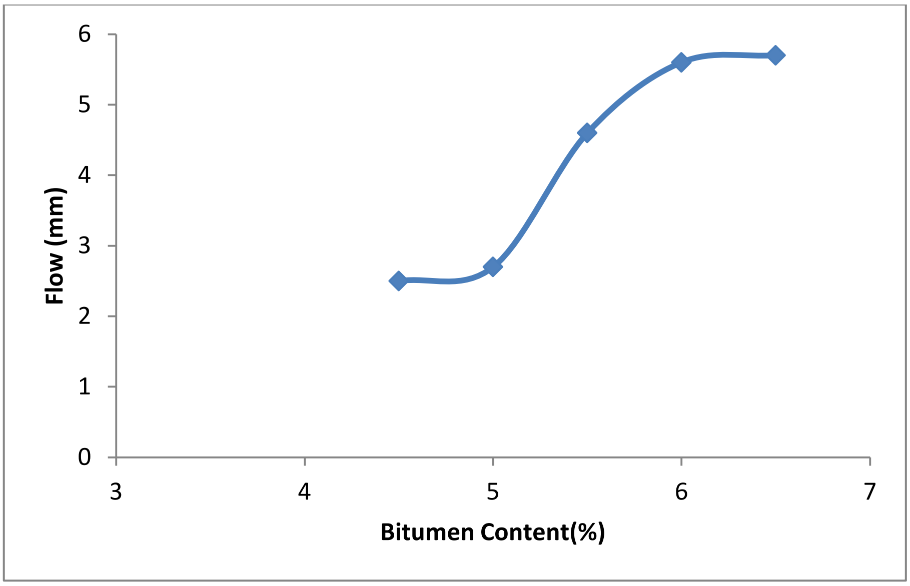

Figure 5.2: Flow Vs bitumen content for riverbed aggregate

From Figure 5.2 it was observed that with increase in binder content there was an increase in flow value. This signifies that with increase in binder content there is more deformation on specimen when loading is applied on it.

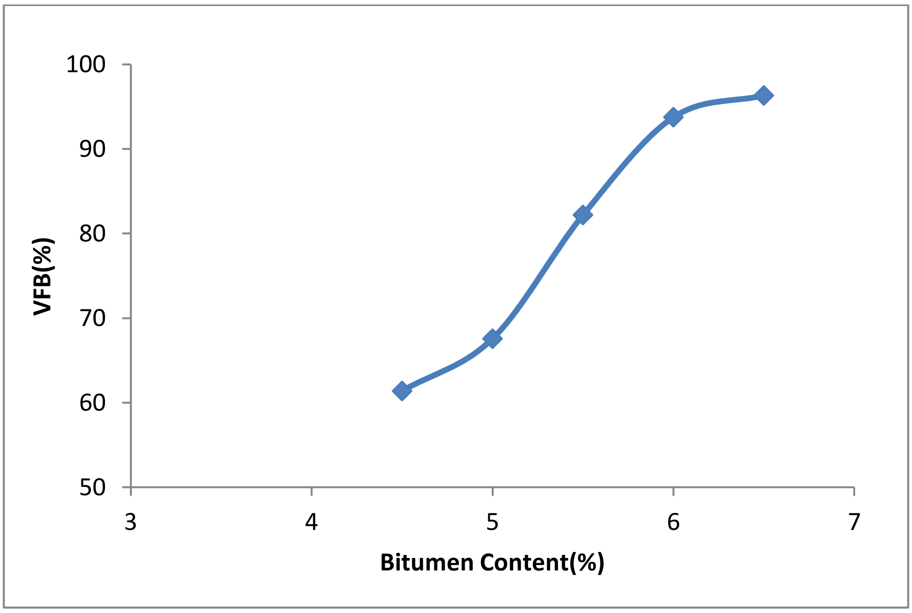

Figure 5.3: VFB Vs bitumen content for riverbed aggregate

It can be observed from Figure 5.3 and 5.4 that with increase in binder content in bituminous mix, more voids are getting filled with bitumen and void % in specimen is decreasing with corresponding increase in binder content.

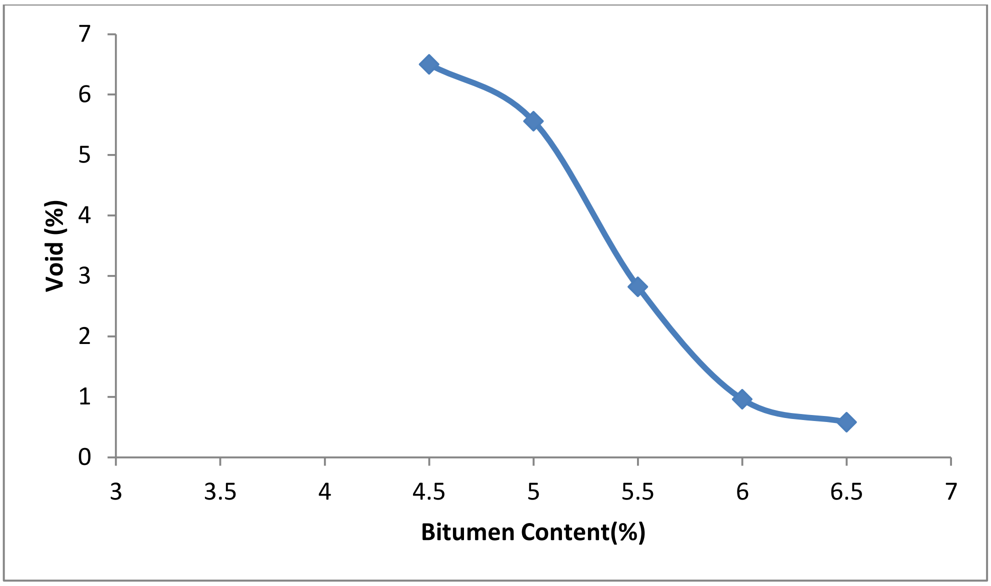

Figure 5.4: Void % Vs bitumen content for riverbed aggregate

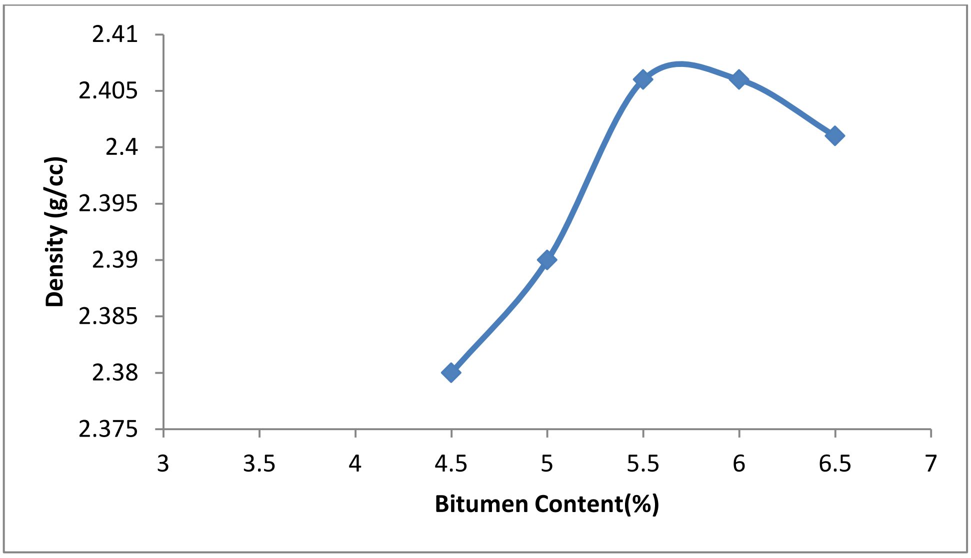

Figure 5.5: Density Vs bitumen content for riverbed aggregate

5.2.2 Limestone Aggregate

Table 5.2 presents the results of various tested Marshall Properties for mixes prepared with limestone aggregates. Maximum stability value was attained at 5% binder content for VG30 bitumen. Maximum density was achieved at 5.5% binder content and binder content corresponding to 4% void was 5.4%. As per Marshall Method of mix design optimum binder content is average of these three bitumen content. Therefore optimum binder content for river bed aggregate is 5.3% by total weight of mix. Further the value for flow, air void, void filled with bitumen is observed corresponding to the value of optimum binder content from the graphs plotted in Figure 5.7, 5.8 and 5.9 and the values are checked with standard MoRTH Specification

Table 5.2: Marshall Test data for limestone aggregate

Binder content, (%)	Bulk density, (gm/cc)	Air void, (%)	Void filled with bitumen, (%)	Corrected stability, (kg)	Flow, (mm)	Marshall quotient, (kg/mm)
4.5	2.41	5.77	64.17	2018	3.43	587
5.0	2.43	4.48	72.19	2313	3.46	667
5.5	2.44	2.39	76.66	1834	4.33	423
6.0	2.43	2.44	85.27	1442	4.9	294
6.5	2.41	2.06	87.98	981	6.03	162

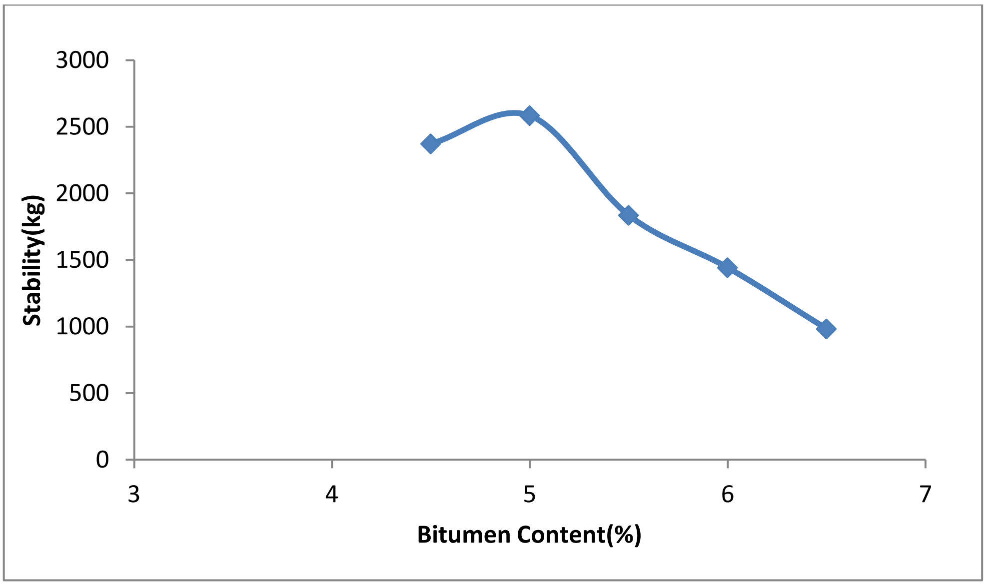

Figure 5.6: Stability Vs Bitumen content for limestone aggregate

It can be observed from the Figure 5.6 that when 4.5% bitumen (by weight of mix) was added in bituminous mix then the stability value was 2018 kg. With increase in bitumen content to 5% there was an increase in stability value to 2313 kg and with further increase in bitumen content there was a gradual decrease in stability value.

From Figure 5.7 it was observed that with increase in binder content there was an increase in flow value. This signifies that with increase in binder content there is more deformation on specimen when loading is applied on it.

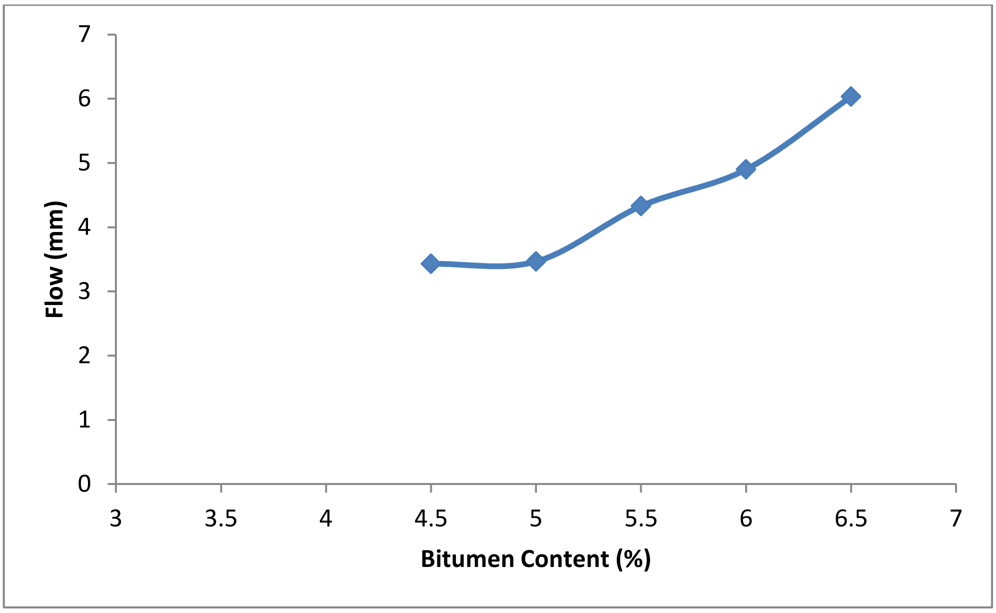

Figure 5.7: Flow Vs Bitumen content for limestone aggregate

It can be observed from Figure 5.8 and 5.9 that with increase in binder content in bituminous mix, more voids are getting filled with bitumen and void % in specimen is decreasing with corresponding increase in binder content.

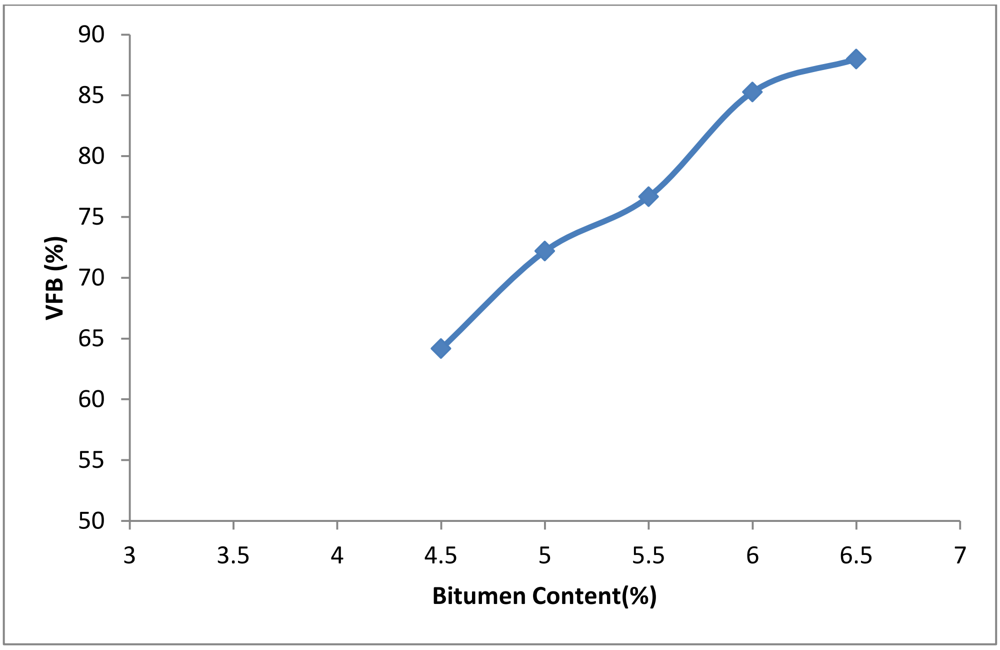

Figure 3.8: VFB Vs bitumen content for limestone aggregate

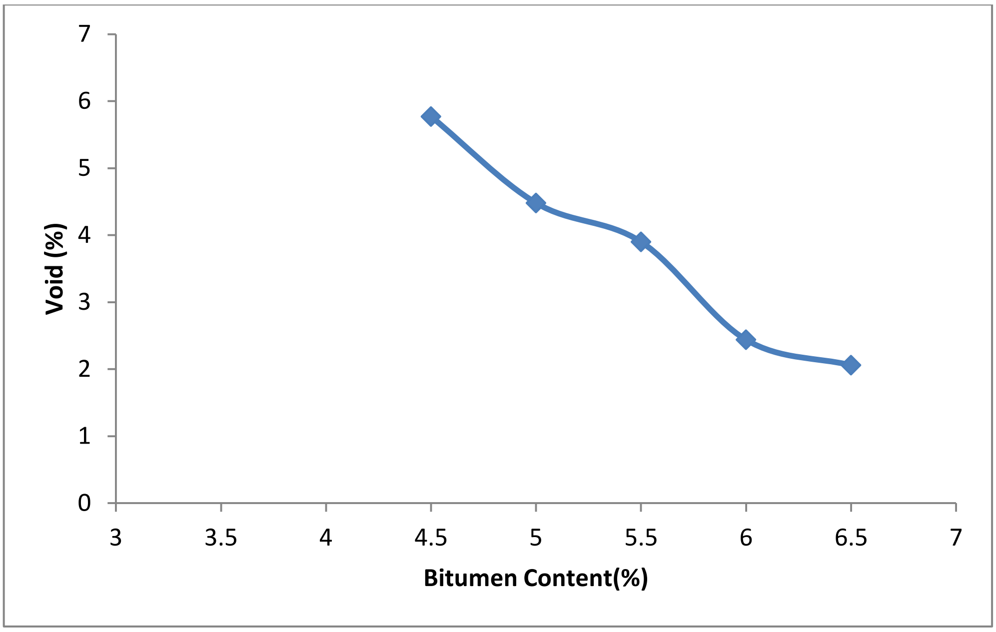

Figure 5.9: Void % Vs bitumen content for limestone aggregate

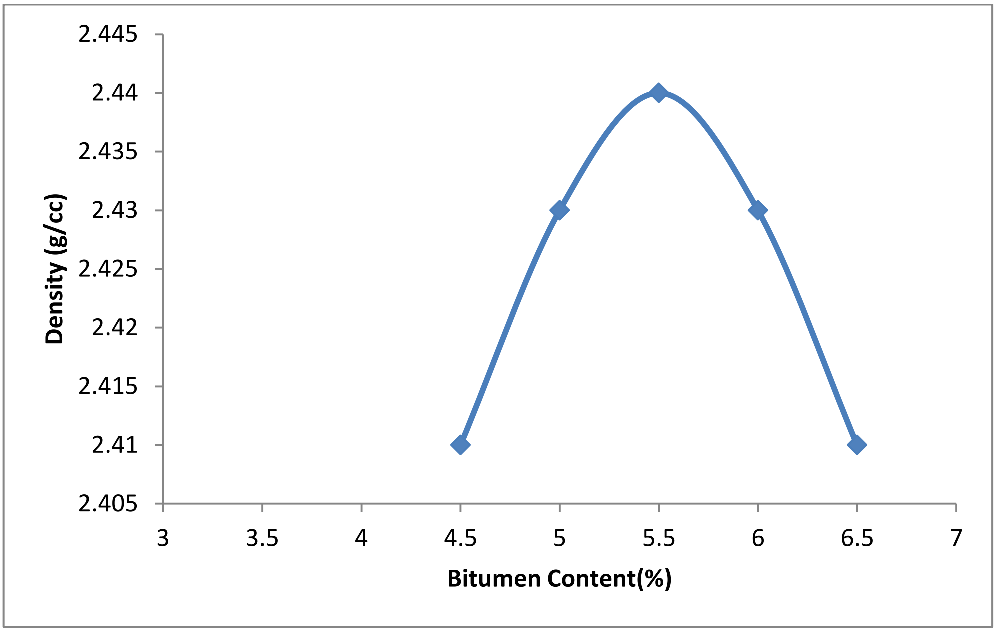

Figure 5.10: Density Vs bitumen content for limestone aggregate

5.2.3 Effect of different aggregates on optimum binder content

It was observed that for same gradation the optimum binder content for limestone aggregate is more as compared to riverbed aggregate. The optimum binder content is 5.26 % for riverbed aggregate and optimum binder content is 5.3% for limestone aggregate. This is due to the difference in absorption capacity of limestone and riverbed aggregate.

5.3 Marshall Stability and Flow Value

Marshall Stability and flow values for different type 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 and different type of aggregate i.e. limestone and riverbed aggregate were recorded and compared with each other as shown in table 5.3. Effect of different binder and different aggregates is studied from the Marshall Stability and flow values of each sample.

Table 5.3: Marshall Stability and flow value

Type of binder	Limestone aggregate		Riverbed aggregate	
	Stability, (kg)	Flow, (mm)	Stability, (kg)	Flow, (mm)
VG30 + 3% SBS	2523	3.55	2446	3.75
VG30 + 5% SBS	2828	3.3	2726	3.45
VG30 + 7% SBS	2854	3.2	2737	3.32
VG30 + Zycotherm	2344	3.6	2014	3.75
VG30 + 3% SBS + Z	2497	3.5	2446	3.8
VG30 + 5% SBS + Z	2803	3.22	2675	3.5
VG30 + 7% SBS + Z	2828	3.12	2701	3.3

5.3.3 Effect of binder on Marshall Stability and flow value

From results of Marshall test presented in Table 5.3, it was seen that with increase in SBS percentage from 3 to 7% there was an increase in stability value and corresponding decrease in flow value. It was also observed that with an increase in SBS percentage from 5 to 7% did not result in a significant increase in stability value. Figure 5.11 and 5.12 presents a camparison of Marshall Stability for SBS modified mixes for riverbed aggregate and limestone aggregate respectively. From these figures, it can be observed that addition of Zycotherm does not result in a major change in Marshall Stability in VG30 and SBS mixes prepared with riverbed aggregate and limestone aggregate

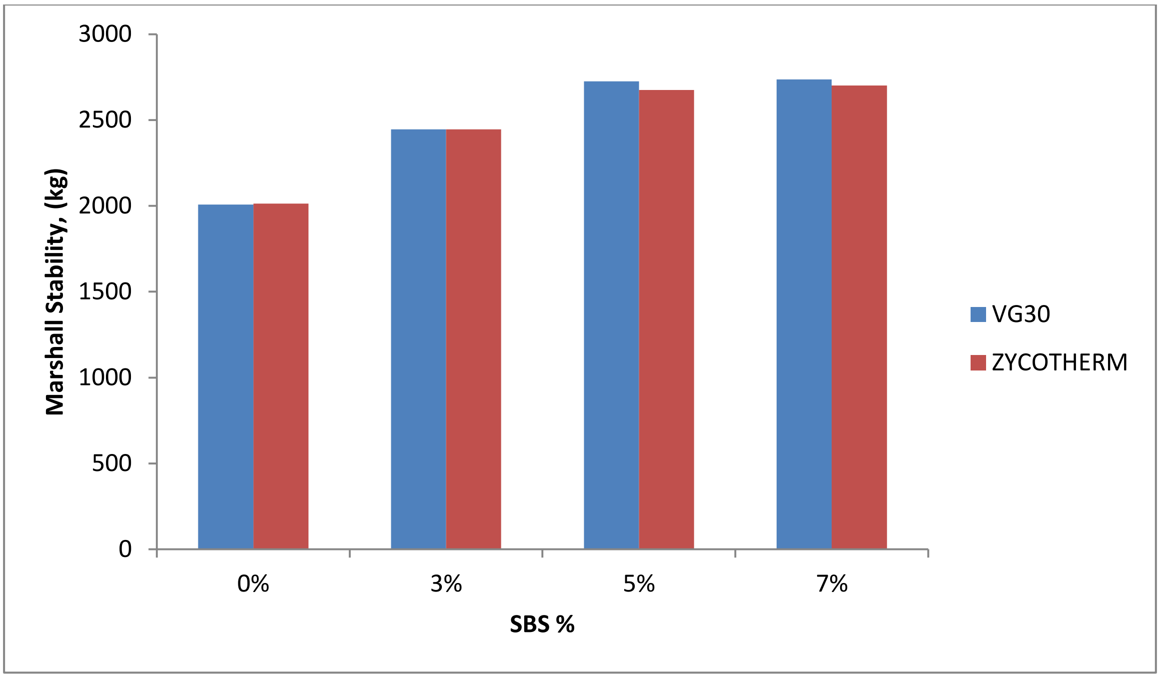

Figure 5.11: SBS% Vs Marshall stability for riverbed aggregate

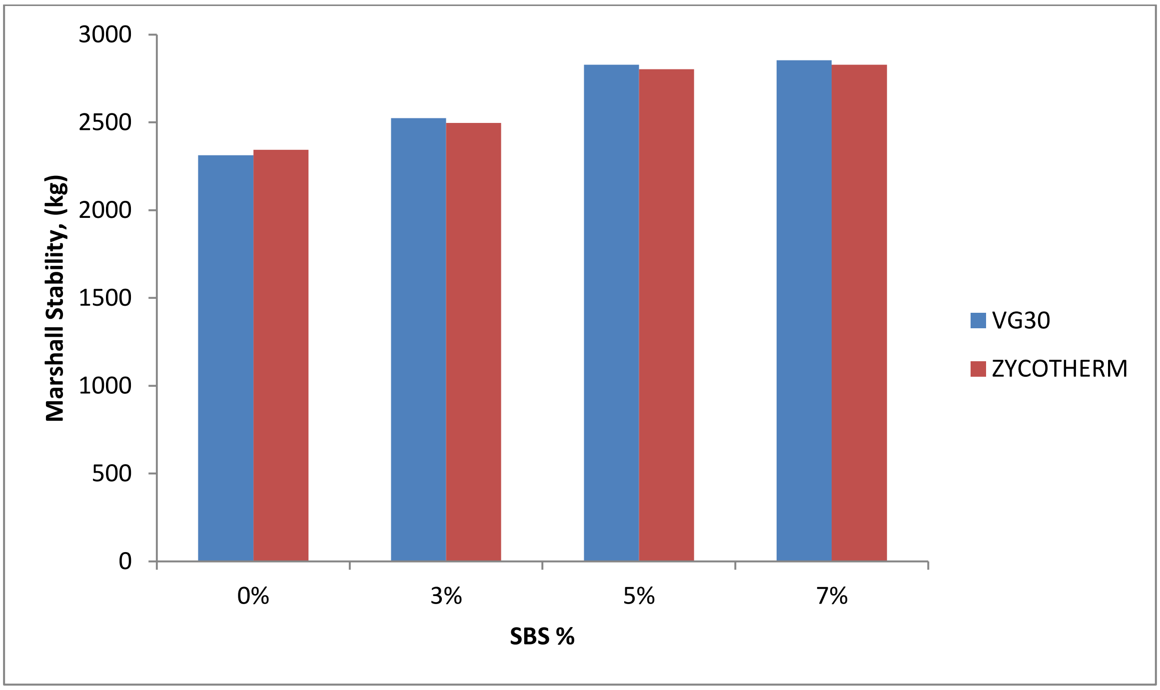

Figure 5.12: SBS% Vs Marshall Stability Value for limestone aggregate

5.3.4 Effect of different aggregate on Marshall Stability and flow value

Figure 5.13 presents a comparison of the stability values for different mixes for different aggregate type. It was observed that limestone aggregate has higher Marshall Stability value as compared to riverbed aggregates for all binder type. Limestone aggregate mixes exhibit higher flow value as compared to riverbed aggregate mixes. 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.

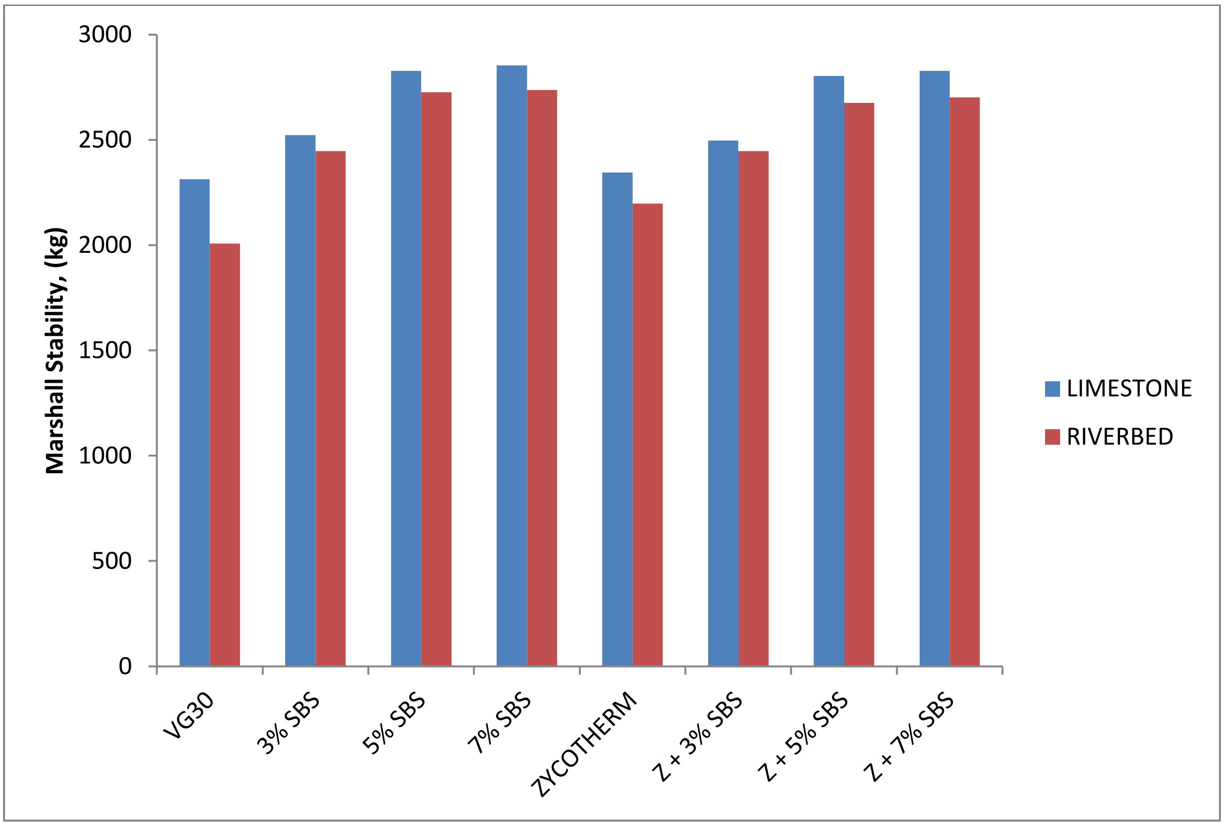

Figure 5.13: Comparison of different aggregates for different binder

5.4 Indirect Tensile Strength Test

Indirect tensile strength (ITS) 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. The results of ITS test were evaluated and compared based on different binder type and different aggregates. These results are shown in Table 5.4.

Table 5.4: ITS value for different mixes

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

5.4.1 Effect of binder on ITS value

From Table 5.4, It was observed 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. Additon of zycotherm additive on SBS modified bitumen does not have any effect on ITS value. Zycotherm additive has no effect on ITS value for neat VG30 binder and SBS modified binder.

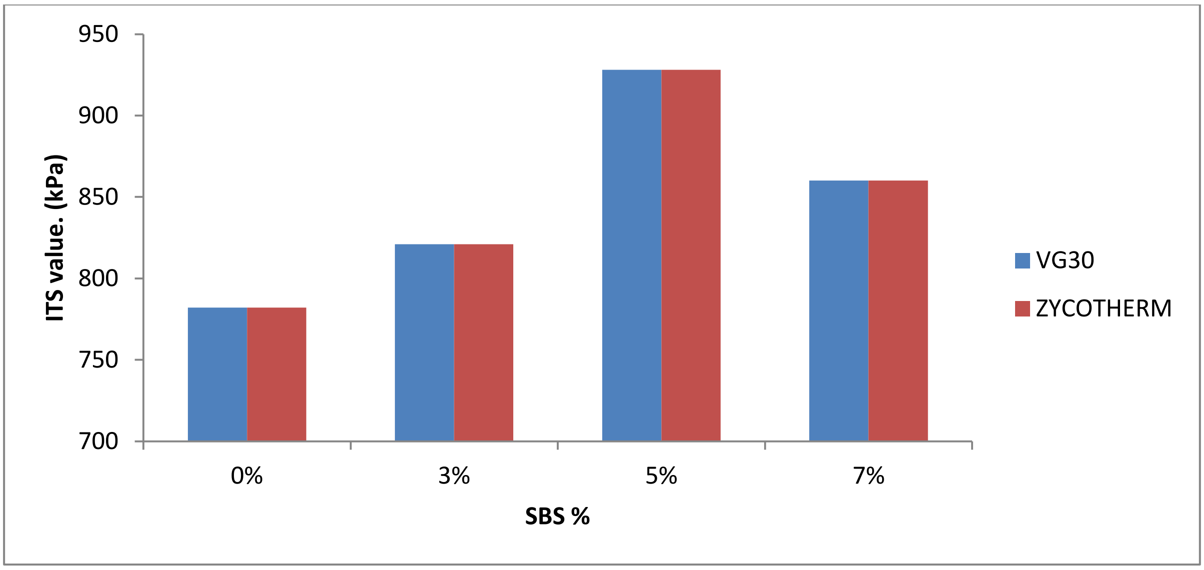

Figure 5.14: SBS% Vs ITS value for limestone aggregate

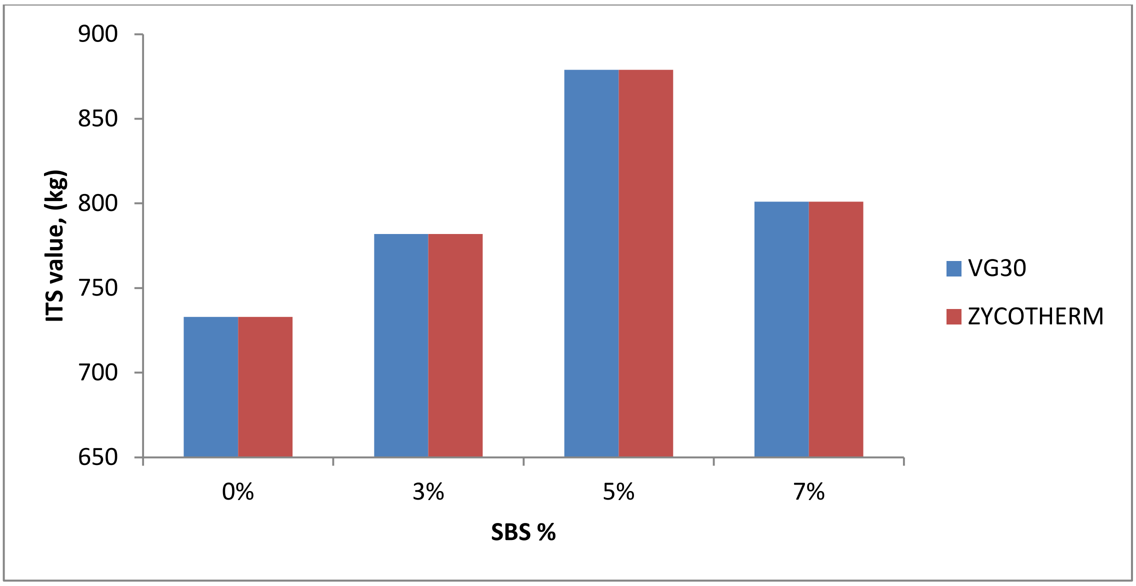

Figure 5.15: SBS% Vs ITS value for riverbed aggregate

5.4.2 Effect of aggregate on ITS value

Figure 5.14 and 5.15 presents the ITS values of various binder mixes of limestone and riverbed aggregate respectively. It was observed that limestone aggregate has more ITS value than riverbed aggregate for same aggregate gradation. This increase in ITS 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.

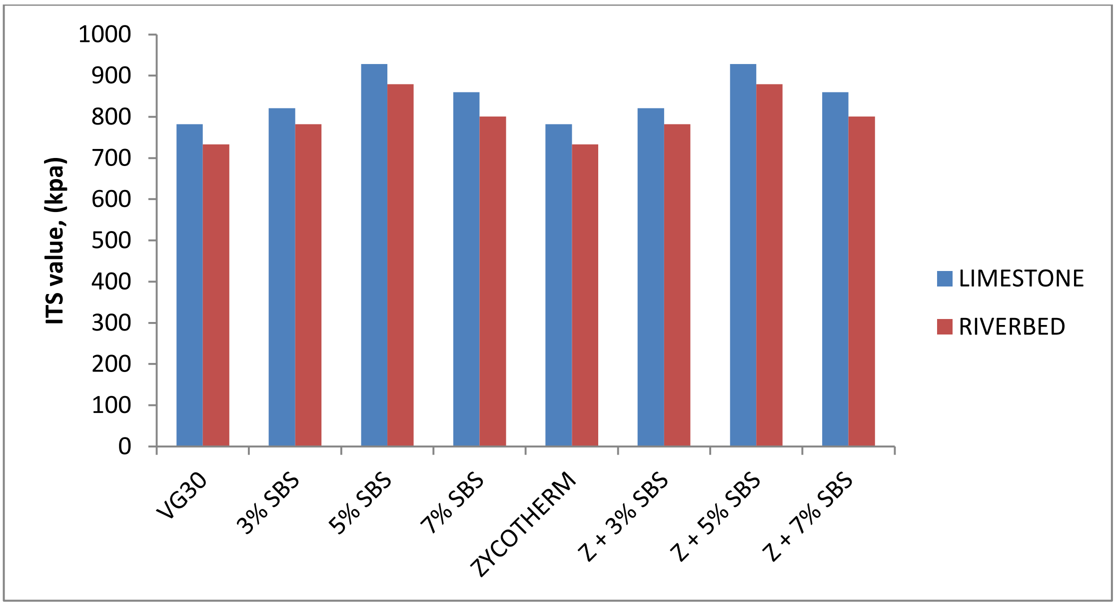

Figure 5.16: Comparison of different aggregate with different binder

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Based on various conventional and rheological test performed on bitumen and based on results drawn from bituminous mixes following conclusions were made:

1. Optimum binder content for VG30 bitumen for limestone aggregate is higher as compared to riverbed aggregate i.e. 5.3% for limestone aggregate and 5.26% for riverbed aggregate.
2. Marshall Stability value for limestone aggregate was higher as compared to riverbed aggregate for all the binders used in this study.
3. It was observed that the indirect tensile strength of all binder mixes prepared using limestone aggregate was higher than the corresponding values for mixes prepared using riverbed aggregates. This implies that limestone aggregate mixes are more resistant to fatigue cracking as compared to riverbed aggregate mixes.
4. Addition of SBS polymer in bitumen results a decrease in penetration value and increase in softening point upto a critical concentration of 5% SBS addition. As the concentration of SBS was increased to 7% the decrease in penetration value and increase in softening point was not that much significant. Thus 5% SBS modification is recommended. Moreover increasing the percentage of SBS can also result in phase separation of polymer in bitumen. Zycotherm additive does not show any significant increase in performance of binder as per conventional test.
5. 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
6. Rheological test on bitumen showed with increase in percentage of SBS in bitumen binder there is an increase in rutting performance of bituminous concrete layer. 5% of SBS and 7% of SBS in bitumen showed nearly similar results. Thus 5% SBS was selected to be the optimum dosage for bitumen.

7. Marshall Stability value for SBS modified bitumen was high and optimum dosage for SBS was chosen to be 5% because with increase in SBS percentage to 7% the stability value began to stabilise. Zycotherm additive has not altered the performance of normal binder and SBS modified binder.
8. Indirect tensile strength showed that addition of SBS in bitumen has increased the tensile strength value of bituminous mix. 5% SBS is chosen as the optimum dosage for bitumen based on ITS values. Zycotherm additive has not altered the performance of normal binder and SBS modified binder.
9. 5% SBS modification in bitumen showed better performance overall. 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.

6.2 Recommendations for future research

1. This study was conducted on only two aggregate i.e. limestone and riverbed. Further research can be carried out to compare the performance mixes with aggregates from various sources and replacement of conventional aggregates using basalt, slag etc.
2. Influence of addition of SBS polymer and Zycotherm additive is studied in this research. The research could be extended further by comparing the performance of binder mixes with different polymers like Crumb rubber, EVA etc. and other additive like Sasobit, Rheofalt etc.
3. In this study Marshall Test and ITS test were conducted to study the properties of mixes. Further tests like moisture susceptibility test, static creep test and wheel tracking test can be performed to check the performance of different binders with different aggregates.

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