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Comparative Study of the Rheological Properties of RAP Binder and Modified Bituminous Binder

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Abstract:- **RAP (Reclaimed Asphalt Pavement) is one of the most replaced materials getting used in asphalt mix for paving the asphalt roads, RAP binder is conglomerate in nature and ascertain to know the adhesiveness and representation of its property is a very challenging assignment. In the recent years, the researchers are focusing on the rheological and creep characteristics, which effect the life span of the pavement while construction and after years later. As there are numerous mechanism to enumerate the viscosity of the RAP binder. Dynamic Shear Rheometer (DSR) Test, which is one of functional test which is used to determine the flow behavior (rheological property) and the stiffness modulus. Therefore, the paper is focused on the thermo-viscous property of modified bituminous binders and distress like rutting factor and fatigue factor. Experimentally work is carried out on RAP binder, CRMB 55, VG 30 and modified binders. The fatigue resistance factor (G*Sin (δ)), Rutting resistance factor ((G*/Sin (δ)), Complex modulus (G*) and Phase angle (δ) parameters are obtained from DSR, the rheological parameter are also collected for the condition from the tests RTFOT for short term aging and PAV for long term aging. The results observed after the experimental work the RAP binder along with the combination of the V30 and Elastomer modifier gave better rutting and fatigue resistance and presence of CRMB have good fatigue resistance value at the intermediate temperature and elastic response compare to all other.**

Key words: Reclaimed Asphalt Pavement, Rheology, Modified binders, Rejuvenator, DSR.

1. INTRODUCTION

Indian traffic is heterogeneous, there is a tremendous increase in the traffic load and axle wheel loads and pavement temperature and thereby it's a duty of highway engineering authorities, to improve the performance of pavement materials. Bitumen is one of the vital product, which plays a crucial role in the overall performance of the pavement life span. As it is viscoelastic and these properties are usually measured where the relationship between stresses and strains is influenced only by the temperature and loading time and not by their magnitude (linear viscoelastic condition, LVE). The rheological properties are important concepts that are studied by the researchers to the core, as it is related to the distresses like characteristic rutting, fatigue, short term and long term aging of the bitumen. In general, most of the Indian flexible pavements are constructed by using virgin bitumen polymer and modified bitumen. Polymer modified bitumen can improve low temperature susceptibility, which also decreases the creep stiffness.

As the temperature susceptibility is decreased in order to increase the stiffness and penetration index. The crumb rubber is considered as a modifier that makes the bitumen to withstand high temperature, also increases riding comfort and life of the pavement. By addition of the crumb rubber we can see the increase in the softening point and the reduction in the brittle point. It also observed that there is significant improvement in the resilient modulus (M_R), stiffness modulus and increases stability and fatigue life. The results showed that CRM has a significant effect on bitumen rheology, which is it increases complex shear modulus G* and decreases phase angle δ. It is necessary to study the viscoelastic property of those bituminous binder and there time temperature recovery when the applied load is removed. There are various that factors affect the performance of the pavement structure. Aging is one among them, which effects the performance of pavement and also hardens the surface of the pavement as the temperature increases. To find the effect of the aging two tests performed and which are performed only for the polymer modified bitumen. The Rolling Thin Film Oven Test (RTFOT) and Pressure Aging Vessels (PAV) are existing methods for testing the aging effects, RTFOT is performed find the effect of the short term aging which occur before and while constructing the road for the short duration whereas the PAV is the long term effect which occurs after several years, these effect should be thoroughly studied and rheology characteristics. Currently, usage of RAP in the construction of new pavement, became one of trending technique to provide the sustainability for the future generation, without realizing RAP binder reaction with the virgin bitumen, elastic modified bituminous binder, rejuvenator and other additives, they are designed for the mix as per the standards. The study of rheology characteristics of RAP binder is important as it contains lots of binder and the fines which are entrapped in film of binder. Here, this paper is focused on the viscoelastic and stiffness characteristics of the bituminous binder and the proper percentage of the RAP in the road construction. And its effect at the low and high temperatures with various percentages of the elastomer modifier bitumen, virgin bitumen, rejuvenator and the cellulose fibre.

1.1 Background

The bitumen is characterized by a chemical composition by separating different groups or fractions based on chemical reactivity, chromatography, molecular size, spectroscopic and precipitation or solubility (Bell-198; Youtcheff and Jones 1994). The hydrocarbon molecules in bitumen are of three broad group structures namely aliphatic, cyclic, and aromatics (Robertson 1991;

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Berkers 2005; Polacco *et al*., 2008; Jones 1992; Lesueur 2009). The molecules are non-polar if it is a single structure, but if the structure is combined the molecules become polar.

The distresses are related to the rheological properties of bitumen, and influence of Crumb Rubber Modifier (CRM) on the rheological properties of bitumen binder such as improvement of high and intermediate temperature is investigated in the binder's fatigue and rutting resistance through physical-rheological changes in the research (Asim Hassan Ali. et. al. 2013) and concluded that Crumb Rubber Modifier increased the stiffness of the bitumen binder improving its resistance to rutting. The higher crumb rubber content, the lower G*Sinδ at 31˚ C after PAV aging, which led to higher resistance to fatigue cracking. Also, the introduction of RAP binder in the construction of the new pavement with similar functional requirements as the virgin bitumen by adding additives are commonly termed as rejuvenator.

The capability of the rejuvenators is measured using the DSR, later the microstructure of the virgin binder and rejuvenated blends are obtained utilizing the atomic force of microscopy (S.N. Nahar. et. al. 2014) studied and as a result, complex modulus value is increased with an aging master curve. At 20% addition of rejuvenator, the master curve overlaps with virgin bitumen. The properties of the binder are modified using SBR for the binder V30. The rheological properties were evaluated using the DSR, the short term aging was done by using the RTFOT and long term aging was done by using PAV. (Moazzam Ali Mughal 2015) As a result, the viscoelastic properties of the original binder, complex modulus also increased and resistance of mix against rutting showed a very good improvement. Fatigue cracking was reduced. The short term and long term aging of bitumen for five samples of modified bitumen with SBS and with or without crumb rubber 25°C. By using the SBS there is an increase in the complex modulus throughout the frequency range and reduction in the phase angle at the increase in the temperature. (Mahdi Ali 2018).The presence of rubber increases the elastic response of the binder at increase temperature even after aging. The presence of rubber reduces the fatigue life at 9% SBS.

2. EXPERIMENTAL PROCEDURE

2.1 Materials used for testing

A total of forty-eight samples with combination of RAP binder from pure RAP binder to different percentage of VG30, CRMB55, Waste Engine Oil (WEO) and EM (Elastomer Modifier) are used which is listed in detail in table 1. First samples is A1 [Reclaimed Asphalt Pavement], A2 [Viscosity Grade Bitumen 30] and CRMB 55 [Crumb Rubber Modified Bitumen-55]. Second set of samples are categorised in order to determine which combination of modified bitumen will enhance rheological property (visco-elastic properties) of RAP binder.

Table 1 Details of the samples used in the present studies

No.	Binder Code	Asphalt Description
1.	A1	RAP
2.	A2	VG 30
3.	A3	CRMB 55
4.	BC11	10%RAP+90%CRMB-55
5.	BC12	20%RAP+80%CRMB-55
6.	BC13	30%RAP+70%CRMB-55
7.	BC14	40%RAP+60%CRMB-55
8.	BC15	50%RAP+50%CRMB-55
9.	BC16	60%RAP+40%CRMB-55
10.	BC17	70%RAP+30%CRMB-55
11.	BC18	80%RAP+20%CRMB-55
12.	BC19	90%RAP+10%CRMB-55
13.	BC21	10%RAP+90%CRMB-55+WEO
14.	BC22	20%RAP+80%CRMB-55+WEO
15.	BC23	30%RAP+70%CRMB-55+WEO
16.	BC24	40%RAP+60%CRMB-55+WEO
17.	BC25	50%RAP+50%CRMB-55+WEO
18.	BC26	60%RAP+40%CRMB-55+WEO
19.	BC27	70%RAP+30%CRMB-55+WEO
20.	BC28	80%RAP+20%CRMB-55+WEO
21.	BC29	90%RAP+10%CRMB-55+WEO
22.	BC31	10%RAP+90%VG30
23.	BC32	20%RAP+80% VG30
24.	BC33	30%RAP+70% VG30
25.	BC34	40%RAP+60% VG30
26.	BC35	50%RAP+50% VG30
27.	BC36	60%RAP+40% VG30
28.	BC37	70%RAP+30% VG30
29.	BC38	80%RAP+20% VG30
30.	BC39	90%RAP+10% VG30
31.	BC41	10%RAP+90%VG30+EM
32.	BC42	20%RAP+80% VG30+ EM
33.	BC43	30%RAP+70% VG30+ EM
34.	BC44	40%RAP+60% VG30+ EM
35.	BC45	50%RAP+50% VG30+ EM
36.	BC46	60%RAP+40% VG30+ EM
37.	BC47	70%RAP+30% VG30+ EM

38.	BC48	80%RAP+20% VG30+ EM
39.	BC49	90%RAP+10% VG30+ EM
40.	BC51	10%RAP+90%VG30+ EM +CF
41.	BC52	20%RAP+80% VG30+ EM +CF
42.	BC53	30%RAP+70% VG30+ EM +CF
43.	BC54	40%RAP+60% VG30+ EM +CF
44.	BC55	50%RAP+50% VG30+ EM +CF
45.	BC56	60%RAP+40% VG30+ EM +CF
46.	BC57	70%RAP+30% VG30+ EM +CF
47.	BC58	80%RAP+20% VG30+ EM +CF
48.	BC59	90%RAP+10% VG30+ EM +CF

Note: EM: Elastomer Modifier, CF: Cellulose Fiber

Among these samples, the four samples are chosen for the rheological parameter have shown the good behaviour in terms of the Marshall stability, rutting resistance and cracking or fatigue resistance which are A1, BC14, BC27 and BC46.

RAP Binder: The RAP materials are procured from NH-206, where the existing 2 lane flexible pavement is removed to construct the cement concrete pavement from the Karnataka-Andhra Pradesh border to Chittoor (India). The pavement was 15-20 years old as per the records. The basic properties of these aggregates are tested and they are within the limits as per MoRT&H specifications.

3. TESTING PROCEDURES:

3.1 Simple distillation test (Separation Test): The RAP binder is separated into two stages: centrifugal extraction and simple distillation process. To extract the binder from the RAP, aggregates are soaked in benzene liquid for the 24hrs the binder is extracted by centrifugal extractor. The combination of the binder and benzene is obtained. Further, the binder should be separated from the benzene for that simple distillation process is followed. The liquid is sent to the round-bottomed flask, and as a result of the process the benzene is obtained as the product in container and binder is left over in the flask. This is because of boiling of the benzene is 80℃. Finally, the pure RAP binder is obtained.

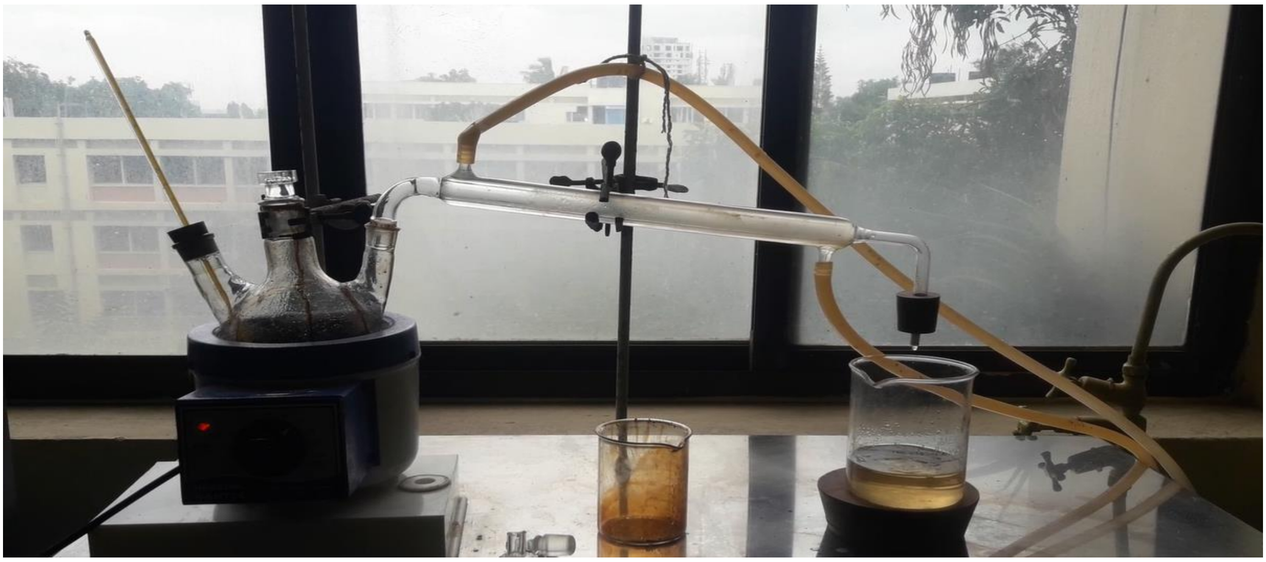

Fig 1 Simple Distillation process

3.2 Short term aging and long term aging analysis:

ROLLING THIN FILM OVEN TEST (RTFOT): It is the process to find the loss in the materials for the shortest duration in the laboratory. This test can be completed to move rapidly than the Thon Film Oven Test (TFOT), ASTM D 2872, this test is preferred for the polymer modified binders. It contains about eight containers, each of them is filled with 35g of sample. Later, fixed to a rotating shelf, hot air is blown. The test is carried at a temperature of 163℃ for 75 minutes. And finally, the samples are weighed before and after the test and calculated as per the specifications. Long term aging occurs in asphalt pavement in the field as a result of exposure to traffic and climate conditions during its service life. As per the SHPR, the rutting or superpave factor is defined as the ratio of the $|G^*| / \text{Sin } \delta$. if the correlation between the unaged sample and the RTFOT sample is good at the temperature of the ratio $|G^*| / \text{Sin } \delta = 2.2$ kPa and at frequency $\omega = 10$ radians/s, then we can consider the original unaged sample for the further rheological characteristics testing without aging the sample further in laboratory [4].

PRESSURE AGEING VESSEL (PAV) TEST: it process to find the loss in the materials for the service life in the laboratory. It performed after the RTFOT/ TFOT for 20 hours (values are tabulated in the table 2). The CRMB in the sample 3

(70%RAP+30%CRMB-55+WEO) is subjected to the short term ageing and later it is blended with the RAP binder and the rejuvenator and tested under the DSR testing machine.

As per the SHPR, the fatigue or cracking resistance factor is defined as the ratio of the |G*| x Sin δ. if the correlation between the unaged sample and the PAV sample is good at the temperature of the ratio |G*| x Sin δ = 5000 kPa and at frequency ω = 10 radians/s, then we can consider the original unaged sample for the further rheological characteristics without aging the sample further in laboratory.

3.3 Dynamic Shear Rheometer (DSR) test: To check the rheological property of the bitumen, the Dynamic Shear Rheometer (DSR AASHTO T-315) is used. The sample is placed in between the plates (concentric plates) and trimmed the excess of the sample, the temperature sweep started at mid-range of the temperature and varied as per test specification. The test is performed with five different temperature 70℃, 80℃, 90℃, 100℃ and 110℃. The appropriate strain is selected from the code while performing the test. So the software can control the stress level automatically. When the temperature has equilibrated, condition the sample by applying the required strain for a recommended 10 cycles or of 8 to 16 cycles at a frequency 0f 10 rad/sec. because it is simulate the shearing action corresponding to the traffic speed of 90 Km/hr (AASHTO T315) and more vital thing is test should be completed within four hours. The parameters like complex modulus (G^*), phase shift angle (δ), storage modulus (G'), loss modulus (G").

4. RESULTS AND DISCUSSION:

By rheological characteristics, which are obtained after the performed after the dynamic shear test (DSR) we can relate those characteristics by application of the time-temperature superposition (TTS) principle, which determines the temperature-dependent mechanical properties of linear viscoelastic materials. Out of forty eight samples, samples which satisfied the rheological properties are discussed detailed in this paper.

Master curve: By the concept time temperature superposition the master curve is developed, the master curves can be used to represent the behaviour of the material in a wide range of time or frequencies where the trend of load is determined by the only experimental curve that encloses both effects of time and temperature.

These master curves can be constructed either in the time domain or in the temperature domain. In their simplest form, master curves are produced by manually shifting modulus versus frequency plots at different temperatures along the logarithmic frequency axis to produce a smooth master curve. The nature of curve resemble the hyperbola and the scale of the graph is log-log graph as shown in the below figure.

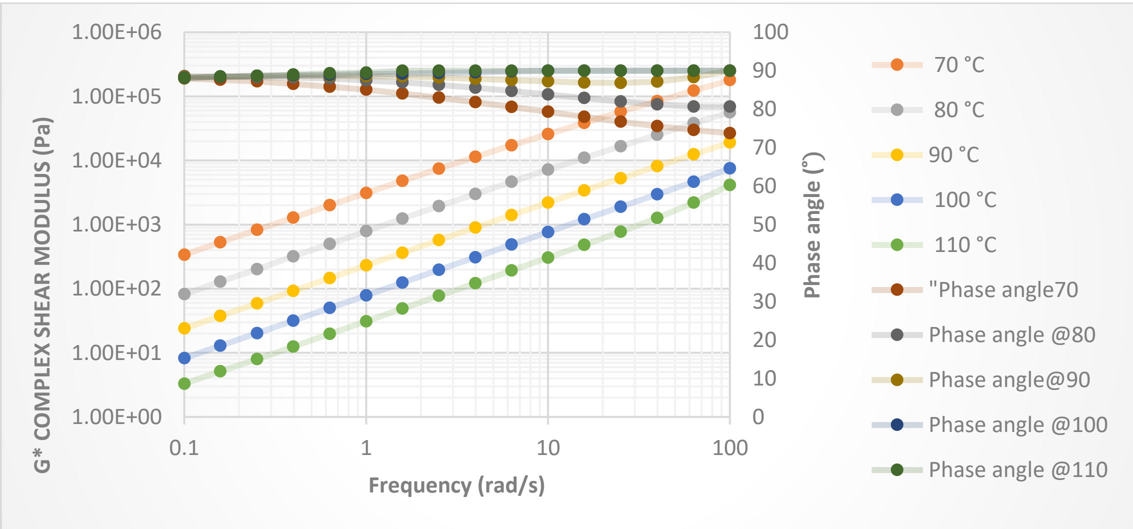

Fig 2 Master curve for Sample A1

Fig 2 represents the master curve of the Reclaimed Asphalt Pavement (RAP) binder. It is observed that bituminous binder at low frequency and high temperature acts as the completely as elastic materials, as the phase angle is reducing from the 90˚. At the low temperature and high frequency, the binder the RAP binder acts the viscoelastic materials. It also observed that the complex modulus G*, at 70℃ the value is initial less and as the frequency increases the complex modulus increased. From the graph, we can conclude that the RAP is acted as less elastic at high temperature, high frequency.

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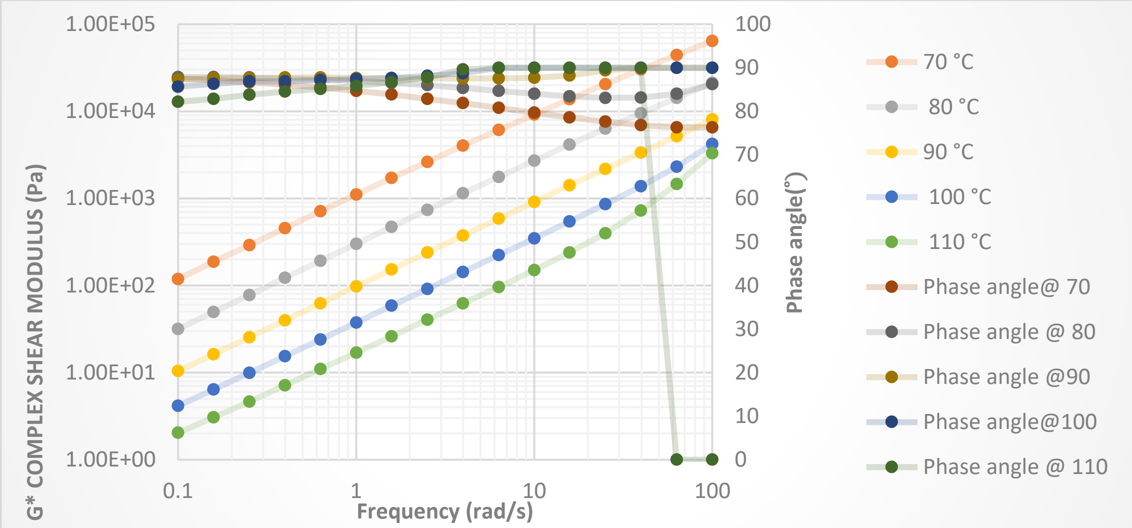

Fig 3 Master curve for Sample BC14

Fig 3 shows the master curve of BC14, where it contains 40% of RAP and 60% of CRMB-55. From the graph, it is observed that the phase angle is increased from the lower frequency to higher frequency as the temperature is increased.But especially it is observed that at 110°C the phase angle almost zero that represents the sample is completely vicious. The G* at low temperature and high frequency shows the maximum value. Finally, the sample is showing that the phase angle increases with frequency and temperature, it is changing from viscous to elastic state.

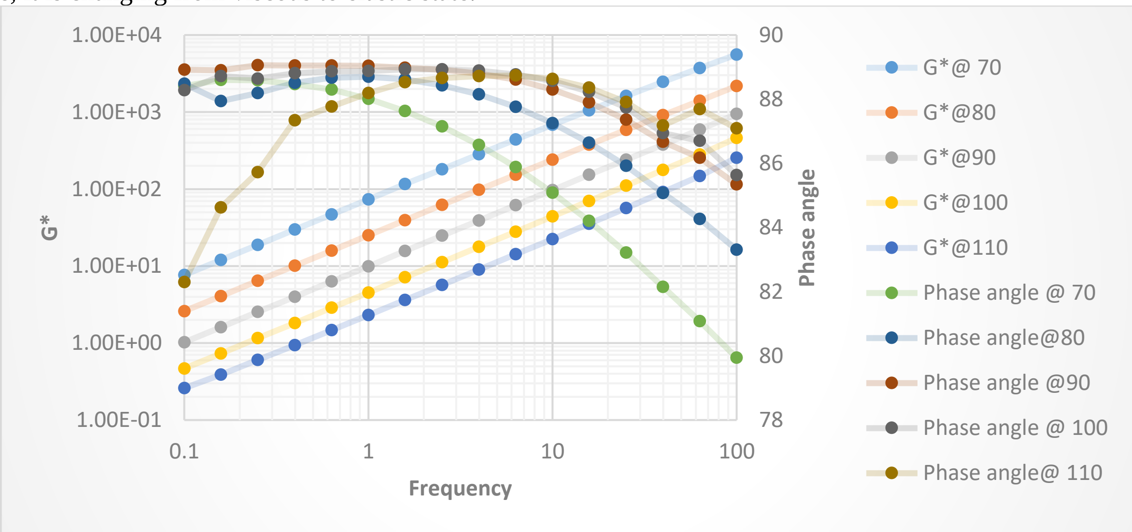

Fig 4 Master curve for sample BC27

Fig 4 shows the master curve for the sample BC27. The bitumen sample shows the phase angle is decreasing as the angular frequency and temperature increases mean while complex shear modulus decreases with an increase in the temperature and the frequency as well as.

The phase angle at 110°C initially it is gradually increasing from lower frequency up to the intermediate frequency, temperature and as it increases we can observe the gradual decrease in phase angle. The sample is converted into viscous material as the temperature rises.

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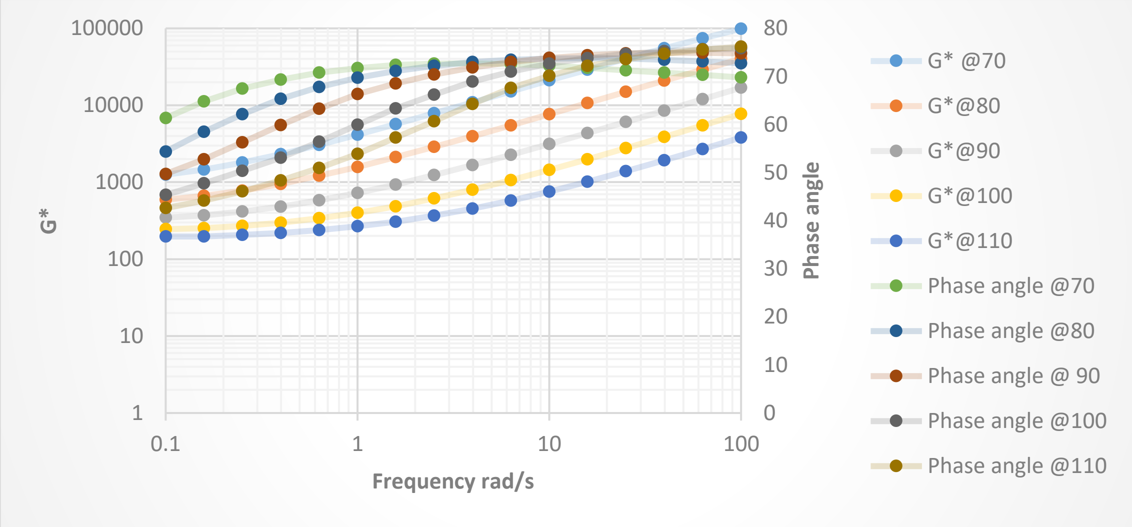

Fig 5 Master curve for Sample BC46

The master curve of the sample BC46 is as shown in fig 5. The complex shear modulus G*, at low temperature and high frequency, shows the highest value compared to the other temperatures. Whereas the phase angle is increased with the rise in the temperature and the frequency but eventually there is little drop in the phase angle. Finally, the sample is changing form viscous state to the elastic state.

Relationship between Fatigue factor and temperature

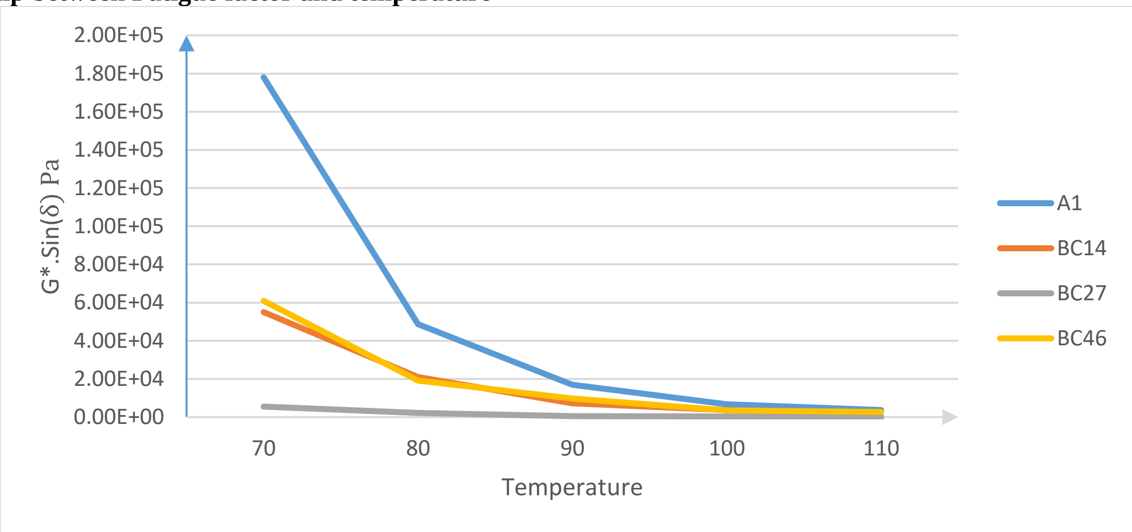

Fig 6 The relationship between G*.Sin δ and temperature @100 rad/s.

Fig 6 shows the relationship between fatigue parameters and temperature. Fatigue is one of the important distress, the fatigue resistance factor is caused mainly due to repeatedly applied load and the micro-cracks of the pavement because of the stiffness of the bituminous binder. The fatigue resistance factor (G*.Sin δ) is increased for the sample BC14 and BC46 as compared to the sample BC14 comparatively, we can observe that RAP is having high fatigue resistance compared to other samples. The fatigue resistance decreases with an increase in temperature.

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Relationship between Rutting factor and temperature

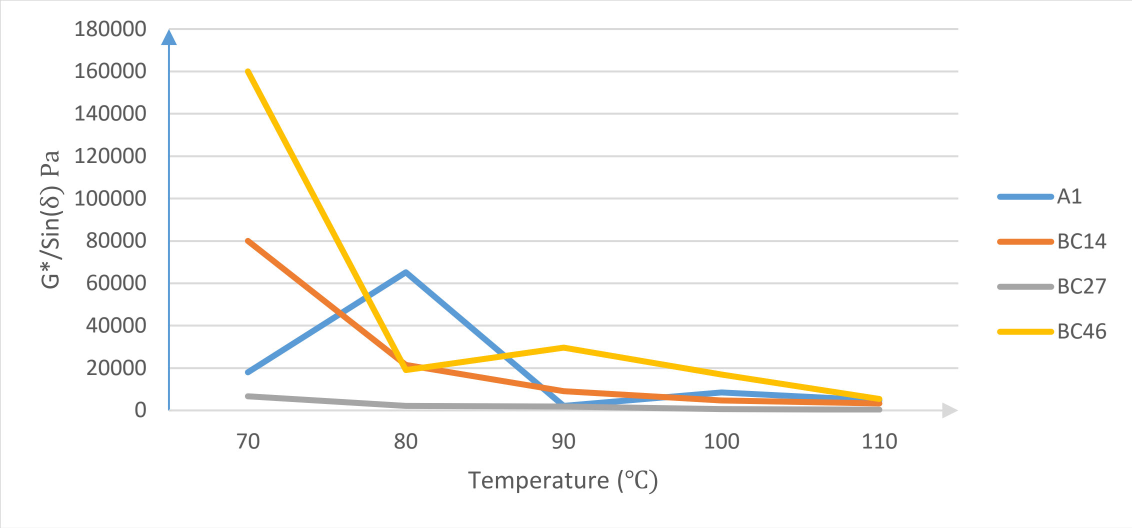

Fig 7 The relationship between G*/Sin δ and temperature @100 rad/s.

Fig 7 represents the effect of the temperature on the rutting resistance factor at five different temperature at 70°C, 80°C, 90°C, 100°C and 110°C respectively. The rutting is one of the important distress in the pavement and stiff characteristics. The rutting parameter is obtained from the DSR testing, the G*/Sin δ of sample A1 is varying with temperature. Sample BC27 is having low rutting resistance compared to all other samples, sample BC14 and BC46 are having same values at 80°C. Compared to all the samples the sample BC46 is having the highest and improved rutting resistance factor.

Relation between Storage modulus (G ') and loss modulus (G ") as a function of temperature

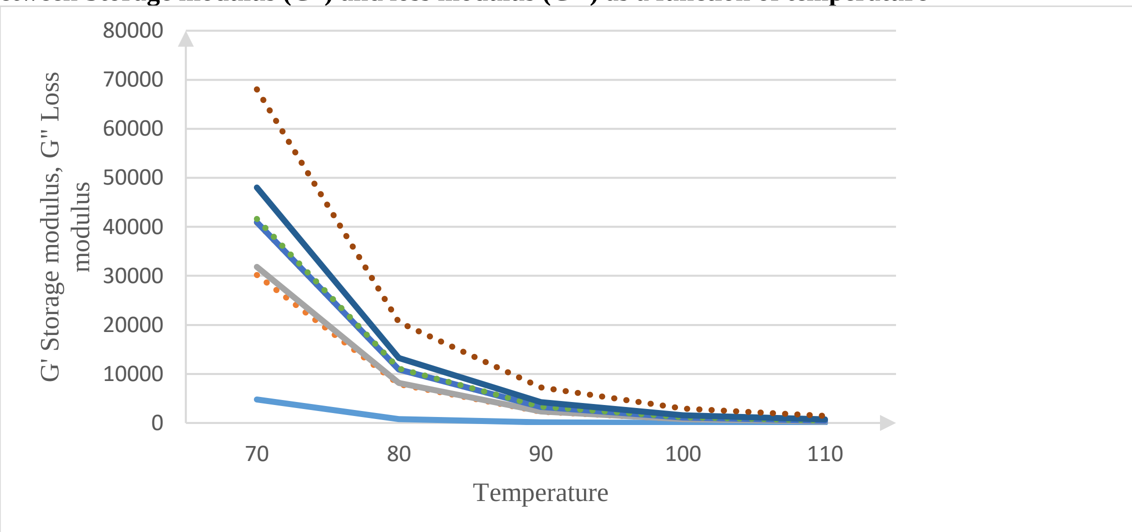

Fig 8 The relation between loss modulus and storage modulus with the temperature

The storage modulus (G ') is one parameter to measure the elasticity of binder, the binder acts as viscous materials as the temperature is increasing. The loss modulus (G") is related to the viscous property of the binders, and the storage modulus of sample A1 is having the least value and the mentioned earlier that for the RAP binder and improved later after adding the modifiers. All sample BC46 shows predominant viscous properties at temperature 70°C to 110°C as shown in fig.7. Finally from results, we can conclude that the storage modulus and loss modulus depends on the temperature, binder content and the polymer percentages.

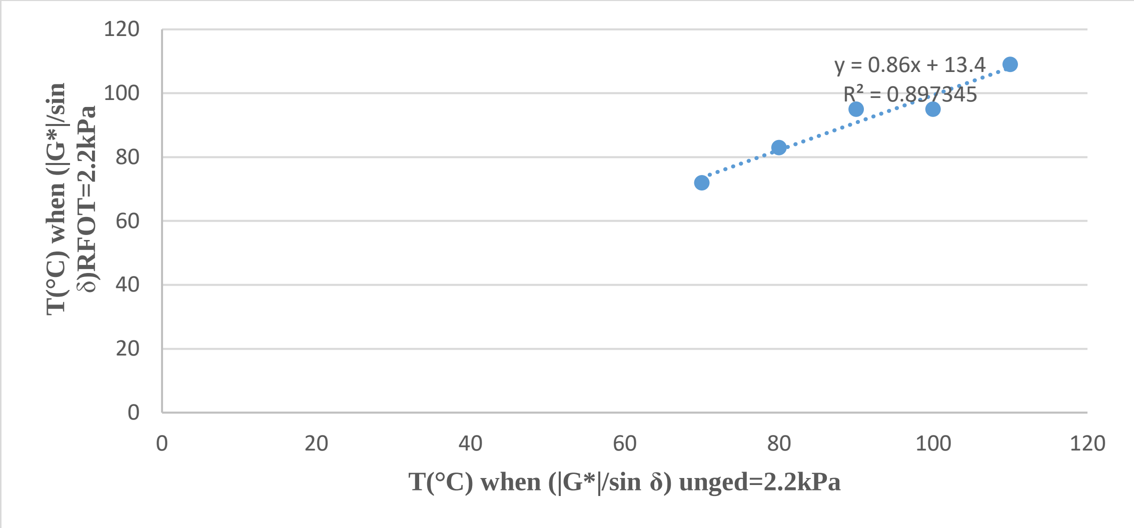

Fig 9 Temperature when |G*|/sinδ = 2.2 kPa for unaged binder and RTFOT-aged binders for the sample BC27

Fig 9 represents the Temperature when |G*|/sin δ = 2.2 kPa for *unaged binder and* RTFOT-aged binders for the sample BC27, by using the Microsoft excel software the multiple regression and the correlation R square is calculated are 0.9472 and 0.897345≅ 0.9. By comparison the unaged and RTFOT binder sample can match up to the 90% confidence limit, this short term aged sample can be easily matched with the unaged binder sample without subjecting it to the RTFOT test.

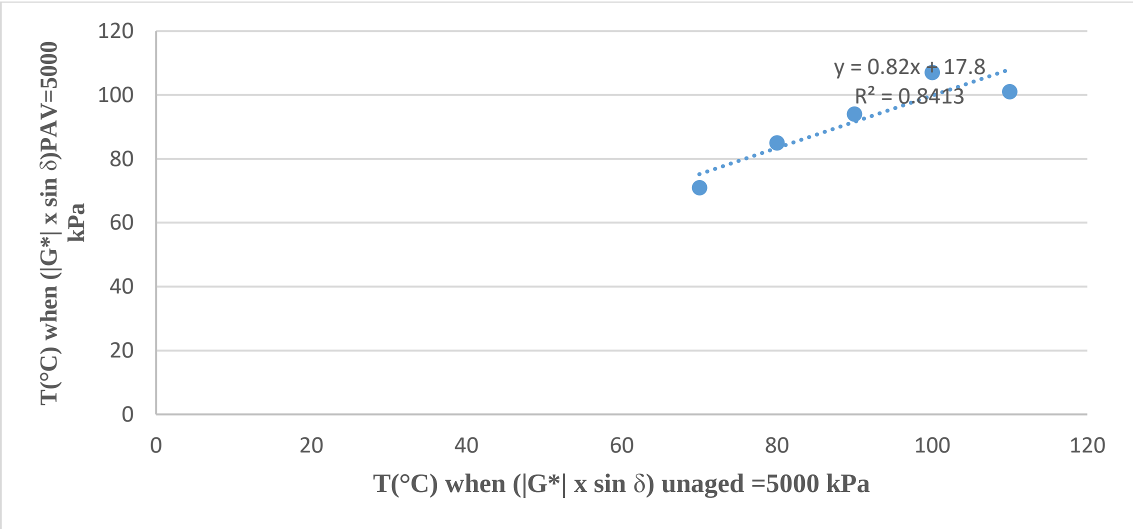

Fig 10 Temperature when |G*|x sin δ = 5000 kPa for unaged binder and PAV-aged binders for the sample BC27

Fig 10 represents the Temperature when |G*| x sin δ = 5000 kPa for unaged binder and RTFOT-aged binders for the sample BC27, by using the Microsoft excel software the multiple regression and the correlation R square is calculated are 0.832033 and 0.8413 ≅ 0.85. By comparison the unaged and PAV binder sample can match up to the 85% confidence limit, this long term aged sample can be easily matched with the unaged binder sample without subjecting it to the PAV test.

5. CONCLUDING REMARKS

Based on the laboratory investigation, the main conclusions are drawn as following

- Subsequently carrying out the precise experiment performed by the DSR test, the combination of RAP binder and VG30, EM as the elevated numerical value of complex modulus at 100rad/s at 100°C is $16*10^4$(Pa) which stands for the elastic nature, which demonstrate increasing resistance contrary to cutting.
- As the viscosity of the crumb rubber reduces as the shear rate increases, the bitumen is separate from each other and the flow increases. The presence of crumb rubber in the RAP bituminous binder along with the rejuvenator at high temperature is being revealed more elastic response.
- Detailed investigation performed was carried out by using the DSR test and it its performed form the low to high frequencies (0.01 Hz to 100 Hz), the fatigue resistance for the combinations of both crumb rubber along with rejuvenator

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and the virgin binder along the with cellulose fiber with respect to RAP binder at the intermediate temperature have better resistances.

- In comparison to all samples, prepared in laboratory and carrying out the DSR test and the numerical values were obtained. The sample BC14 and sample BC46 have the comparable fatigue resistance factor values i.e., $5.5*10^4$ Pa and $6.04*10^4$ Pa respectively at the temperature 70℃ of frequency 100 rad/s. Finally, we can interpret the RAP binder along with the virgin bitumen with the combination of the cellulose fiber showed better resistance for the fatigue factors.
- Although the RAP is one which is available in vast amount and it's a challenging part is the increase in concerns about the conceivable negative effect of the aged RAP binder on the field performance, principally fatigue and the rutting resistances of the high RAP mixtures as a part the project, RAP is being used as part asphalt motor, and to bring down the environmental hazardous. In the present research, the rheological parameters like G*, G*/Sin δ, G*. Sin δ and δ for the sample BC46 have a superior value compared to all other samples, this can be used for the high traffic condition at 70℃ temperature and the sample BC14 can be used in the moderate traffic condition and low-cost roads.

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