ENGINEERING CHARACTERIZATION OF SULPHUR MODIFIED BITUMINOUS BINDERS

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ABSTRACT

The demand on bituminous flexible pavement, as a result of growth in heavy traffic loads and their tyre contact pressure with adverse climatic conditions, fatigue and rutting performance has resulted in an interest towards the modified bituminous binders. There are various popular modified binders already available worldwide. These modifiers significantly alter the rheological and morphological properties of the binder, as characterized by rheological testing methods along with the morphological rather than the conventional methods, to enhance the performance of the binder. This study is intended towards the modification of the conventional viscosity grade VG 30 bitumen and applications of commercial sulphur available in local market to modify the VG 30 bitumen and to evaluate the rheological characteristics of unaged and aged samples of these two binders using a Dynamic Shear Rheometer (DSR). Attempt has been made to decide the appropriate conditions for binder development such as mixing/blending time and temperature to ensure proper modification, through the rheological parameters of phase angle and complex modulus. This development ultimately helps to influence the fatigue and rutting resistances of bituminous mixes. The modification of bitumen with sulphur at six different mixing temperature such as 100ºC, 110ºC, 120ºC, 130ºC, 140ºC, 150ºC and 160ºC, each made at five different mixing times such as 5 min, 10 min, 15 min, 20 min, 30 min. has also been carried out. The optimum modification level has been evaluated considering unaging and aging criteria for five sulphur contents such as 1%, 2%, 3%, 4% and 5% by weight of the bitumen. It is observed that the addition of 2% sulphur by weight with bitumen blended at 140ºC temperature for about 30 min., results in the best modification of VG 30 bitumen in terms of the rheological properties, and satisfying the requirements of conventional properties.

Key words: *Bitumen, Rheology, Viscosity, Elasticity, Phase angle, Complex Shear Modulus.*

INTRODUCTION

In India roads and highways are preferred as primary modes of transportation. Roads constructed with flexible pavements always given more importance due to its smooth riding quality and less construction costs than in case of rigid pavements. Bituminous materials along with aggregates are utilized for the construction of flexible pavement roads. The Indian road transportation infrastructure is a great challenge in development of National Highways Development Programs (NHDP), Pradhan Mantri Gram Sadak Yojana (PMGSY) and State Highways Improvement Programs (SHIPs) etc. where huge money is being invested by the Government of India in order to empower the pavement performance.

Bitumen is a civil engineering material used for construction of highways in terms of Flexible pavement. One of the advantage of bitumen as an engineering construction material is its great versatility. Bitumen is a strong binding material that has very high adhesive property and highly waterproof and durable, making it useful in road Constructions. It is also highly resistive to the actions of most acids, alkalis, and salts

[Minnesota Asphalt Pavement Association, 2003].

The principle of use of bitumen is as a binder in the road construction where it is mixed with aggregate to produce bituminous mixture. This mixture is then laid as the structural pavement layers as base and surface course of a road. The main function of these 'bitumen-bound' layers is to transfer upcoming traffic loads evenly over the unbound pavement layers of the road and natural sub-grade to prevent failure due to overstressing [Airey, 2009].Bitumen being a viscoelastic material is effectively used as a binder. VG-30 and VG-10 grades of bitumen are commonly used as depending on the climatic conditions. In addition to increase the performance in terms of stiffness and elasticity, bituminous mixture must be able to resist the most and primary modes of flexible pavement distress types, namely, fatigue cracking and permanent deformation, known as rutting failure. As the mechanical properties of bituminous mixture are strongly dependent upon the properties of the binder, it has to fulfil certain mechanical and rheological requirements to ensure the integrity of the road [Lesueur, 2009].

Generally two characteristics of bitumen affect the service life of flexible pavement. First it has to stiff enough to resist rutting deformation at the highest pavement service temperature nearby 60ºC, depending on the climate. Second, it should be elastic enough at lower temperatures down to 20ºC depending on the local climate to resist fatigue cracking. But due to the increase in heavy traffic loading and adverse climatic conditions the conventional VG-30 bitumen is not fulfilling the performance criteria in the improvement of service life of the flexible pavement. To enhance the flexible pavement performance regarding fatigue and rutting resistance of the bitumen so as the pavement, bitumen need to be modified with some additives whose tendency is to empower the bitumen performance. Several modifiers are available in the market. But in this study sulphur in powder form has been utilized as a modifier by considering its huge production in industries.

The performance related study of bitumen is also known as bitumen rheology and its analysis is conducted by Dynamic Mechanical Analysis. The rheological properties of bitumen are typically determined in terms of dynamic mechanical analysis (DMA) utilizing a dynamic shear rheometer (DSR) tests. The test is lead within the linear viscoelastic (LVE) region [Airey, 2002a]. The rheological properties of bitumen have been growing and importance in specifications in the USA since the early 1990's following the Strategic Highway Research Program (SHRP). The DSR instrument, however, does have its limitations where the measured rheological data are exposed to the measurement error particularly at low temperatures and/or high frequencies.

Apart from these the modification process has a great importance on the homogeneity of the modification of bitumen with sulphur modifier. The morphological analysis provides an idea about the disperse medium of unmodified and modified bitumen, as a result of which the homogeneity of the blending of bitumen with modifier can be observed properly.

LITERATURE REVIEW

Resistance to flow of a liquid is known as Viscosity and also can be defined as the ratio between the applied shear stress and the rate of shear strain. It is well known as a fundamental characteristic of bitumen. Viscosity of a fluid are defined in two ways as absolute and kinematic viscosity. In general, specifications are based on determination of absolute viscosity at 60°C and kinematic viscosity at 135°C using Dynamic shear rheometer and vacuum tube capillary viscometers respectively. Absolute viscosity can also be measured using a fundamental method known as vacuum capillary tube viscometer.

The rotational viscometer test according to ASTM D 4402-02 is presently considered to be the most practical means of determining the viscosity of bitumen. The thermoset system based Brookfield rotational viscometer, allows the testing of bitumen over a wide range of high temperatures. The viscosity of bitumen is determined for various shear rates according to the variation in R.P.M. of the spindle. To get very accurate viscosity torque of the spindle should be at least 10%. The torque on the rotating spindle is used to determine the relative resistance to rotation of the binder at a particular temperature and shear rate. The torque value is then changed by means of calibration factors to yield the viscosity of the bitumen [Airey, (2009)].

The performance of bituminous pavements is not characterized only by physical properties as they are subjected to complex environmental and loading conditions. In addition to this modified bituminous binders also cannot essentially be characterized only by the empirical properties. It is very much important to understand stress-strain behavior of bituminous binders under a wide range of loading time and temperatures conditions. Thus, fundamental tests were established to investigate dynamic mechanical properties and viscoelastic behavior of binders under various environmental conditions. The Strategic Highways Research Program (SHRP), United States of America, developed a synchronized effort to produce binder specifications which are classified based on performance-grade system in accordance with the fundamental testing results[Petersen et al., 1994; Anderson et al., 1994].

Rheology is a part of continuum mechanics and the study of flow and deformation. Rheology is the description of the dynamic mechanical properties for different materials under various deformation conditions [Vinogradov et al (1980)]. The rheological properties of asphalt binder as an indicator of performance of flexible pavement, which are related to the permanent deformation and fatigue cracking of flexible pavement at high and low temperature respectively. With improved rheological properties of asphalt binder, resistance to fatigue and rutting stiffness values has been improved [Bahia and Davies (1994)].

The rheological properties of asphalt binder play an important role in the performance of asphalt flexible pavement. The fundamental asphalt binder rheology can be used to quantify the performance asphalt flexible pavement. Dynamic shear rheometer (DSR) apparatus is used to evaluate the rheological properties of asphalt binder [Anderson et al (1994)]. Dynamic shear rheometer was used to evaluate the effect of ageing on polymer modified bituminous binder rheology. The test results are used to evaluate the changes in the rheological properties of SBS polymer modified binder. He concluded that there is increase in the viscous behavior of modified binder after aging as compared to elastic behavior of unmodified bitumen [Airey. (1997)].

The dynamic shear rheometer (DSR) was used to characterize the viscoelastic behavior of bituminous binder over a wide range of temperatures. The Stress-strain behavior defines the response of binder to loading conditions. Asphalt binder exhibits both elastic and viscous behavior for which it is well known as a viscoelastic material [Bahia and Anderson (1995)].

Sulfur utilized as a restoration executor in recycling reclaimed asphalt pavement from a normal fizzled section of Dammam-Abu (Hadriyah Expressway) [Arora and Rahman (1985)]. Research facility testing system was planned to measure upgrades in building properties of sulfur-asphalt-sand (SAS) blends attributable to the vicinity of sulfur in the mix considering mainly accessible sands and predominating natural conditions in eastern Saudi Arabia [Akili (1985)]. Sulfur augmented asphalt as a real outlet for sulfur that outflanked other asphalt mixes blends in the Gulf [Mohammed et al (2010)].

The Federal Highway Administration (FHWA) finished a field study to analyze the execution of sulfur-expanded asphalt (SEA) to expected asphalt concrete (AC). The essential decision was that there was no distinction in general execution between the SEA and AC segments. Sulfur did not build or abatement most test properties, and regularly it had no impact on a given test property of a mixture. Sulfur did diminish the imperviousness to dampness helplessness in the research facility. There were likewise minor patterns showing that with some mixtures, sulfur might decrease the helplessness to rutting and expanded the weakness to fatigue cracking. Sulfur extended asphalt blend utilized within asphalt mix design. It finishes up that Thiopave has the potential to decrease the general obliged asphalt pavement depth while as of now controlling strain at the bottom of the asphalt [David and Mary (2009)].

The convergence of the altered sulfur pellets in the mixture is intended to improve asphalt mixture properties keeping up workability and similarity. The results inferred that the asphalt mixtures holding the changed sulfur pellets were indicated enhanced execution contrasted with the customary asphalt mixtures [Bailey and Allen (2009)].

METHODOLOGY

The viscoelastic behavior of bitumen is exceptionally complex to depict by basic traditional experiments of consistency, for example, penetration tests and softening point tests. Hence, the assessment of bitumen attributes ought to be focused around its performance regarding fatigue and rutting safety. Hence, new test instruments like the Dynamic Shear Rheometer (DSR), Brookfield Viscometer have been created to give rheological properties of bitumen over an extensive variety of loading and encompassing conditions.

The DSR might be acknowledged as the most compelling and complex instrument for characterization of the bitumen flow properties. It is additionally really vital to comprehend the chemical progressions of bitumen that has been made throughout change by sulphur. To study the chemical compound arrangement framing, thermal and morphological investigation of unmodified and modified bitumen, a few tests have been led utilizing new innovation instruments, for example, FESEM, TGA, DTA and FTIR Spectroscopy individually.

Determination of rheological properties of bitumen

Rheological properties are utilized as execution parameter has favorable circumstances and disadvantage. The point is that it permits estimation of physical properties with wide temperature range at high and low recurrence, which is prone to be accomplished in the field because of movement. Dynamic shear rheometer need qualified individual with high encounter to work the element tests and additionally to get great rheological results. In this section a concise representation of the element shear rheometer (DSR) device and in addition the geometry and example creation and example measurement will be exhibited. In this section additionally a point of interest description of all rheological test methods received for the characterization of materials are given.

The examination led for the Strategic Highway Research Program (SHRP), testing system acquainted with describe the rheological, durability and failure properties of asphalt binders totally focused around the rheological properties. The examination results were examined in four principle points:(i) The viscoelastic nature of bitumen and its connection to performance of pavement; (ii) the crucial issues identified with these tests and; the sorts of traditional estimations are utilized now (iii) the idea of selecting the new test routines and the new properties; and (iv) how to analyze the new measured properties to the traditional properties.

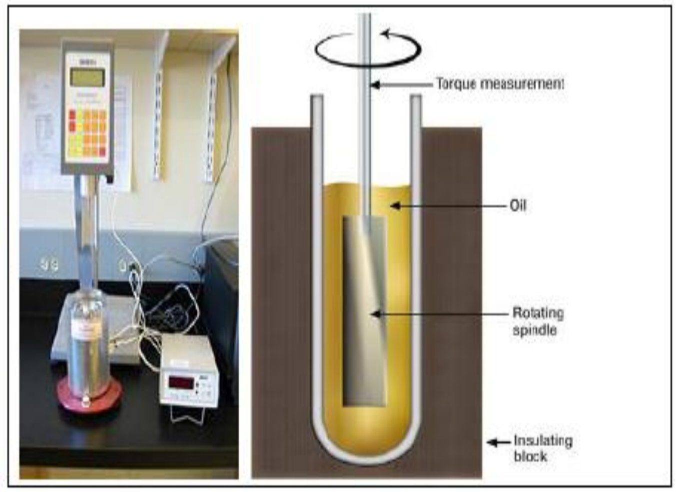


Figure: Rotational Viscometer and working principle.

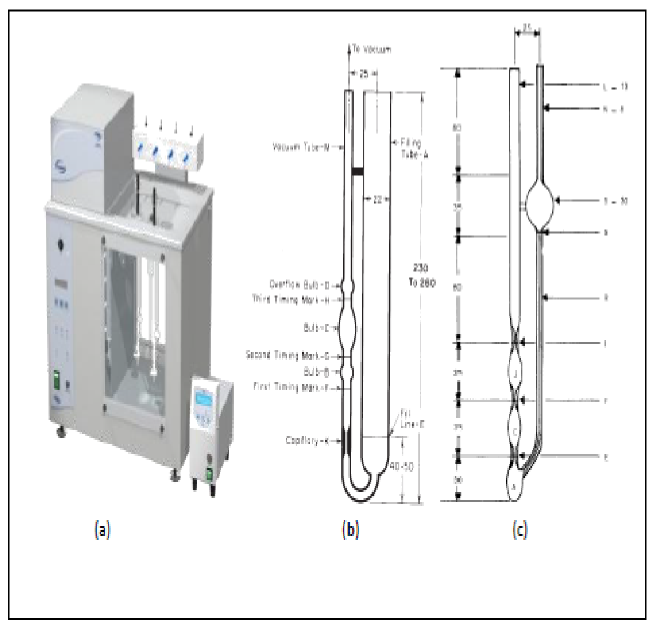
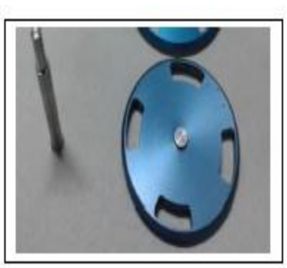


Figure: (a) Cannon Capillary Vacuum Viscometer (b) Glass tube for Absolute viscosity measurement (c) glass tube for Kinematic viscosity measurement.

Specimen geometry

The DSR geometry was picked as indicated by the test condition and particular. The 25mm diameter geometry with specimen thickness (1mm) utilized for high temperature test to spare the sample from dissolving. At intermediate road temperature the sample ought to have little diameter (8mm) with specimen thickness (2mm) to keep it from fatigue failure. The DSR geometry has been shown in [figure 3.5].The bitumen specimen is sandwiched between two parallel plates. The upper plate geometry is permitted to pivot about its own particular hub while base plate stays settled throughout testing.



25mm Parallel Plate 8 mm Parallel Plate

Figure: Two Types of Parallel Plate Geometry.

Phase Angle

For an applied stress shifting sinusoidal with time, a viscoelastic material will additionally react with a sinusoidal strain for low amplitudes of stress. The sinusoidal variety in time is typically portrayed as a rate specified by the recurrence (f = Hz; □ =rad/sec). Phase angle is defined as the lag between the applied stress and resulting strain of a body when subjected to a sinusoidal shear stress. The phase angle is a critical parameter to portray the viscoelastic behavior of bitumen, which is a yield result from the dynamic mechanical examination through DSR.

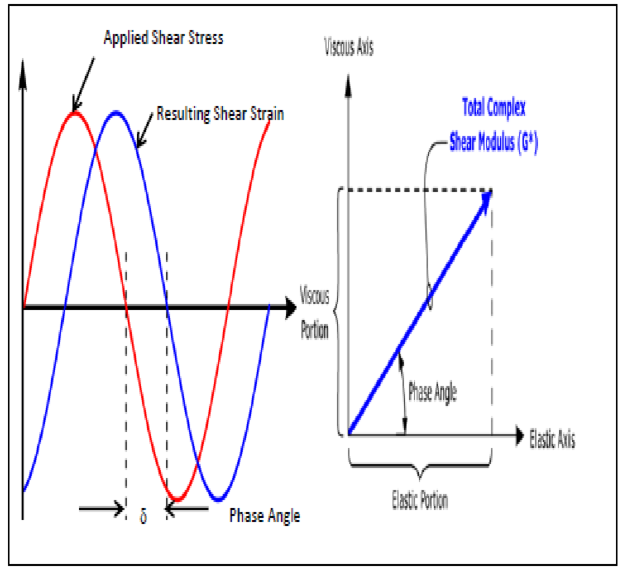


Figure: Illustrating the phase angle and complex modulus**.**

Stress Level, Strain Amplitude and Frequency of Oscillation

A viscoelastic material, bitumen does not carry on straightly as far as their stiffness as a function of stress or strain. Accordingly the dynamic shear modulus and phase angle rely on the size of the shear strain with both expanding and diminishing shear strain. A linear region is characterized as at little strains where the complex shear modulus is autonomous of shear strain [Airey]..

The point of confinement of the straight viscoelastic behavior is characterized as the measured quality of G* reductions to 95% of its zero strain esteem. The rheological tests ought to be performed with in the straight viscoelastic area of bitumen performance [Airey]. So a strain range test was led at 60^0c as demonstrated for VG-30 and sulfur modified bitumen.

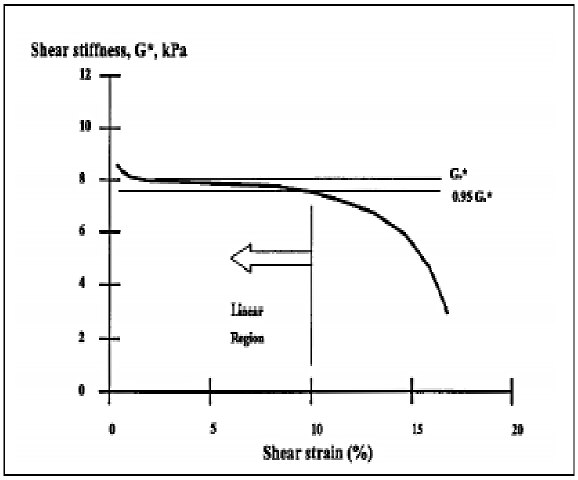


Figure: Strain sweep used to determine linear viscoelastic region (Airey)

EXPERIMENTAL PROGRAM

The work demonstrated in this section has been partitioned into four zones. The primary zone of this study comprises the type of material used, their standard properties and sample preparation for testing. The secondary region of study depicts the operational confinements of the Viscometry and DSR in wording of connected stress levels and recoverable strain levels along with the testing conditions of samples. The third range of study examined the impact of different temperatures on the physical properties tests. The fourth zone of this study summarized with chemical, morphological and thermal analysis with testing conditions of the samples. In this study the rheological, physical, storage stability, chemical, thermal and morphological properties of both unmodified and modified bitumen, their working standards have been briefly discussed.

Material

It is known from the studies that the level of modification relies on upon the neat bitumen type and modifier type. Different studies have been carried out in the field of sulfur modification and there are a few descriptions for the need of utilizing modifier within bitumen industry. There are different explanations behind utilizing bitumen modifier within bitumen industry began with expansion the service life of the pavement, enhance its performance, meet the overwhelming traffic demands and at last saving the expense of maintenance. In this test project viscosity grade bitumen VG-30 has been utilized. The physical properties of VG-30 bitumen were given in table underneath.

Properties	Result
Absolute viscosity 60°C (Cp)	2462
Kinematic Viscosity 135°C (cst)	365
Softening point °C	47
Penetration (dmm) 25 °C	57
Ductility (cm) 25°C	>100
Elastic Recovery (%)	26

Table: Physical properties of VG -30 bitumen

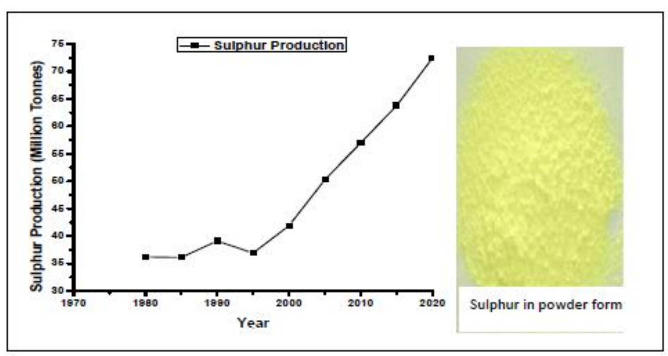


Figure: Production of sulphur over years and Elemental sulphur powder

Sample Preparation

At first the Rheological properties of sulfur extended bitumen have been tested to know about the progressions in the viscoelastic properties of modified specimen. To discover a good structure for a good sulphur modified bitumen , four steps are carried out , under which a few sets of tests are to be directed with viscometry and DSR instrument to evaluate the rheological properties of sulphur extended bitumen to evaluate the optimum sulfur content and ideal condition for proper modification and are explained below. After obtaining the proper sulphur content and blending condition in terms of blending time and temperature analysis of physical, chemical, thermal and morphological properties has been carried out.

To prepare the modification of VG 30 bitumen with sulphur, about 1.0 Kg of bitumen is taken in a 3 liter metal container and heated up to fluid condition. The blending of sulphur with bitumen is carried out using a mechanical stirrer at a stirring speed of 3000 R.P.M. for temperature beyond 120 °C, but for temperature within 100°C to 120°C, speed of the stirrer for blending was kept 1500 R.P.M.

Softening point Test

In this test bitumen sample in fluid condition poured in a brass ring, levelled and kept for 30 minutes at room temperature. Glass beaker containing distilled water kept at B.O.D. incubator at 5ºC for 30 minutes. A steel ball of weight 3.5 g is placed on a bitumen sample contained in a brass ring that is suspended inside a water bath, maintaining bath temperature to be raised at 5ºC per minute. The softening point of bitumen was determined as per IS: 1205-1978.Temperature at which the bitumen sample touches the lower plate is reported as softening point of that sample.

Ductility Test

The test has been carried out at a temperature 27^0 C and a rate of pull of 50mm/min. The experimental procedure has been followed according to ASTM D113 – 07. The distance from the starting point of bitumen thread formed to the broken point of bitumen thread was reported as ductility value.

Elastic Recovery Test

Sample preparation up to attachment of mould with sample and briquette in ductility testing machine is same as ductility testing of sample. The experimental procedure has been followed according to ASTM D6084. After that elongation of sample was done up to a distance of 10 cm at speed of 50 mm/min. Sample at that condition was for 1 hour at 15 ºC. After that the two broken sample was made to come closer and the distance was recorded. Using formula as given below in equation 4.1, the percentage elastic recovery was reported.

Adhesion Test

The extent of stripping was estimated visually while specimen was still under water and boil water for 15 minutes. Determination of striping value has been carried out according to IS 6241 (1971). The stripping value is the ratio of the uncovered area observed visually to the total area of the aggregates in each test expressed as a percentage. 4.7 Storage Stability test

The sample was poured into an aluminum tube specially made up with 30 mm internal diameter and 150 mm in height. The tube was sealed from bottom and kept vertically in an oven at 163◦C for a period of 48 hour, then taken out and cooled to room temperature, and the tube with sample was splices horizontally into three equal sections. The samples taken from the top and bottom sections were used to evaluate the storage stability of binder by measuring their softening points [Haiying Fu et al].

Morphology analysis

Field emission scanning electron microscope (FESEM) instrument used for the study of the microscopic structure of VG 30 bitumen and sulphur modified bitumen with a resolution of 10µm. Its automated advance features include focus, stigmator, gun saturation, gun alignment with very good contrast and brightness.

RESULTS AND ANALYSIS

This section portrays the rheological properties in terms of fatigue and rutting behavior results for unmodified bitumen and sulphur modified bitumen as well as short dissection of test information. The skeleton of testing covers was chosen keeping in mind the end goal to research that impact of sulfur in the bitumen properties subjected to distinctive loading parameters. The rheological properties of the different binders were portrayed utilizing dynamic shear rheometer over wide ranges of temperatures and frequencies. In this study both VG 30 bitumen and its modification with sulphur was tried and a summary of all results introduced underneath in tables and graphical structure.

Rheological properties of unaged and aged binder test results

SHRP test results for appropriate mixing/blending temperature for modification of bitumen by sulphur under Standard Conditions of SHRP test

Test results are analyzed on the basis of phase angle and complex shear modulus and their behavior with variations in blending temperature and are presented in diagrams.

(a)Two statements are observed one is the phase angle of sulfur modified bitumen having less esteem than the unmodified VG 30 bitumen, which indicates towards more elastic nature than conventional bitumen. Second is at 1400c of mixing/blending temperature the sulphur modified bitumen indicates least value of phase angle than other temperature because of the expansion in viscosity of sulphur powder for temperature beyond 150°C.

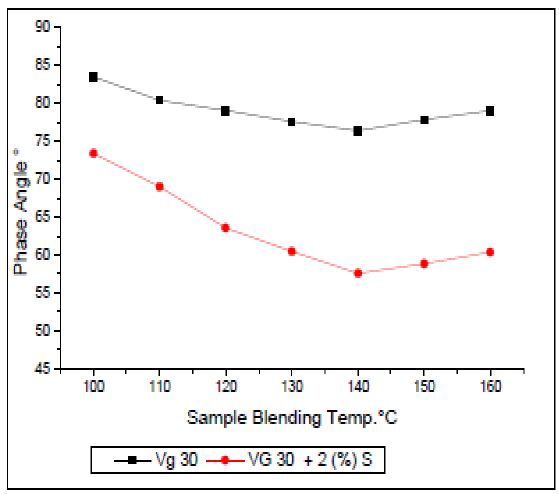


Figure: Variations of phase angle with different blending temperature

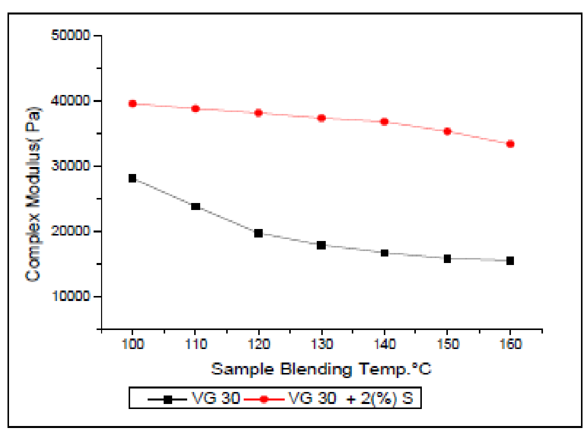
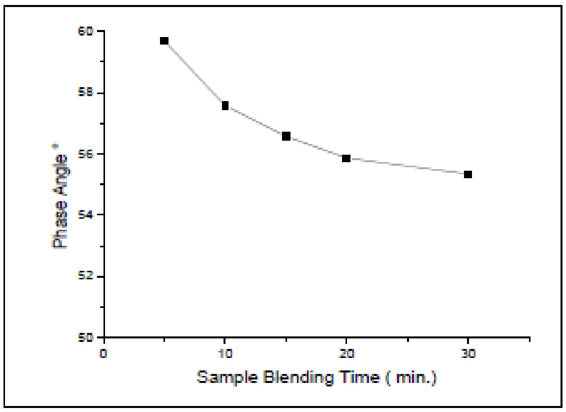


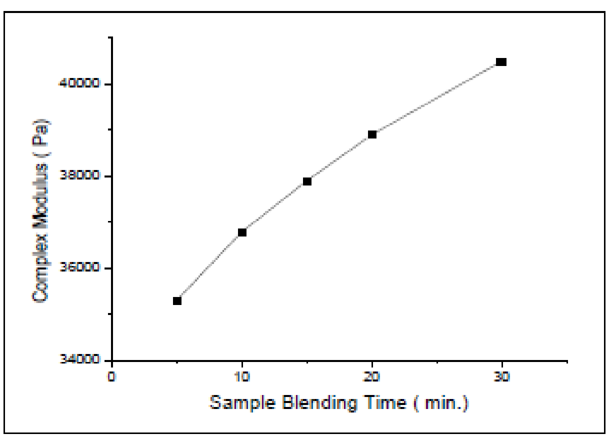
Figure: Variations of complex modulus with different blending temperatures

SHRP test results for appropriate mixing/blending time for modification of bitumen by sulphur under Standard Conditions of SHRP test

These test results are mulled over regarding phase angle and complex modulus for proper time needed for mixing/blending of sulfur and bitumen. Their relationships with different blending temperature are presented in graphs below.



Behavior of phase angle with change in blending time for 2% sulphur modified bitumen



Behavior of complex modulus with change in blending time for 2% sulphur modified bitumen

From the above variations of phase angle and complex modulus with variations of blending time for modification of bitumen with sulphur it can be suggest that about 30 minutes of continuous blending provides a homogeneous blending for which decrease in phase angle and increase in complex modulus occurred, as a result of which sulphur modified bitumen becomes more elastic and possess more strength.

SHRP grade determination test results

This test result for VG 30 bitumen and 2% sulphur modified VG 30 bitumen for both un aged and aged are shown in tabular form below Table 5.1.From the result from SHRP grade determination test in tabular form indicates that the VG 30 bitumen and 2% sulphur modified VG 30 bitumen satisfy the rutting and fatigue criteria according to the specification.

Frequency Sweep Test results

Results are obtained in terms of phase angle and complex modulus with variations of frequencies and are represented in graphs are illustrated below [figure 5.5 (a) & 5.5(b)]. The graph figure 5.5(a) shows there is a decrease in behavior of phase angle for sulphur modified bitumen with increase in loading frequencies than neat bitumen, which intend towards more elastic property of sulphur modified than neat bitumen binder.

SHRP grade determination test results

Sample type	Test Temp. °C	Angular Frequency rad/s	Phase Angle ° (δ)	Complex Modulus Pa (G*)	G*/Sin(δ) Pa	G*x Sin(δ) Pa	Specification pa	Remarks
VG 30	60	10	77.37	1.77E+04	1.81E+04		>1000	ok
VG 30 - RTFOT	60	10	68.37	3.18E+04	3.42E+04		>2200	ok
VG30 - PAV	60	10	65.03	3.59E+04		3.25E+04	< 5000 Kpa	ok
VG 30 + 2% S	60	10	55.34	3.65E+04	4.44E+04		>2200	ok
VG 30 + 2% S RTFOT	60	10	51.17	3.88E+04	4.98E+04		>2200	ok
VG 30 + 2% S PAV	60	10	48.58	4.11E+04		5.48E+04	< 5000 Kpa	ok

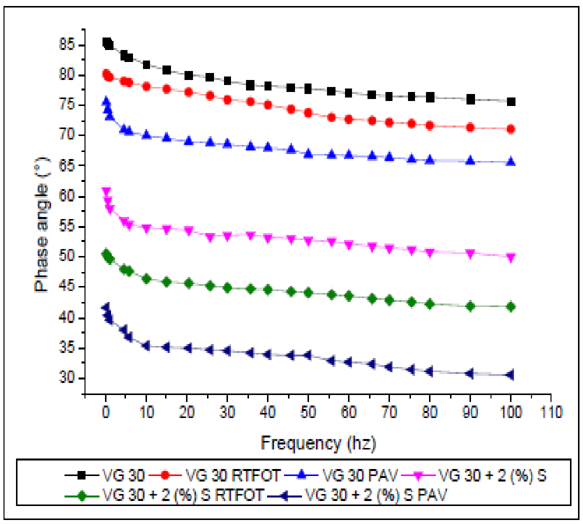


Figure: Master curve: Variations of phase angle with various loading frequencies.

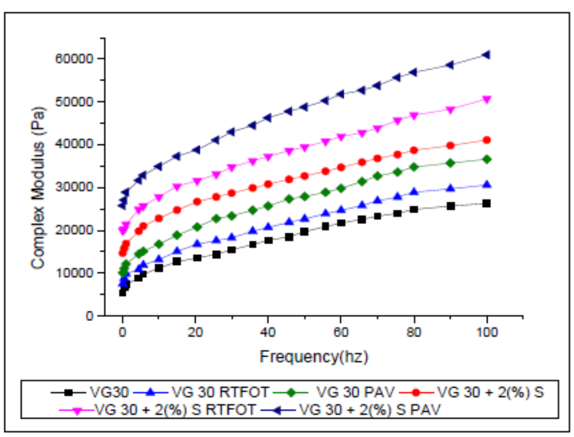


Figure: Master curve: Variations of complex modulus with various loading frequencies.

In the above figure shows increase in complex modulus with increase in frequencies of sulphur modified bitumen than neat bitumen. This is because of the increase in both viscous and elastic modulus of the binder. This complexity in the behavior of phase angle and complex modulus for sulphur modified Vg 30 bitumen is due changes occurred with addition of sulphur in its inter molecular structure

Morphology analysis test results

The compatibility between sulphur and VG 30 bitumen is critical to the properties to understand. The morphology of the Sulphur modified bitumen before and after ageing was investigated using Field emission scanning electron microscopy by characterizing the distribution and fineness of sulphur in bitumen matrix. More focus was given towards the homogeneity in the blending of sulphur and bitumen. Some pictures have been demonstrated in figure 5.8 (a), (b), (c), (d), (e) & (f).

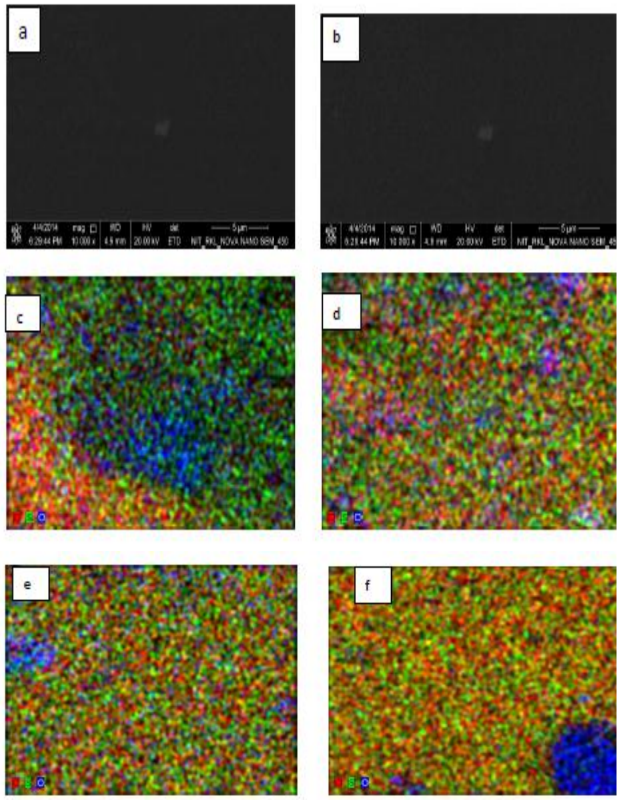


Figure: (a) morphology development for VG 30 bitumen

(b) Morphology development for VG 30 bitumen modified with 2% of sulphur

(c) EDX for VG 30 bitumen,

(d) EDX for VG 30 bitumen modified with 2% of sulphur,

(e) VG 30 bitumen modified with 2% of sulphur after RTFOT

(f) VG 30 bitumen modified with 2% of sulphur after PAV.

CONCLUSIONS AND RECOMMENDATIONS

Several modifiers have been tried to improve the properties of bitumen in terms of engineering properties and performance criteria to derive the maximum benefits to withstand the wheel loads of the modern day traffic causing heavy stresses. Sulphur is one additive which is found to enhance the performance of the bitumen binder. In this research work, sulphur has been added to VG 30 bitumen maintaining at140oC temperature through mechanical stirring for about 30 minutes to introduce a homogeneous modified binder. To ascertain the modification in quality and quantity, the temperatures for mixing/ blending, mixing/ blending time sand the sulphur concentrations in bitumen were varied from 100°C to 160°C, from 5 min to 30 min and from 0% to 5% by weight respectively. A number of rheological properties have been studied for binders under both aged and unaged conditions. The following concluding remarks have been drawn:

- Considering the criteria of complex modulus and Phase angle, addition of 2% sulphur by weight of VG 30 bitumen blended at 140^0C temperature for about 30 minutes time results in the optimum mixing/blending condition.
- In respect of unaged binder situation, the addition of sulphur to the extent of 2% to the conventional VG 30bitumen improves the viscoelastic behavior in terms of resistance to fatigue and rutting in comparison to the unmodified binder.
- The sulphur modified binder is observed to possess superior viscoelastic and other rheological characteristics in case of the aged binders also.
- The sulphur modified binder is found to satisfy the physical property requirements.

- The morphological tests show homogeneity of sulphur in the bitumen matrix.
- The storage stability test in case of modified binder does not show any non-homogeneity as observed by the conduct of the softening point test.

RECOMMENDATIONS FOR FUTURE WORK

There are some recommendations for further future research work as briefly listed below.

- It is recommended to conduct time sweep test through DSR for different models for fatigue life determination of modified binders.
- It is proposed to execute determination of fatigue life of bituminous binder with dissipated energy method.
- It is recommended for study of multiple stress creep recovery to study the performance of binder.
- The correlation of Rheological test of modified binders may be made with the mix properties such as, indirect tensile strength, resilient modulus and fatigue life.

REFERENCE

- AASHTO Provisional Standards: AASHTO T315-08, "Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)", Washington.2011
- ASTM D5/D5M-13, "the standard test method for penetration of bituminous materials".
- ASTM D113 – 07, "the standard test method for ductility of bituminous materials".
- ASTM D36 / D36M – 12, "the standard test method for softening point of bitumen (ring- and-ball apparatus)".
- ASTMD70-03,"thestandardtestmethodforspecific gravityanddensityofsemi-solid bituminous materials (pycnometer method)".
- ASTM Standards D 8, "terminology relating to Materials for Roads and Pavements".
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- ASTM Standards D2171"Standard Test Method for absolute Viscosity of Asphalts by Vacuum Capillary Viscometer."
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