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Experimental Study On Sulphur Altered Bituminous Binders

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ABSTRACT

The call for on bituminous flexible pavement, due to boom in heavy site visitors masses and their tyre contact stress with adverse climatic conditions, fatigue and rutting performance has led to an hobby towards the changed bituminous binders. There are numerous popular modified binders already available international. These modifiers considerably alter the rheological and morphological houses of the binder, as characterized through rheological testing methods along with the morphological instead of the traditional strategies, to decorate the overall performance of the binder. This look at is intended in the direction of the change of the conventional viscosity grade VG 30 bitumen and programs of industrial sulphur available in nearby marketplace to alter the VG 30 bitumen and to evaluate the rheological characteristics of unaged and elderly samples of those binders the use of a Dynamic Shear Rheometer (DSR). Attempt has been made to decide the best situations for binder development such as blending/mixing time and temperature to make certain proper change, through the rheological parameters of section perspective and complex modulus. This improvement in the end allows to influence the fatigue and rutting resistances of bituminous mixes. The amendment of bituminous with sulphur at six extraordinary mixing temperature inclusive of 100ºC, 110ºC, 120ºC, 130ºC, 140ºC, 150ºC and 160ºC, each made at 5 distinct mixing times inclusive of five min, 10 min, 15 min, 20 min, 30 min. Has also been done. The most useful modification level has been evaluated thinking about unaging and getting older criteria for five sulphur contents which include 1%, 2%, 3%, 4% and five% by using weight of the bitumen. It is found that the addition of 2% sulphur with the aid of weight with bitumen mixed at 140ºC temperature for about 30 min., outcomes within the best change of VG 30 bitumen in terms of the rheological homes, and pleasurable the necessities of traditional residences.

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

INTRODUCTION

Background of the study

In India roads and highways are desired as number one modes of transportation. Roads constructed with flexible pavements continually given more significance because of its clean riding excellent and less production expenses than in case of rigid pavements. Bituminous substances along with aggregates are utilized for the development of bendy pavement roads. The Indian road transportation infrastructure is a tremendous assignment in development of National Highways Development Programs (NHDP), Pradhan Mantri Gram Sadak Yojana (PMGSY) and State Highways Improvement Programs (SHIPs) etc. In which large money is being invested via the Government of India in an effort to empower the pavement performance.

Problem Statement

In India, the sort of bitumen grade used is primarily based at the penetration take a look at, that's conducted to understand the softness of bitumen at a temperature of 25°C. The pavement failure is because of

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heavy visitors masses and seasonal variations, which are at once, affect the durability and overall performance of pavements. The most common hassle associated with the overall performance of bituminous pavements is low temperature distress kind or fatigue cracking and Permanent failure or rutting failure.The pavement surface temperature on hot summer season is within 60°C, which makes bitumen smooth and results in everlasting deformation as rutting in pavement. It typically takes place along longitudinal course of the flexible pavement underneath the traffic wheel direction accompanied by using small upheavals to the sides. At low temperature in iciness season, bituminous pavements turn out to be too brittle and there exist fatigue cracking. Fatigue cracking is processed as cumulative harm attributable to repeated visitors loading. Therefore, to limit the distresses of the flexible pavement a few measures may be achieved such as:

- Improving the mix design of bituminous mixtures.
- By improving the construction methods and maintenance techniques.
- Introduce modification of bitumen so as to improving the bituminous mixture.

Objectives of Research

In general, this research is lead to explicate better understanding of the rheological properties of modified and unmodified bitumen binders. Considering the problem statement above, the main objectives of this research are summarized as follows:

- The aim of this have a look at is to explore the use of changed binder to enhance the overall performance of bendy pavements.
- The dynamic shear rheometer (DSR) is used to determine the rheological traits of bitumen binder over a huge range of temperature and rate of loading situations.
- Comparing the rheological properties at excessive, medium, low temperatures for unmodified bitumen and modified bitumen through Dynamic Mechanical Analysis.
- The impact of sulphur on change of bitumen in phrases of rheological, garage stability and morphology has been studied.
- The effect of getting older on unmodified and modified bitumen rheology and morphology the use of Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel(PAV) and FESEM respectively.

Scope of the study

The scope of this look at is to attention on the characterization of sulphur modified bituminous binder. The assessment of rheological homes of VG-30 bitumen binder with out and with amendment with sulphur from dynamic mechanical evaluation accompanied by morphological and thermal analysis is the main purpose of this observe. The rheological residences, creep recovery checks, morphology and thermal analysis are carried out the use of dynamic shear rheometer (DSR) and field emission scanning electron microscope (FESEM), apparatus. Ageing of bitumen and modified binders has been apprehend using the Rolling Thin Film Oven (RTFO) for short term ageing and Pressure Aging Vessel (PAV) for long time growing old and impact of growing old on the rheological, morphological and thermal parameters are studied.

METHODOLOGY

Introduction

The viscoelastic behavior of bitumen is enormously complex to depict by fundamental conventional experiments of consistency, as an instance, penetration exams and softening factor assessments.

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Hence, the assessment of bitumen attributes must be focused around its overall performance concerning fatigue and rutting protection. Hence, new test gadgets like the Dynamic Shear Rheometer (DSR), Brookfield Viscometer were created to provide rheological houses of bitumen over an extensive sort of loading and encompassing conditions.

The DSR is probably acknowledged as the most compelling and complicated instrument for characterization of the bitumen float homes. It is additionally simply important to understand the chemical progressions of bitumen that has been made during exchange via sulphur. To have a look at the chemical compound association framing, thermal and morphological research of unmodified and modified bitumen, some checks were led utilising new innovation contraptions, for instance, FESEM, TGA, DTA and FTIR Spectroscopy in my view.

Determination of rheological properties of bitumen

Rheological homes are utilized as execution parameter has favorable situations and disadvantage. The point is that it permits estimation of physical residences with huge temperature range at excessive and occasional recurrence, that's vulnerable to be done inside the subject because of movement. Dynamic shear rheometer want certified person with high stumble upon to paintings the detail assessments and additionally to get great rheological outcomes. In this segment a concise representation of the element shear rheometer (DSR) device and further the geometry and example advent and instance dimension may be exhibited. In this Phase moreover a point of interest description of all rheological take a look at methods obtained for the characterization of materials are given.

The examination led for the Strategic Highway Research Program (SHRP), trying out gadget familiar with describe the rheological, sturdiness and failure homes of asphalt binders absolutely focused around the rheological houses. The examination outcomes have been examined in four principle factors:(i) The viscoelastic nature of bitumen and its connection to overall performance of pavement; (ii) the important troubles identified with these assessments and; the sorts of traditional estimations are utilized now (iii) the idea of selecting the brand new check workouts and the brand new homes; and (iv) how to analyze the new measured residences to the traditional homes [Bahia et al (1993)].

Viscoelastic Properties of bitumen

Viscoelastic properties from Dynamic mechanical analysis through DSR imply the response of a material as it's far subjected to a cyclic strain. These residences can be communicated as some distance as dynamic storage modulus, dynamic loss modulus, and a mechanical damping time period. The performance of bituminous binders is tormented by viscosity and vital rheological parameters as phase attitude and complicated modulus. The constraints and their impact over bitumen performance were mentioned quickly under [Airey].

Viscosity of bitumen

Viscosity is defined as the resistance to waft. Bitumen is a visco elastic cloth this is at room temperature it act as a semi solid in high temperatures over 60°C it acts as a Newtonian fluid or low viscosity liquid.

Three Phase Angle

For an applied stress transferring sinusoidal with time, a visco elastic cloth will moreover react with a sinusoidal strain for low amplitudes of strain. The sinusoidal range in time is commonly portrayed as a price targeted by means of the recurrence (f = Hz; =rad/ sec). Phase angle is defined because the lag among the applied stress and resulting pressure of a

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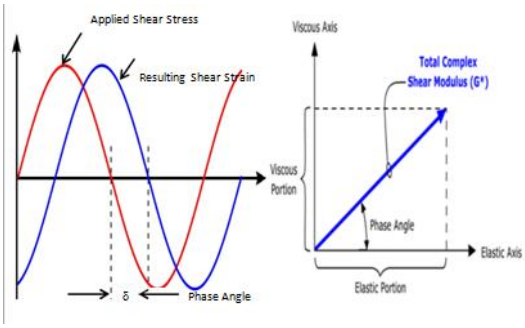
frame whilst subjected to a sinusoidal shear pressure. The segment angle is a critical parameter to painting the viscoelastic conduct of bitumen, that is a yield result from the dynamic mechanical examination via DSR. Typical segment angle has been illustrated under[figure 3.6].



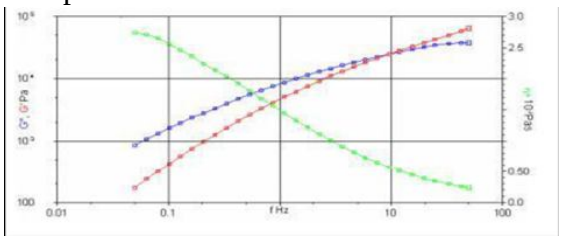
Tests Performed using DSR

Strategic Highway Research Program Grade Determination (SHRP)

The Strategic Highway Research Program (SHRP) grade determination, methods had been optimized to grade asphalt binder so that they will be liked and bought as it should be as SUPERPAVE products. The SHRP checking out regime carries numerous steps, this being best one of them. The SHRP grade determination is fully depend on the G*/Sin(δ) cost and the characterization of original binder is rely upon the segment attitude and complicated shear modulus normally acquired from SHRP consequences.

Frequency sweep

Frequency sweep take a look at is used to decide the damage evaluation of binder. The frequency sweep take a look at is accomplished at the usual provider temperature, and oscillatory shear load of regular amplitude are implemented over a extensive variety of frequencies loading. For this test technique, the frequency sweep check is selected from the DSR producer's controller software, employing an applied load of 12% strain over a range of frequencies from 0.1 – 100 Hz. A typical plot [figure 3.9] for frequency sweep result data.

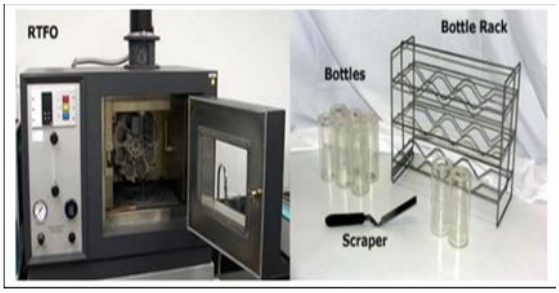


Aging of bituminous binder

Aging takes place due to publicity to environmental condition beneath repeated movement of load at area in the course of carrier life. Aging may be defined as lack of volatile substances and oxidative response happens due to adverse effect of climatic situations.

Short time period growing older

This sort of getting older in bituminous fabric happens in the course of the mixing, laying and compaction procedure within the area. Also quick time period aging includes ageing occurs just after application of bituminous mixes in the area up to 3 years, which can be because of lack of risky material because of excessive temperatures. Equivalent short term aged pattern are normally prepared in the laboratory the use of Rolling Thin Film Oven Test (RTFOT) equipment proven [figure 3.11].



EXPERIMENTAL PROGRAM

Introduction

The paintings proven in this phase has been partitioned into 4 zones. The number one region of this have a look at incorporates the type of cloth used, their fashionable homes and pattern instruction

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for testing. The secondary area of have a look at depicts the operational confinements of the Viscometry and DSR in wording of linked strain degrees and recoverable pressure tiers along with the trying out situations of samples. The 0.33 range of have a look at examined the effect of different temperatures on the physical residences assessments. The fourth quarter of this look at summarized with chemical, morphological and thermal evaluation with checking out situations of the samples. In this take a look at the rheological, bodily, storage stability, chemical, thermal and morphological homes of both unmodified and changed bitumen, their operating requirements have been in brief mentioned.

Material

It is known from the research that the extent of modification is predicated on upon the neat bitumen type and modifier kind. Different research had been completed in the subject of sulfur change and there are some descriptions for the need of utilizing modifier within bitumen industry. There are unique explanations at the back of utilising bitumen modifier within bitumen industry started out with enlargement the carrier existence of the pavement, beautify its overall performance, meet the overwhelming traffic needs and at remaining saving the expense of renovation. In this take a look at task viscosity grade bitumen VG-30 has been applied. The bodily properties of VG-30 bitumen have been given in table beneath.

Table 4.1 Physical properties of VG -30 bitumen

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

Observing the production and cost, Sulfur being in powder structure utilized as modifier for modification of bitumen as shown in figure below. The essential properties of sulphur have been represented in [figure 4.1] beneath

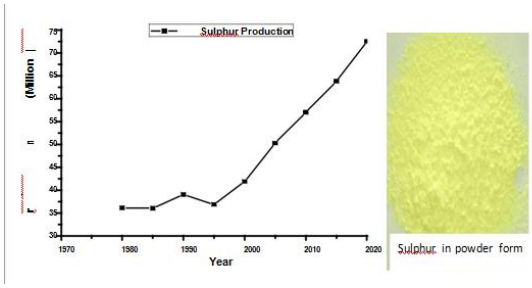

Figure 4.1: Production of sulphur over years and Elemental sulphur powder

Table 4.2 Physical properties of elemental Sulphur [Source: www.sulphuric-acid.com]

Properties	Result
Appearance	Yellow crystalline solid
Melting point	120°C
Specific Gravity	1.92

RESULTS AND ANALYSIS

Introduction

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

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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[figure 5.1 (a) & (b)].

From the Figure 5.1 (a) two statement are observed one is the phase angle of sulfur modified bitumen having less esteem than the unmodified VG 30 bitumen, which indicate 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^{o}C.

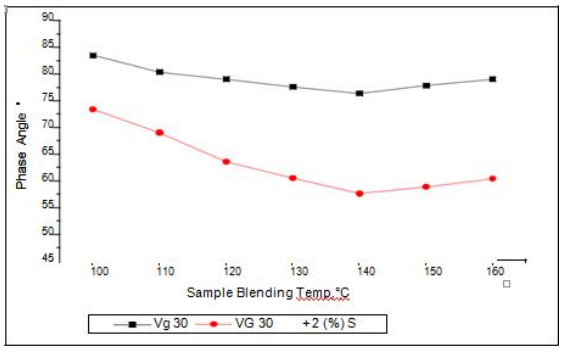

Figure 5.1 (a): Variations of phase angle with different blending temperature

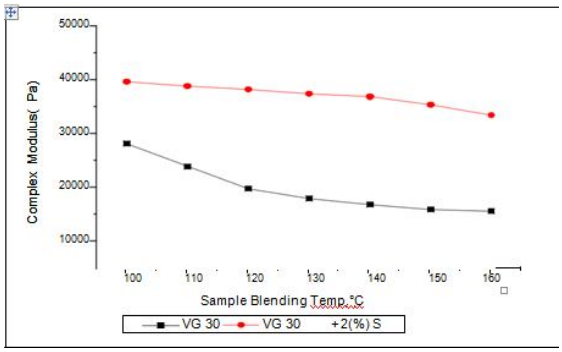

Figure 5 .1 (b): Variations of complex modulus with different blending temperatures

Then again from Figure 5.1 (b) there is an increment in complex modulus of sulfur modified bitumen than routine VG 30. Likewise the complex modulus of sulfur modified bitumen beyond 140^{o}C declines. Thus for legitimate mixing/blending of sulfur and bitumen, 140^{o}C temperature has been taken with respect to both the elastic and strength properties of sulphur modified bitumen.

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 [Figure 5.2 (a) & (b)] below.

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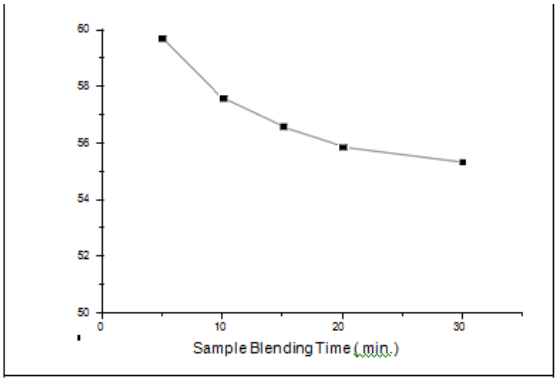

Figure 5.2 (a): Behavior of phase angle with change in blending time for 2% sulphur modified bitumen

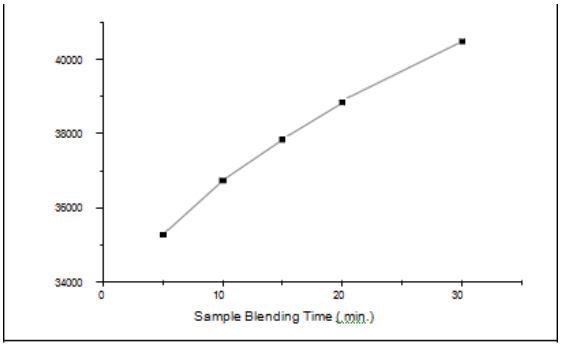

Figure 5.2 (b): Behavior of complex modulus with change in blending time for 2% sulphur modified bitumen

SHRP test results for optimum sulphur content to get good modified bitumen binder

The results obtained are presented in graph [figure 5.3 (a) & (b)] to observe the variations of phase angle and complex modulus very clearly.

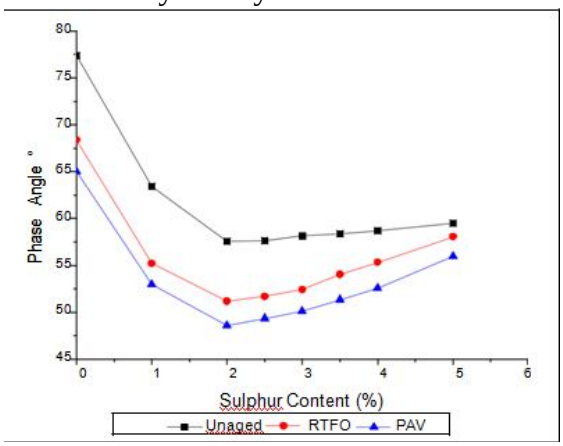

Figure 5.3 (a): Variations of phase angle with increase in sulphur content

It can be clearly seen that 2% sulphur content is the optimum modifier content from phase angle point of view due to having least phase angle value. But there is a wide variation in case of phase angle that it increases as the sulphur content increases which is due to the increase in viscous properties of bitumen with excess addition of sulphur. Also at 2% sulphur content complex modulus value is quite high from normal.

Test results for viscosity at high temperatures

This experiment has been carried out through Brookfield rotational viscometer. The tests have been carried out to observe the behavior of viscosity VG 30 bitumen after modification with sulphur with variations of temperature and shear rate. The test results are demonstrated in graphical [figure 5.4 (a), (b) & (C)] presentation underneath. From figure 5.4 it is clearly shown that VG 30 bitumen and sulphur modified VG 30 bitumen showing liquid behavior with rise in testing temperature. Thus the shear resistance of bitumen to resist the pivoting of the spindle of Brookfield viscometer decreases, as a result of which the viscosity of sample decreases.

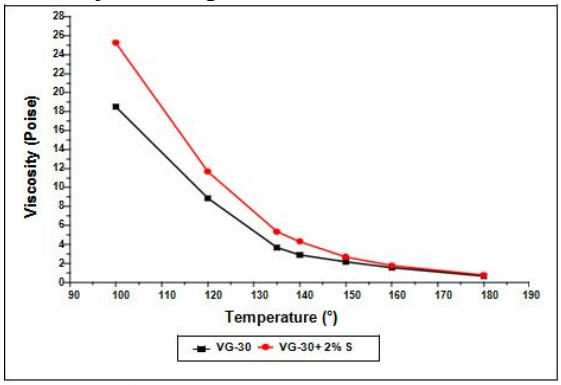

Figure 5.4 (a): Behavior of viscosity of bitumen with variation of Temperature.

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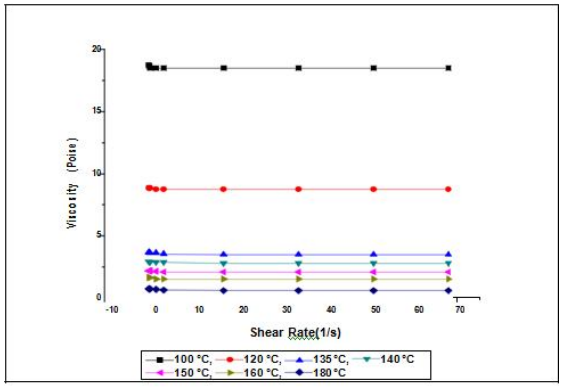


Figure 5.4(b): Variations of viscosity of VG 30 bitumen with increase in shear rate for different temperatures.

Also due to addition of sulphur the viscosity of VG 30 bitumen increases as a result of which the rutting resistance of sulphur modified bitumen increases. This test result is very helpful to decide the mixing temperature for preparation of bituminous mixes, so that required viscosity can be achieved.

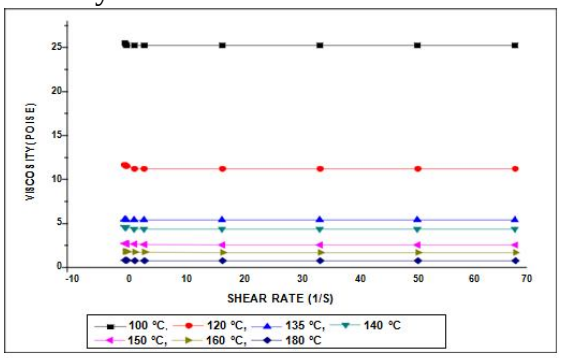
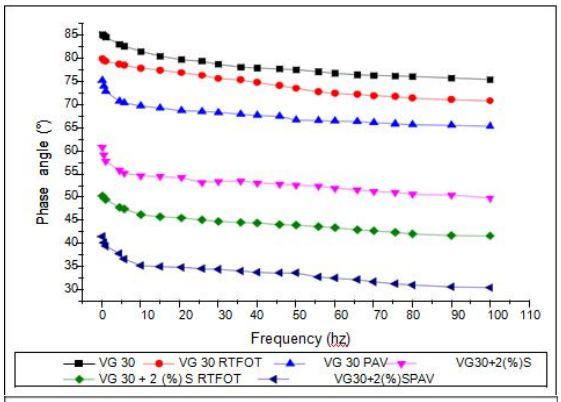


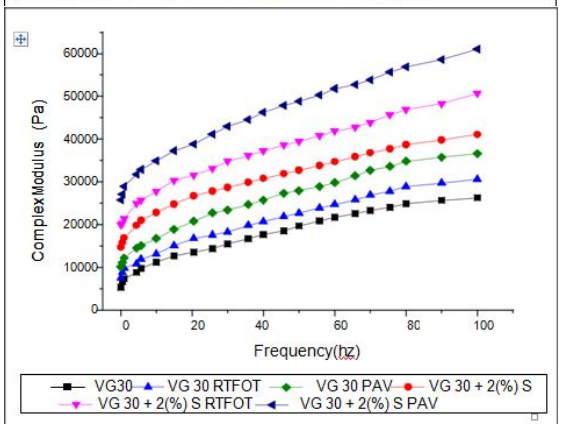
Figure 5.4(c): Variations of viscosity of 2% sulphur modified VG 30 bitumen with increase in shear rate for different temperatures.

According to Newton, for Newtonian fluid the viscosity of that fluid doesn't change with shear rate, rather it is independent with shear rate. Here also in the figure 5.4 (a), behavior of VG 30 bitumen is just like a Newtonian fluid as there is no alteration exist in the viscosity due to change in shear rate. Similarly there is no sign of change in the viscosity of 2% sulphur modified VG 30 bitumen with rise in shear rate, which intend towards the Newtonian fluid behavior of the sulphur modified bitumen.

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.





In the other hand figure 5.5 (b) 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.

Conclusions

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

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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 at140^{o}C 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^{0}C 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.

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