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Effect Of Natural Asphalt On Performance Characteristics Of Bitumen And Its Mixes

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Trinidad Lake Asphalt (TLA) is natural bitumen. The soluble bitumen in Trinidad Lake Asphalt has a high viscosity and if this is blended with paving grade bitumen, it can produce a material with high resistance to deformation and with suitable weathering properties. In this study TLA pellets have been used as a modifier to modify VG-30 grade paving bitumen, and it was found that it improved the properties of the VG 30 grade binder. Various binder properties were checked like softening point, penetration value, viscosity indices, and properties of modified and unmodified binder after short term aging were studied, and Rheology of binders was also studied. After witnessing the improved properties of binder, bituminous (asphalt) mixes were prepared to check the performance characteristics of TLA modified asphalt mixes. Results of wheel tracking test, beam fatigue test, and tensile strength ratios indicate that a worthwhile improvement in resistance to deformation, comparable to conventional asphalt mix, can be obtained by the addition of 2% of TLA by weight of VG 30 grade bitumen.

Keywords: Trinidad lake Asphalt, Rheology, Modified binder, Bituminous mixWheel tracking test, Beam fatigue.

1. Introduction

With our country expressways, highways net coming into being and traffic's growth each passing day, the proportion of over loading vehicles increases, disease of bituminous pavements is more serious. The bitumen used in bituminous roads of our country is refined by paraffin based petroleum mostly. The bitumen is very sensitive to the temperature of the pavement, extreme weathering conditions. It cracks in winters and flows in summers, and pavements face early failure. The conditions are not suitable to the needs of highway use. The use of modified binder is the main means to improve its performance. Most of the high molecular polymer modifiers such as Polyethylene and SBS (Styrene Butadiene Styrene) are mostly used and they are not easily compatible with bitumen and the investments in production and processing equipment are raising e.g. special shearing equipments and high energy use. Modified natural asphalt avoids these issues[1]. TLA (Trinidad Lake Asphalt) is a natural material[2]; it is asphalt itself and not a synthetic additive, its physicochemical property is completely accordant with conventional bitumen. So if this natural asphalt is added into the bitumen, the two materials can be compatible to each other very well and the properties of conventional bitumen are improved. Research has established that the unique bituminous micelles and fine mineral matter of TLA combine to deliver stabilizing and improved durability characteristics to pavements, when used in asphalt mixes[3,4].

2. Trinidad Lake Asphalt (TLA)

Trinidad Lake asphalt, naturally occurring asphalt, was first used in the world in the 1870[5]. TLA is a mixture of asphalt and/or oil and mineral matter which occurred as a result of complex geological movements.TLA is the most famous source of natural bitumen. It occurs as a semi-solid emulsion of soluble bitumen, mineral matter and other minor constituents[6]. Mined from the world famous 'Pitch Lake' in the south west of Trinidad, West Indies, it has enjoyed continuous use in asphalt products for well over 100 years.TLA is first surface mined from the 100 acre 'lake'. The mined TLA is subjected to a simple refining process resulting in a material remarkably constant in its soluble bitumen content. The mineral constituent works in combination with the bitumen component to produce the beneficial properties of TLA[4]. The typical physical properties of TLA are given in Table 1.

Table 1: Physical properties of TLA

Softening Point	93-98^{0}C
Ash (mineral matter)	35-39%
Penetration, 25°C, 100gm,1/10th mm, 5sec	1-4
Soluble bitumen (trichloroethylene)	52-55%
Specific gravity at 25C	1.4
Maltenes (as % of bitumen)	63- 66%
Asphaltenes (as % of bitumen)	33-37%

Research done in other countriesindicates that when TLA is added to the bituminous mixture as a modifier it increases mix stiffness and permanent deformation resistance, and provides increased stability, fatigue resistance, and low temperature performance. It also improves adhesion to the aggregate, aging resistance, durability and mix workability[3.7 &8].The main objective of thisstudy was to determine the properties of Trinidad Lake Asphalt modified bitumen with respect to VG-30 grade bitumen mostly used in India, and also to evaluate the performance of TLA in bituminous mixes.

3. Experimental Methods

3.1 Materials

A paving grade bitumen (VG-30) and quartzite aggregatesof different sizes (20mm, 6mm) and stone dust and lime powder were obtained from the local quarry and was used in this study. TLA pellets were obtained from La Brea, Trinidad, and West Indies. The bitumen was tested for physical properties as per IS73:2006 and test results are given in Table 2.The physical properties of aggregate were studied to determine its performance as per [IS: 2386-1963 (Part 1-6)].The test results are given in Table 3.

Table 2: Physical Properties of Bitumen VG 30

Test	Test Method	Result	MORTH Specification
Specific Gravity at 27°C	IS 1202	1.01	0.99(min)
Ductility at (27°C, cm)	IS 1208	100+	75(min)
Softening point, $^{\circ}$C	IS 1205	49.5	35-50
Penetration at 25°C, 100g, 5 sec. $1/10^{th}$ mm	IS 1203	63	60-70
Viscosity, 60°C, poises, Min	ASTM D4402	3660	2500
Viscosity, 135^{0}C, poises, Min	ASTM D4402	7.2	4.50

Table 3: Physical Properties of Aggregates

Properties		Test results	**MoRTH specifications**
Specific gravity	Coarse aggregates (20mm)	2.78	2.5-3.0
	Fine aggregates (6mm)	2.73	
	Stone dust	2.5	
	Lime	3.1	
Water absorption (%)	Coarse aggregates (20mm)	0.12	2 Max.
	Fine aggregates (6mm)	0.26	
Particle size	Flakiness & Elongation	28%	Max 30% (combined)
Toughness	Aggregate Impact Value	23%	Max 24%
Adhesion to bitumen	Stripping value of aggregate	2%	Max 5%

3.2 Preparation of blends

Mixing of TLA in VG-30 grade bitumen was performed in laboratory using an arrangement of oven, fitted with a stirrer having a speed regulating system. The frequency of the stirrer was 2000 rpm for preparing the blends and the time taken was 30-60 minutes. The TLA pellets were used to modify neat bitumen i.e. VG-30 bitumen at a percentage of 2% and 4% by wt of bitumen. The blendswere prepared at a temperature of 150°C. The resultant blends were covered with foil and stored at room temperature for further work. These blends are tested for their physical properties like penetration, softening point and viscosity tests. The viscosity of VG-30 bitumen and TLA modified bitumen is determined using the Brookfield Viscometer at a rotational speed of 20 RPM of the Brookfield spindle 27. The viscosities of all the samples were measured in the temperature range from 90ºC to 170ºC to study the viscosity trend of the modified and unmodified bitumen with respect to temperature and it was graphically shown in Figure 1.The standard test method as per ASTM D 4402 is followed.

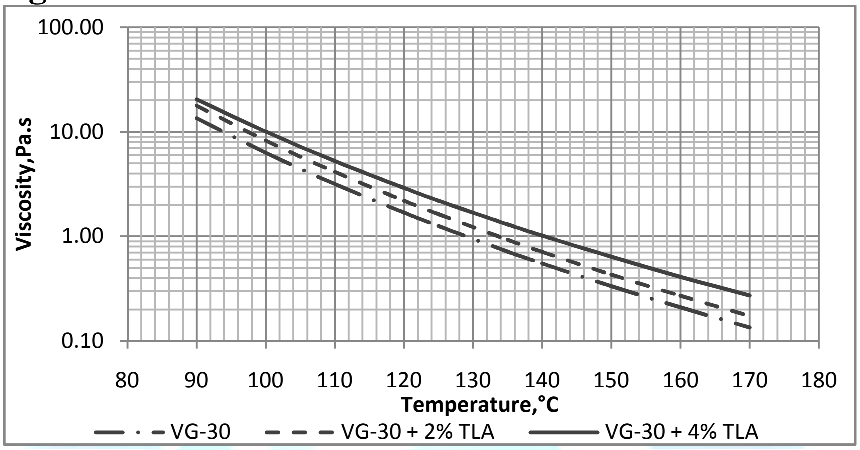

Figure 1: Viscosity temperature graph for neat and TLA blends

3.3 Short Term Aging

The aging of bitumen is one of the principal factors causing the deterioration of asphalt concrete pavements. There are two basic mechanisms involved in binder aging; these include an irreversible process like chemical changes of the bitumen, consisting of oxidation of bitumen molecules, and loss of volatile components which subsequently has an impact on the physical and rheological properties of the binders. The TLA modified binders and control VG-30 binders were exposed to short term aging and were oxidized. In this study the rolling thin film oven test (RTFOT) was used to simulate short-term aging during asphalt mix production at the plant. The RTFOT measures the effect of heat and air on a moving film of semi-solid asphaltic binder. The test temperature of 163°C and time for the RTFO test is 85 min expected to produce aging effects comparable to average site conditions. The aged/oxidized blends and control VG 30 binders were again checked for their softening point, penetration value and viscosity values. Table 4 shows the change in the softening point and penetration value of the aged binders. Table 5 shows the comparison of viscosity values of TLA blends and VG-30 bitumen at 135°C and 150°C before aging and after aging.

Table 4: Physical properties of Un Aged and Aged VG-30 and TLA modified binders

Type of binder	Binder	Softening Point, °C	Penetration Value(1/10th mm)
Un aged binders	VG-30	50.2	64
	VG-30 + TLA 2%	55.4	48
	VG-30 + TLA 4%	59.8	39
RTFOT aged binders	VG-30	58.5	35
	VG-30 + TLA 2%	61.5	31
	VG-30 + TLA 4%	65	28

Table 5: Viscosity values of aged and un-aged binders at 135°C and 150°C

Type of binder	Binder Type	Viscosity at 135°C, cP	Viscosity at 150°C, cP
Un aged binders	VG 30	680	330
	VG-30 + TLA 2%	930	430
	VG-30 + TLA 4%	1310	640
RTFOT aged binders	VG 30 Aged	1075	500
	VG-30 + TLA 2% Aged	1273	500
	VG-30 + TLA 4% Aged	1850	500

3.4 Rheology of Aged & Un-aged Binders

The Viscoelastic response of the modified bituminous binders was evaluated using a Dynamic Shear Rheometer with parallel plate geometry by measuring complex shear modulus and phase angle. Measurements were taken in the temperature range of40°C to 90°C. The oscillatory type test is conducted by using 25mm steel plate with a gap of 1mm for Un aged and aged binders, and test was conducted at a frequency of 10 rad/s. The DSR measures a specimen's complex shear modulus (G*) and phase angle (δ). The complex shear modulus (G*) can be considered the sample's total resistance to deformation when repeatedly sheared, while the phase angle (δ), is the lag between the applied shear stress and the resulting shear strain. Phase angle describes the viscoelastic behaviour of the bitumen binder. If the binder is purely viscous, where δ=0 and if the binder is purely elastic where δ=0.In this test the sample is sandwiched between the two parallel plates is subjected to a sinusoidal angular displacement of constant frequency. The specified DSR oscillation rate of 10 rad/s (1.59 Hz) is meant to simulate the shearing action corresponding to a traffic speed of about 55 mph (90 km/hr). G* and δ are used as predictors of HMA rutting and fatigue cracking.The rutting parameter (G*/sinδ) and phase angle (δ) of un aged and aged binders are graphically shown in figure 2 and figure 3.

For coating on mineral aggregates and adequate compaction, a viscosity value of 0.1to 0.3 Pa.s is needed. During compaction of bituminous mixture, higher value of viscosity reduces workability of mixture, leading to poor density of compacted bituminous layer. Production of bituminous mixes at such high temperatures requires higher quantity of fuel, eventually contributes to higher green house gases. Higher working temperature is also harmful to crew at construction sites.After the complete characterization of TLA modified blends it was found that VG-30 bitumen gave the optimum and best properties when 2% of TLA by weight is added to the VG 30 bitumen.The acceptable compaction of bituminous mixes always requires an optimum value of viscosity [9]. When 4% of TLA was added to VG-30 binder, it made the binder too stiff which can cause early cracking of the pavement. So for bituminous mix testing only 2% of TLA modified bitumen blend was considered.

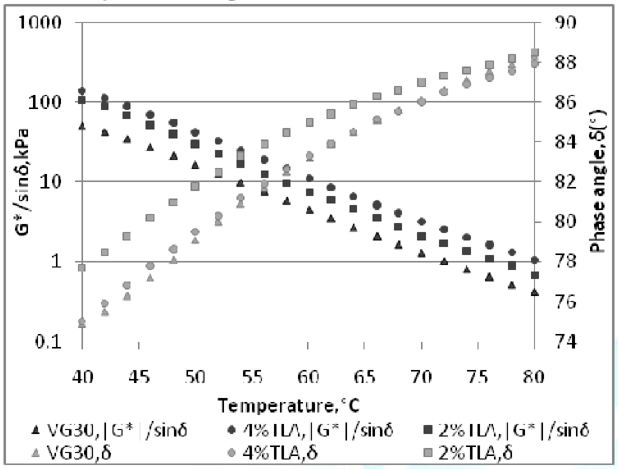

Figure 2: G*/sinδ and δ of unaged binders

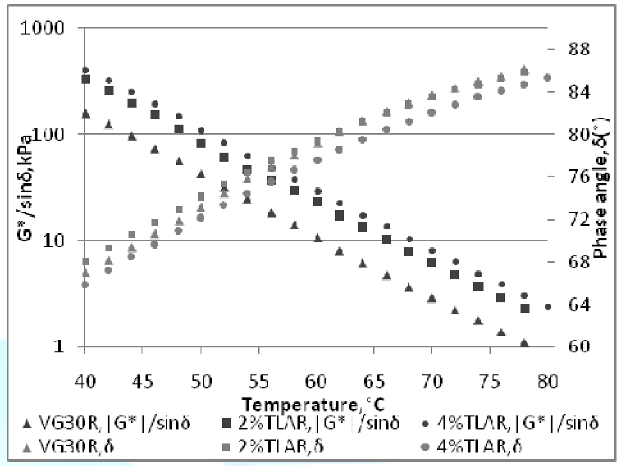

Figure 3: G*/sinδ and δ of RTFOT aged binders

3.5 Mix Design for Bituminous Concrete

Grading of aggregate was done as per Ministry of Road Transport and Highways Specification (MoRTH, 2001-IV Revision) for 50 mm thick bituminous concrete is given in Table 6 and its gradation was shown in Figure 2. The optimum binder content (OBC) in bituminous mix with VG-30 bitumen was obtained by Marshall bituminous mix design method. For determination of OBC for 60/70 paving grade bitumen and 2%TLA modified bitumen at 155-160^{0}C mixing temperatures, the Marshall samples were prepared with binder content of 4.5% to 6% with 0.5% of increments.The OBC determined was 5.2% by wt. of mix for VG 30 and 5 4% for 2% TLA modified bitumen. Table 7 shows the various voids and MarshallParameters in bituminous mix samples made with VG-30 bitumen and TLA modified bitumen.

Table 6: Gradation of Bituminous Concrete Mixes

Sieve Size mm	Cumulative % passing	Specified Grading
19.0	96	79-100
13.2	69	59-79
9.5	64	52-72
4.75	52	35-55
2.36	39	28-44
1.18	26	20-34
0.60	22	15-27
0.30	16	10-20
0.15	11	5-13
0.075	6	2-8

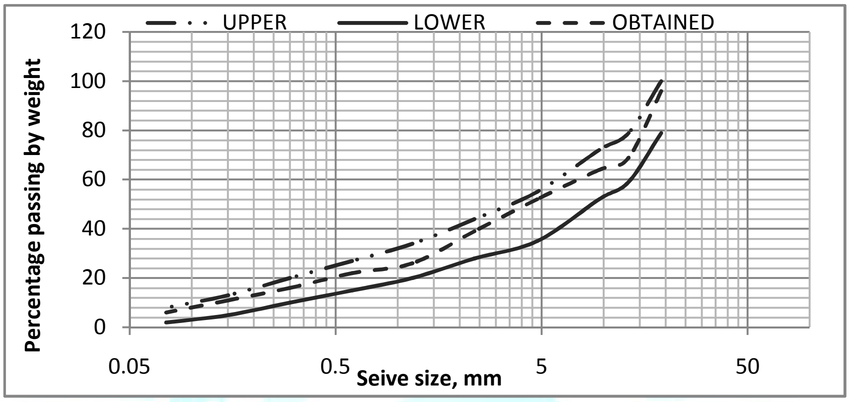

Figure 4 Gradation of the Bituminous Concrete

3.6 Performance Characteristics of Bituminous Mix With TLA Additive

Samples were prepared at OBC with TLA pellets as an additive at 150° C temperatures to determine the various performance characteristics. The various performance tests of the prepared samples were carried out in the laboratory. The behavior of the TLA modified bituminous mix was studied and compared with the conventional VG-30 bituminous mix through various laboratory performance tests.3samples were tested for each performance test and averages of the values are given.

3.6.1 Retained Stability

Retained Stability is the measure of moisture induced striping in the mix and subsequent loss of stability due to weakened bond between aggregates and binder. The test was conducted on the Marshall machine with the normal Marshall samples. The stability was determined after placing the samples in water bath at 60° C for half an hour and 24 hours.

$$\text{Retained Stability (\%)} = \frac{Stability after\ 24\ hoursinwatertbathat\ 60°C}{Stability\ after\ 30 minutes\ in\ water\ bath\ at\ 60\ °C} * 100$$

3.6.2 Indirect Tensile Strength (ITS) & Tensile Strength Ratio (TSR)

ITS tests were conducted on Marshall Samples of conventional bituminous mixes and TLA modified mixes at 25°C. The ITS test was performed by loading a Marshall specimen with a single compressive load, which acts parallel to and along vertical diametrical plane. This loading configuration develops a uniform tensile stress perpendicular to the direction of the applied load and along the vertical diameter. The load at which the specimen fails is taken as the indirect tensile strength (also referred as the dry indirect tensile strength) of the bituminous mix.

The tensile strength ratio of the bituminous mixes is used to determine the moisture susceptibility of the mixes.The Marshall specimens were placed in the water bath maintained at 60°C for 24 hours and then immediately placed in the environmental chamber maintained at 25°C for two hours. These conditioned samples are then tested for indirect tensile strength. The indirect tensile strength of these soaked samples is called wet indirect tensile strength. The ratio of the wet to dry indirect tensile strength is recorded as Tensile Strength Ratio (TSR) of the bituminous mix.

$$T = \frac{2 * P}{\pi * t * d}$$

Where,

P = Load at which failure of sample occurred in kg. t = thickness of sample in cm

d = diameter of sample in cm: T = Indirect tensile strength in kg/sq cm

The tensile strength ratio (TSR) is calculated as follows

$$\text{Tensile strength ratio (TSR)} = \frac{\text{Average tensile strength of conditioned specimen}}{\text{Average tensile strength of unconditioned specimen}} * 100$$

Table 7: Volumetric and Mechanical properties of VG-30 Bitumen and TLA blend

Properties	Method	VG 30	VG 30+2%TLA
Optimum binder content	**ASTM D 3203**	5.2	5.4
Bulk Density, G_b (g/cc)	**ASTM D 2726**	2.371	2.388
% Air voids, Vv	**ASTM D 3203**	4.317	4.057
Stability, Kg,60°C	**ASTM D 1559**	1414	1634
Flow, mm	**ASTM D 1559**	4.3	3.9
Retained stability after immersion,%	**ASTM D 1075**	77.93	87.9
Dry Indirect tensile strength, kg/cm²	**AASHTO T283**	12.87	13.21
Indirect tensile strength after immersion, kg/cm²	**AASHTO T283**	10.23	11.43
Indirect tensile strength ratio,%	**AASHTO T283**	78.8	86.5

3.6.3 Flexural Beam Fatigue Test

The fatigue resistance of asphalt mixture is commonly determined by the flexural bending beam test [10].Pavements that are experiencing fatigue failure will suffer cracking caused by repeated traffic loading. These cracks occur in the wheel paths, initiating as longitudinal cracks and progressing to an alligator crack pattern. A pavement can use the results from a beam fatigue test to provide an estimation of the number of wheel loads that can be carried before fatigue cracking appears.A constant haversine loading was applied in bituminous mix beam with a number of load repetitions to get the failure status of the beam. The load rate is fixed, but is normally 1 to 2 cycles per second. This produces a constant bending moment over the centre of the beam. A load is often applied in the opposite direction, forcing the beam to return its original position to maintain the zero position during the test period. The deflection caused by the load is measured at the centre of the beam. The stress and strain at the outer fibres', and the stiffness modulus after about 50 load applications, are calculated using basic relationships for stress and strains in beams.

Flexural Beam Fatigue test was conducted at controlled strain mode in beam fatigue system complying with SHRP M009. Beams of 64mm wide, 45mm height, 400mm long were prepared by static compaction with a compaction level of 94 to 96 percent.The prepared specimen is conserved on anenvironmental chamber for four hours to get the testtemperature of 20°C for the specimen, before thefatigue test is strated. They Havre sine wave shape loading of 0.1s magnitude with rest period was applied at the frequency of 10Hz.The test were completed when the initial flexural stiffness value reduced to 50% of its initial value. This test was carried at a constant strain level of 500 micro strains. Poisson's ratio at 20 °C was assumed to be 0.35 for all the mixes. The test results are given in Table 8.

Table 8: Flexural Beam Fatigue Results

Parameters	**60/70**	**TLA blend**
No. of cycles	83630	136793
Flexural Stiffness, (Mpa)	832	990
Micro Strain	500	500
Phase angle (degree)	40.5	24.6
Cumulative Dissipated Energy, (MPa)	0.41	0.49

3.6.4 Hamburg Wheel Tracking Test

The rutting in bituminous concrete layer is caused by combination of densification (volume change) and shear deformations, both resulting from repetitive application of traffic loads. The rate of permanent deformation accumulation increases rapidly at higher temperatures; thus the laboratory testing was conducted at a higher temperature of 50°C. This test method covers the determination of rut depth of rectangular specimen (slab) of bituminous mixes. Rutting in the specimen occurs due to repetitive action of wheel subjected to standard axle load. Specimens were prepared for TLA modified mix and conventional mix at 155-160°C. The test was continued until 20,000 passes reaches.

Wheel tracking test is to find out the behaviour of slabs of bituminous mix under continuous moving load and to determine the rut depth in mm to ascertain the strength characteristics of a mix against rutting. Results obtained were in the form of standard no. of cycles of load repetition vs. the rut depth. Higher the rut depth lesser is the resistance offered by the mix. The behaviour of the two mixes is shown in Figure 5.

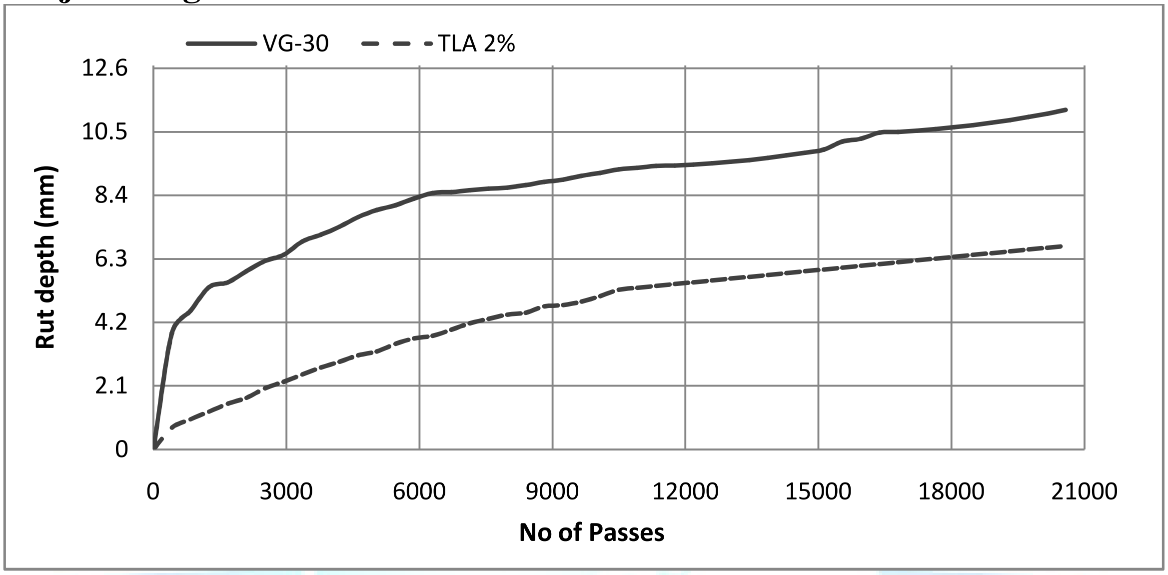

Figure 5: Number of passes versus Rut depth

4. Results and Discussion:

The TLA pellets when mixed with bitumen changed the properties of bitumen as well as bituminous mix. The performance of mix in terms of retained stability, tensile strength ratio and rutting is discussed in the subsequent sections.

4.1 Physical properties of Binders

Table4 and 5 shows that the physical properties like softening point,penetration value andviscosity of VG-30 bitumen changed to a greater extent after the addition of TLA pellets. Addition of 2% & 4% TLA pellets imparted hardness and stiffness to the neat VG-30 grade binder. From Table 4 and 5 it shows that when these binders were exposed to short term aging, VG-30 binder aged to a greater extent and showed maximum change in the physical properties values in comparison to TLA modified binders. From the figure 1 Viscosity temperature graphit shows that the addition of 2% TLA with VG 30 bitumen has mixing temperature viscosity 0.1 to 0.3 Pa.s lies in between 158-167°C, where as 4% TLA with VG 30 has 20°C more than the 2% TLA modified bitumen. This higher mixing temperature requires higher quantity of fuel and also the oxidation of bitumen causes brittleness in the pavement. From the Table 5 it was found that the viscosity of 4% TLA at 135°C has 29% and at 150°C has 32%more than the 2%TLA blended bitumen where as for the short term aged all three binders show similar viscosity values at 150°C.The similar viscosities at of aged binders 150°C shows that the TLA blended bitumen loses its volatile components and behave as a virgin bitumen at high temperatures.

4.2 Viscoelastic Response of Binders

Figure 2 shows almost linear relationship between complex modulus G* and temperature. The slopes of the lines are similar for both 2% TLA modified bitumen and control VG-30 grade bitumen in case of un-aged binders.But un-aged 4% TLA modified bitumen gives lower complex modulus in comparison to 2% TLA modified bitumen and VG-30 bitumen. In the temperature range of 30°C to 70°C both 2% TLA modified blend and VG-30 bitumen gave similar modulus value but at higher temperatures 2% TLA modified blend gave better values than neat bitumen.Higher modulus at high temperature indicates better resistance to permanent deformation (rutting). Whereas when the binders were exposed to short term ageing, they gave entirely differently values. 2% TLA modified binder gave the highest modulus values after ageing in comparison to 4% TLA modified binder and neat VG-30 binder.

Figure 3 shows that the phase angle (δ) of both the TLA modified blends and neat VG-30 is almost similar, there is no change seen in the elastic response of the bitumen after adding TLA pellets. But figure 6 shows that the aged binders did show some change in the elastic response of 2% TLA modified blend. Phase angle of 2% TLA modified blend was much lower than that of 4% TLA modified blend and neat VG-30 bitumen. Lower phase angle indicates lower viscous flow and higher elastic response. This indicates that 2% TLA modified binders have high consistency and elasticity.

Figure 4 shows that at high temperature i.e. between 70°-90°C there was an increase in the G*/sinδ parameter of the neat binder when 2% of TLA pellets were addedwhereas 4% TLA modified blend showed lower values. When these binders were aged in an RTFO and G*/sinδ parameter was studied with dynamic shear Rheometer, it was found that 2% TLA modified blend showed the best values as shown in figure 7. This indicates that the stiffness of both the un-aged 2% TLA modified binder and aged 2% TLA modified binder increases with the addition of 2% of TLA pellets.

4.3 Effects of TLA pellets on moisture sensitivity

Bituminous mixture should have an acceptable resistance to changes in performance properties caused by ingress of moisture. In this study two tests are used to evaluate this parameter; Retained Stability Test and Indirect Tensile Strength Ratio Test. The values of retained stability as well as ratio of indirect tensile strength (table 7) of 2%TLA specimen are better than control VG 30 mix, indicating better performance during static immersion test in water at 60 °C for 24 hours. From the data given in table 7, it is clear that resistance to moisture damage under influence of water is better for 2%TLA modified bituminous mix as compared to conventional VG30 mix. The more the value better will be the performance of mix under moisture in field. 2%TLA pellets increased the Retained stability value up-to 11.34% compared to control bituminous mix. The indirect tensile strength is useful in predicting the cracking potential. The tensile strength of asphalt concrete at high temperature is relatively low and falls with the increase in test temperature. TSR from table 4 shows that the tensile strength ratio of bituminous mix increases with the addition of TLA pellets. It showed TSR value of 8. 9% increases for the additions of 2% TLA compared to TSR of control sample.

4.4 Beam Fatigue Testing

Fatigue cracking prediction is normally based on the cumulative damage concept which was given by Miller[10]. The allowable number of load repetitions is related to the tensile strain at the bottom of the Bitumen layer. The fatigue resistance of Bitumen mixture is commonly determined by the flexural bending beam test. A constant Haversine loading was applied on Bitumen mix beam with a number of load repetitions to get the failure status of the beam. Fatigue failure is defined as 50% reduction of initial stiffness. From four point fatigue beam test it is clearly shown that TLA Modified mix gives more number of fatigue cycles and have high flexural stiffness compared to un-modified mix at 20°C.A high fatigue life implies a slow fatigue damage rate and consequently higher fatigue-resistance for a given tensile strain.TLA modified blended mixture has 16.3% higher cumulative dissipated energy than the VG 30 bituminous mixtures; this indicates that the highercumulative dissipated energy has generally beenassociated with a higher fatigue life. The phase angle of the control bituminous mixture has value of 40.5° which shows that the control mixture behaves as a viscoelastic mixture at 20°C where as TLA modified mixture has phase angle value of 24.6° which shows that TLA modified mixture behaves as pure elastic at 20°C.

4.5 Rutting

It is evident from figure 5 that the observed value of rut depth was 6.3mm for bituminous mix made with the addition of TLA pellets and 10.7mm forcontrol mix which shows considerably better performance in terms of rutting than conventional VG-30 paving grade bituminous mix. This increase in rutting resistance is due to better stability and bonding between aggregates and binder.

5. Conclusions

The addition of TLA pellets to the bitumen has significantly affected the binder properties and the bituminous mix properties. The following conclusions can be drawn from the laboratory work carried out:

- TLA pellets can be successfully used to enhance the properties of the binder and the mix as compared to conventional binder.
- TLA modified bituminous mix is able to achieve the desired properties of mix like, stability, durability, workability, compaction, resistance to deformation.
- Other properties of bitumen like softening point, penetration, oxidation (ageing) and viscosity are also found to be improving with the addition of TLA pellets; incorporation of TLA pellets increased the viscosity of base binder but at temperatures i.e. 150^0C above this increase was not significant.
- Blend of 2% by weight of TLA and neat VG-30 gave the best binder properties.
- Bituminous mix prepared with modified binder (with TLA pellets) have indicated improved resistance to permanent deformation as obtained from the wheel tracking tests as compared to the mix with neat bitumen.

- The Beam fatigue test result showed that the addition of TLA pellets increased the fatigue life of the bituminous mix; it could sustain higher number of load cycles in comparison to conventional VG-30 bituminous mix.

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