Studies on Effect of Wheel Configuration-Temperature and Type of Binder on Rutting Characteristics of Bituminous Concrete Mix

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Abstract-This report presents the investigation of rutting characteristics of bitumen mixes using plain bitumen (VG-10) and modified binders (CRMB-60 and PMB-70). The report will be of particular interest to engineers in the public and private sectors with responsibility for the design, construction, maintenance and rehabilitation of HMA pavements. The present work is aimed at understanding the properties of mix and the machine parameters which influence the deformation causing ruts for mixes. The rutting was caused on the beam specimens prepared in the laboratory. The study includes the influence of different types of binders, air voids, and along with the applied loads on the rutting characteristics. The results are analyzed to formulate regression equations. It is found that modified binders resist rutting compared to plain binders. PMB-70 binders perform better than VG-10 and CRMB-60 binders under the laboratory induced applied pressures and number of passes.

Key words: Plain Wheel, Treaded Wheel, VG-10, CRMB 60, PMB 70, Rut Depth, Number of Passes and Temperature

I.INTRODUCTION

Rutting is a longitudinal depression or groove in the wheel tracks. The ruts are usually of the width of wheel path. Swerving from a rutted wheel path at high speed can be dangerous. Accumulation of water in the impressions can cause skidding. Rutting may or may not be accompanied by adjacent bulging of the road surface, which may give some indication of the depth of the source of failure. Rutting, also known as permanent deformation can be defined as the accumulation of small amounts of unrecoverable strains as a result of applied loading to a pavement. Rutting occurs when the pavement under traffic loading consolidates and/or there is a lateral movement of the hot bituminous mix. The lateral movement is a shear failure and generally occurs in the upper portion of the pavement surface. As a result of rutting, the pavement service life is reduced. If the rutting depth is significant, water may accumulate in the rutted area, which can lead to vehicle hydroplaning.

II. PRESENT INVESTIGATIONS

The present investigation is focused on the effect of rutting characteristics of bituminous concrete mix with modified binders (PMB-70 & CRMB-60) and normal bitumen (VG-10) for beam specimen using optimum binder content, different parameters like applied pressure, volume of voids, number of passes, varying temperature for bituminous concrete mix.

III. METHODOLOGY

As per standard test procedure of Immersion Wheel Tracking Equipment (IWTE) developed for research work of Sri. K. Ganesh, to determine the effects of rutting by moving a hard moulded rubber wheel on the bituminous concrete surface. To determine the depth of rut on the beam specimen by allowing number of passes of the wheel under different applied pressures. To determine the effects of rutting, by using optimum binder content for plain bitumen VG-10 and for modified binders PMB-70 and CRMB-60.

IV. MATERIALS USED IN THE STUDY

The different materials used in the study are aggregates, conventional and modified binders. Granite aggregate available in the quarry near Bangalore was selected. The Proportion of aggregates used are 20 mm, 12.5 mm, 6 mm and Crusher dust which is used as a filler material for the preparation of rutting beam specimens. The type of binders used in the study are VG-10 grade as a Conventional Binder, CRMB-60 and PMB-70 grade as Modified Binders.

V. OBTAINED GRADATION

The different sizes of aggregates, that is, 20 mm, 12.5 mm, 10 mm, 6 mm and dust are selected from the heap and the sieve analysis is done to obtain the individual gradation of these aggregates. Then by trial and error method, by using the Microsoft excel, the desired gradation for bituminous concrete were obtained to match the midpoint gradation as shown in Table 1.1. Plain bitumen of grade VG-10 and modified binders PMB-70, CRMB-60 were used for the study and the physical properties of the aggregates have met the requirements as given in Table 1.2. The gradation obtained for bituminous concrete mix is shown in Figure.1.

Table 1.1 Aggregate gradation of Bituminous Concrete mix

Sl. No.	Sieve size (mm)	% Passing				Obtained Gradation	Desired Gradation	
		20 mm	12.5 mm	6 mm	Dust		Lower	Upper
1	26.5	100	100	100	100	100	100	100
2	19	75.05	100	100	100	92.77	79	100
3	13.2	1.63	100	100	100	71.47	59	80
4	9.5	0.15	48.75	100	100	60.79	52	75
5	4.75	-	3.6	35.8	100	36.95	35	55
6	2.36	-	0.45	22.6	99.2	33.06	28	50
7	1.18	-	0.35	20.7	79.2	27.01	20	35
8	0.6	-	0.30	20.4	70.4	24.46	15	30
9	0.3	-	0.25	20.1	53.2	19.57	10	20
10	0.15	-	0.2	19.4	17.6	9.43	5	10
11	0.075	-	0.1	18.7	0.2	4.38	2	8

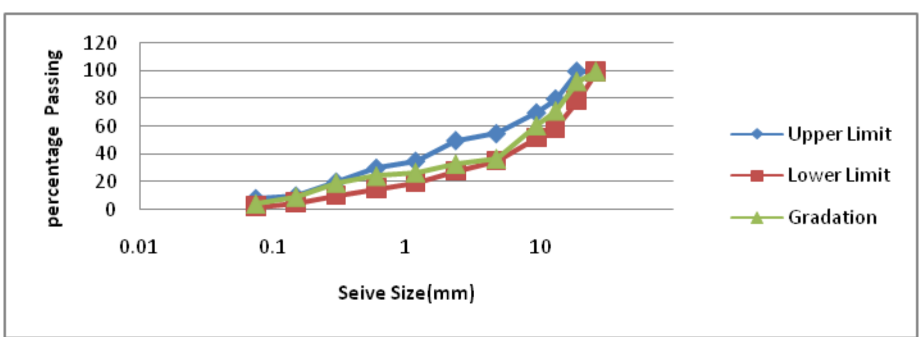

Figure 1 Gradation obtained for Bituminous Concrete mix

Table 1.2 Properties of plain & modified binders

Properties	VG-10	CRMB-60	PMB-70
Penetration (0.1 mm)	82	42	62
Ductility (cm)	89	65	45
Softening Point (^{0}C)	48	84	89
Specific Gravity	1.0	1.07	1.12
Flash & Fire point (^{0}C)	279&292	276 & 310	270 & 295
Elastic Recovery of Half Thread in Ductilometer at 15˚C, %	-	60	79
Separation Difference in Softening point, R&B, ˚C	-	3.6	1.3
Thin Film Oven test (TFOT) on Residue			
Loss in Weight, %	-	0.37	0.29
Penetration of Residue at 25˚C, 0.1mm, 100g, 5 sec	-	24	26
Increase in Softening Point, R&B, ˚C	-	3.4	0.8
Elastic Recovery of Half Thread in Ductilometer at 25˚C, %	-	58	62

VI. TECHNICAL SPECIFICATIONS OF IMMERSION WHEEL TRACKING EQUIPMENT

This equipment has been designed and fabricated at BMS College of Engineering. The wheel tracking apparatus measures effects of rutting by rolling a rubber wheel on the surface of a bituminous concrete (BC) slab. The wheel tracking apparatus consists of a loaded rubber wheel mounted on the surface of the bituminous concrete mix slab (specimen to be tested) fitted on a movable table driven from AC motor through crank and pinion. The water bath reciprocates with to and fro motion at a frequency of maximum 40 passes per minute. The wheel is of 200 mm x 50 mm solid rubber wheel. The wheel is loaded by using cantilever arrangement up to a maximum load of 3925 N. A tank with temperature controlled is fitted on the moving platform. The specimen in the form of bituminous concrete beam is fitted inside the tank. A screw lever arrangement is provided for adjustment for the slab thickness. The water temperature inside the tank is maintained at room temperature. Two LVDT (Linearly Variable Differential Transducer) are fitted on the axel of the rubber wheel to monitor the rut depth. The output of the LVDT is connected to computer through '**PC ADD ON'** card. A dedicated software monitors the rut depth and plots the graph for no. of passes Vs rut depth. The test DATA is stored in a text file for further analysis of the data. The photographic view of Immersion Wheel Tracking Equipment is shown in Figure 2.

Figure 2 View of Immersion Wheel Tracking Equipment

VII. PREPARATION OF THE SPECIMEN FOR RUTTING TEST

- Weigh the required, sizes and quantities of aggregates, according to the proportion found by Rothfutch's method.
- Materials of size 20 mm and down size (29%), 12 mm and down size (20%), 6 mm and down size (23%), Crusher dust (28%) and Optimum Bitumen content (5.93%) are taken for the preparation of rutting specimen.
- Pour all the weighed and mixed aggregates in the pan and heat the aggregates up to 150-170°C.
- Add binder (150-165°C) and mix it and heat to the required temperature of mix, should be between 140°C to 160°C.
- The bituminous mix is poured in a pre-heated mould (pouring temperature should be between 100°C to 145°C).
- The mix is compressed at constant rate of loading using Universal Testing Machine (UTM) up to a required thickness of 75 mm.
- The schematic diagram of Immersion Wheel Tracking Equipment for recording rut depth are shown in Figure.2.

VIII. ANALYSIS OF TEST RESULTS

The Bituminous Concrete Beams of 40 mm thickness were subjected to rutting at varying temperatures from 30 to 50°C using the Immersion Wheel Tracking equipment. The variables considered are the mix characteristics defined by varying temperature and type of Binder, Number of Passes of the wheel, wheel tread configuration and applied pressure on the wheel. The binder used is conventional bitumen of grade VG-10 and modified binders of grade CRMB-60 and PMB-70.

8.1Analysis of Rut Depth versus Number of Passes for Plain Wheel and Treaded Wheel Configuration in 40mm thick Bituminous Concrete mix

Graphical analysis of Rut Depth and Number of Passes for different Temperatures and Binders for Plain Wheel and Treaded Wheel in 40mm thick Bituminous Concrete mix were carried out using the rutting data. The graphs were plotted as shown in figures 3 to 4 (Plain Wheel) and figures 5 to 6 (Treaded Wheel) for Conventional and Modified Binders in Bituminous Concrete mix.

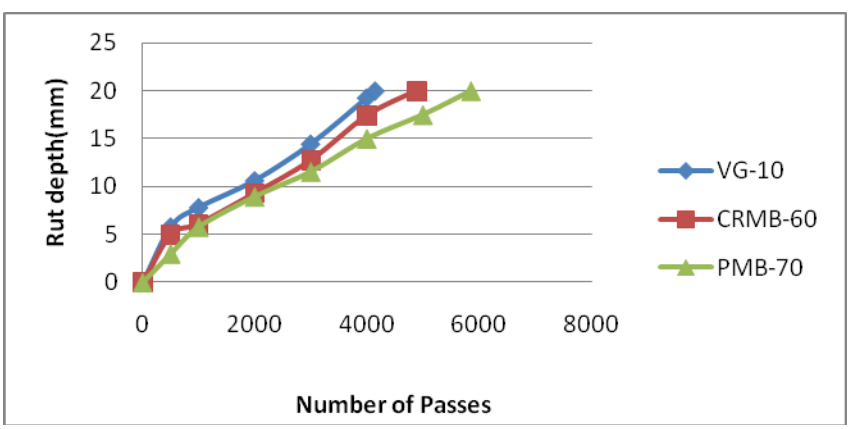

Figure 3 Number of passes versus Rut depth for 40mm thick Bituminous Concrete mix using Conventional and Modified Binders at 30˚C (Plain Wheel)

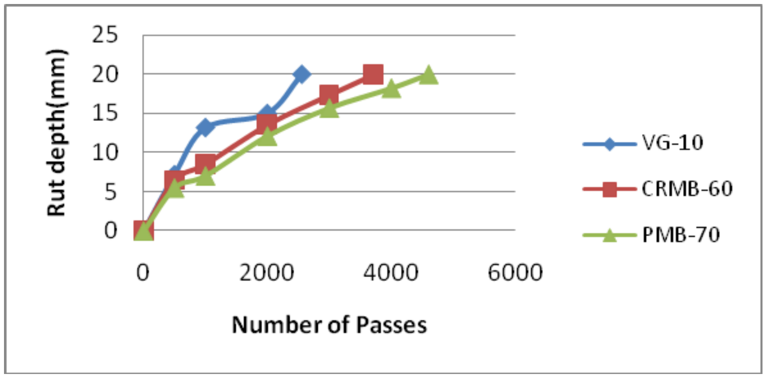

Figure 4:Number of passes versus Rut depth for 40mm thick Bituminous Concrete mix using Conventional and Modified Binders at 50˚C (Plain Wheel)

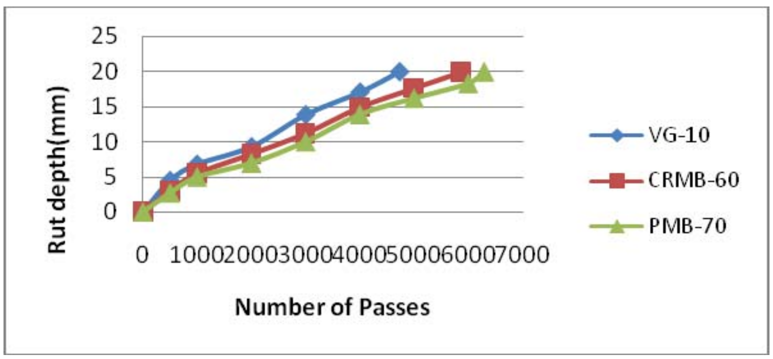

Figure 5: Number of passes versus Rut depth for 40mm thick Bituminous Concrete mix using Conventional and Modified Binders at 30˚C (Treaded Wheel)

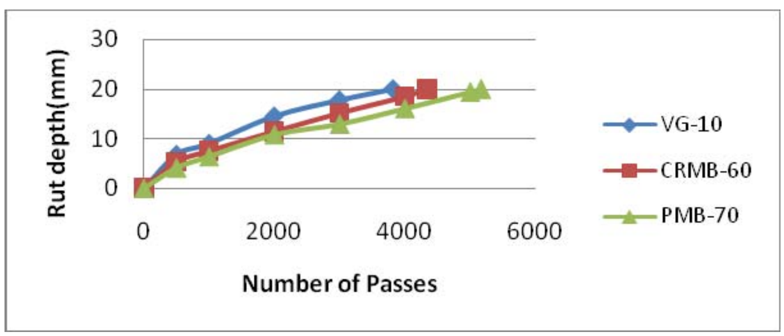

Figure 6: Number of passes versus Rut depth for 40mm thick Bituminous Concrete mix using Conventional and Modified Binders at 50˚C (Treaded Wheel)

8.2 Analysis of Number of passes at failure Rut depth of 20 mm in 40mm thick Bituminous Concrete mix using Conventional and modified Binders at varying Temperatures (Plain and Treaded Wheel Configuration)

The variation in Number of passes to cause failure (20mm rut depth) of Bituminous Concrete Mix at different Temperatures for the above Binders and Wheel Configuration are indicated in table 3. Graphs have been plotted for the above binders and are shown in figures 7 and 8.

Table 3 Relation between Number of Passes and Temperature in Bituminous Concrete mix using Plain and modified binders for Plain and Treaded Wheel Configuration

Temperature (˚C)	Number of Passes at 20mm Rut Depth					
	VG-10		CRMB-60		PMB-70	
	Plain	Treaded	Plain	Treaded	Plain	Treaded
30°C	4152	4728	4891	5880	5858	6295
35°C	3659	4428	4586	5388	5505	6113
40°C	3387	4261	4296	5197	5105	5904
45°C	2966	4011	4099	4678	4826	5486
50°C	2558	3821	3720	4350	4603	5167

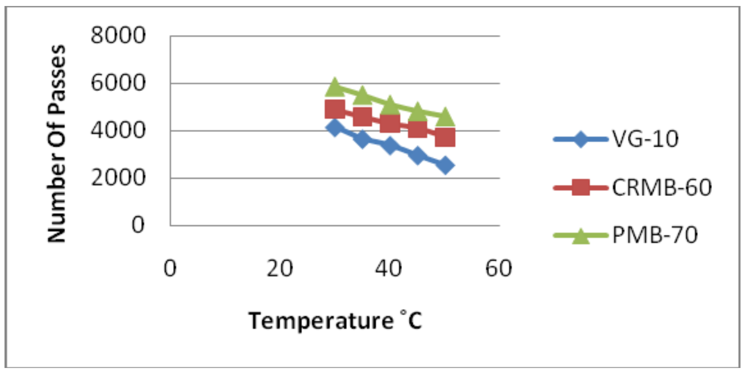

Figure 7 Number of passes versus Temperature for 40mm thick Bituminous Concrete Mix using Conventional and Modified Binders for varying Temperature (Plain Wheel Configuration)

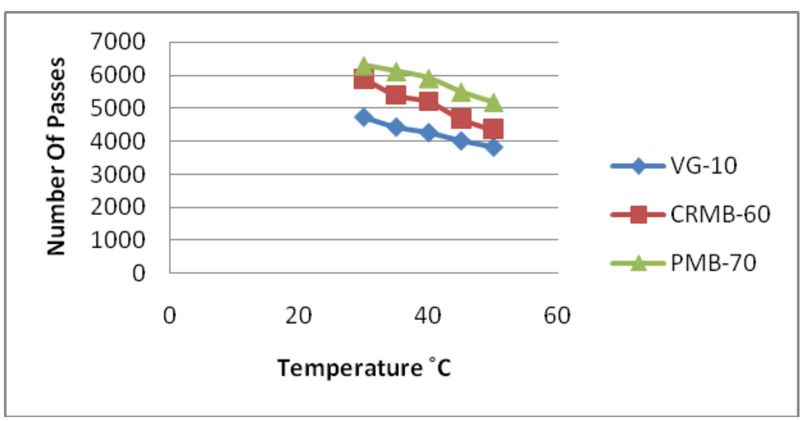

Figure 8 Number of passes versus Temperature for Bituminous Concrete Mix using Conventional and Modified Binders for varying Temperature (Treaded Wheel Configuration)

8.3 Analysis of Rutting Co-efficient A and B for different Binders at varying Temperatures in 40mm thick Bituminous Concrete mix

The rutting Coefficients A and B are obtained for 40mm thick Bituminous Concrete mix for the above selected three binders at varying temperatures from 30°C to 50°C by fitting an exponential curve and the results are as shown in table 4. The results fit an exponential curve of the form,

$$\mathbf{R}D = \mathbf{AN^B}$$

Where, RD = Rut Depth,

N= Number of passes.

A and B are rutting coefficients representing the elastic and plastic components after deformation.

Table 4 Rutting Coefficients A and B for Bituminous Concrete using Plain and Modified Binders for Plain and Treaded wheel Configuration

SL.No	Binder Type	Temperature in ˚C	PLAIN WHEEL		TREADED WHEEL	
			A	B	A	B
1	VG-10	30	0.144	0.581	0.072	0.656
		35	0.156	0.578	0.086	0.64
		40	0.171	0.576	0.137	0.591
		45	0.198	0.573	0.17	0.57
		50	0.232	0.563	0.216	0.549
2	CRMB-60	30	0.089	0.626	0.027	0.757
		35	0.142	0.576	0.038	0.726
		40	0.152	0.575	0.092	0.624
		45	0.161	0.574	0.103	0.617
		50	0.175	0.573	0.114	0.61
3	PMB-70	30	0.03	0.746	0.022	0.77
		35	0.58	0.677	0.026	0.75
		40	0.08	0.643	0.036	0.72
		45	0.101	0.62	0.055	0.68
		50	0.117	0.608	0.063	0.66

IX. DISCUSSIONS ON TEST RESULTS

The Rutting tests were conducted on 40mm thick Bituminous Concrete beams with 7.2 kg/cm^2 tire pressure at varying temperatures from 30°C to 50°C and using three different Binders VG-10, CRMB-60 and PMB-70 which have yielded the data for discussions as indicated below.

9.1 Discussions on Rut Depth versus Number of Passes for Plain Wheel and Treaded Wheel Configuration

For Plain Wheel

Figure 3 and 4 drawn for 30˚C to 50˚C change in temperature show that the trend of increasing rut depth with increase in number of passes is maintained for all binders viz VG-10, CRMB-60 and PMB-70 at different temperature.

The hierarchy of PMB-70 grade binder being maximum resistance to rutting compared to VG-10, is also maintained for different temperatures where as the number of passes at failure of 20mm rut depth varies considerably with different binders in 40mm thick Bituminous Concrete mix

As seen from figures 3 and 4, the difference in number of passes increases with the increase in temperature. This gap increases more with VG-10 and CRMB-60 binder compared to CRMB-60 and PMB-70 binder.

From table 3, with increase in temperature from 30˚C to 50˚C for VG-10 grade binder the change in number of passes is 4152 for 30˚C to 2558 for 50˚C which decreases in number of passes as 79.7 per ˚C as the gradient. From table 4.1, with increase in temperature for 30˚C to 50˚C for CRMB-60 the change in number of passes is 4891 for 30˚C to 3720 for 50˚C which decreases in number of passes as 58.55 per ˚C as the gradient.

With increase in temperature from 30˚C to 50˚C for PMB-70 grade binder the change in number of passes is 5858 for 30˚C to 4603 for 50˚C which decreases in number of passes as 62.6 per ˚C as the gradient.

From the above test results, it is clear that PMB-70 has shown higher number of passes compared to other binders i.e., CRMB-60 and VG-10 grades.

For Treaded Wheel

Figure 5 and 6 drawn for 30˚C to 50˚C change in temperature show that the trend of increasing rut depth with increase in number of passes is maintained for all binders viz VG-10, CRMB-60 and PMB-70 at different temperatures.

The hierarchy of PMB-70 grade binder being maximum resistance to rutting compared to VG-10, is also maintained for different temperatures where as the different number of passes at failure at 20mm rut depth varies considerably with different binders in 40mm thick Bituminous Concrete mix.

As seen from figures 5 and 6 the difference in number of passes with the increases in temperature. This gap increases more with VG-10 and CRMB-60 binder compared to CRMB-60 and PMB-70 binders.

From table 3, with increase in temperature from 30˚C to 50˚C for VG-10 grade binder the change in number of passes is 4728 for 30˚C to 3821 for 50˚C which is decreases in number of passes as 45.35 per ˚C as the gradient.

With increase in temperature for 30˚C to 50˚C for CRMB-60 the change in number of passes is 5880 for 30˚C to 4350 for 50˚C which is decreases in number of passes as 76.5 per ˚C as the gradient.

With increase in temperature for 30˚C to 50˚C for PMB-70 the change in number of passes is 6295 for 30˚C to 5167 for 50˚C which is decreases in number of passes as 56.4 per ˚C as the gradient.

From the above test results, it is clear that PMB-70 has shown higher number of passes compared to other binders i.e., CRMB-60 and VG-10 grades.

9.2 Discussions on the Effect of Binder and Temperature on the Rutting coefficients

The Rut depth versus Number of Passes has a general trend of $RD=AN^B$ with A, B coefficient as shown in table 4. As the temperature increases, the Elastic part of the binder increases as shown with increases in value of A for all binders and the Plastic portion represented by coefficient B decreases. Similar trend have been observed for both Plain and Treaded Wheel. Higher values of A and B for plain wheel at 30˚C were 0.144 and 0.581,component which indicated that the VG-10 binder is more susceptible to temperature changes compared to other binders i.e., CRMB-60 and PMB-70 grade binders..

9.3 Discussions on the Effect of Wheel Configuration on Rutting characteristics.

Two Wheel Configuration Plain Wheel (PW) and Treaded Wheel (TW) in the present study have clearly demonstrated that there is considerable influence of wheel configuration on the rutting characteristic as indicated by number of passes to failure and the trend of rut depth versus number of passes as shown in figures 3 through 6.

Using VG-10 grade binder, it is seen that the difference in number of passes at 20mm rut depth (failure) increases with temperature 30˚C to 50˚C. The Treaded Wheel has always indicated higher number of passes compared to the plain wheel the difference is 4152 passes at 30˚C to 2558 passes at 50˚C.

Comparing the rutting results of BC mix using the above three binders, it is indicated that the gap in the number of wheel passes decreases with CRMB-60 and PMB-70 with the least gap for PMB-70 grade binder for different temperatures. This shows that PMB-70 is not very sensitive to the tread configuration compared to the VG-10 grade conventional bitumen.

X. CONCLUSIONS

Based on the analysis and discussions made using Conventional and Modified Binders in 40mm thick Bituminous Concrete mix, the following conclusions on the rutting characteristics were obtained

i. From the laboratory investigation presented here in and the analysis of data clearly indicated that PMB-70 grade binder has higher Rut resistance compared to VG-10 by nearly 40 percent at 30˚C and 80 percent at higher temperature of 50˚C.

ii. The Rutting test results clearly shows that CRMB-60 grade binder has higher resistance to rutting compared to VG-10 grade by nearly 17 percent at 30˚C and 45 percent at 50˚C

iii. The temperature at which the rutting test were performed has shown significant influence on Rutting .The Rutting increases with increase in temperature and PMB-70 grade binder has shown higher resistance to Temperature indicating less temperature susceptible compared to VG-10 grade binder in Bituminous Concreter mix.

iv. The Wheel configuration has also indicated to be an influence factor in rut formation for all binders viz VG-10, CRMB-60 and PMB-70 grades. The rut depth variation is found to be linear in Treaded Wheel compared to Plain Wheel Configuration.

v. As the temperature increases, the Elastic part of the binder increase as shown for varying temperature by increase in value of coefficient A for all binders and the plastic portion represented by coefficient B decreases.

XI. ACKNOWLEDGEMENTS

The authors would like to thank Department of Civil Engineering B.M.S. College of Engineering, Bangalore for providing the facilities and extending the help in different aspects of academia. Authors would like to thank the reviewers for their constructive comments and their suggestions.

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