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Effect of Tyre Pressure and Temperature on Rutting Characteristics of Warm Mix Asphalt in Bituminous Concrete Layer

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Abstract: - *Many new processes have been developed to reduce the mixing and compaction temperature of hot mix asphalt without scarifying the quality of flexible pavements. Investigation in the laboratory was carried out to determine Warm Mix Asphalt (WMA) if the addition of Sasobit as additive it has potential to increase the stability comparison with Hot Mix Asphalt (HMA). For the current study, the use of Sasobit has been tried to achieve the higher stability at low temperatures. Further addition of Sasobit to bituminous mix has been evaluated by testing their laboratory performances as compared to HMA mixes with binder's viz. VG-20 and VG-30.The present work is aimed at understanding the properties of mix at temperature and various pressures which influences the rutting characteristics of the mix. Rutting test was performed on the slab specimens prepared in the laboratory at its Optimum Binder Content (OBC) of Bituminous Concrete Grade-2 mix. The study includes the behavior of different type of binders at varying temperature from 30⁰ to 70⁰ C along with a tyre pressure of 7.1 kg/cm2 on the rutting characteristics. It is found that bitumen grade VG-20 and VG-30 performs better with WMA when compare to HMA at laboratory tests.*

Keyword: - HMA, WMA, BITUMINOUS CONCRETRE MIX, RUTTING

1.0 INTRODUCTION

Over the last two decades, traffic volume and the percentage of heavy truck have increased enormously demanding from pavement engineers stronger and long lasting pavements. Flexible pavements with bituminous surfacing are widely used in India. The high traffic intensity in terms of commercial vehicles, overloading of axles and significant changes in daily and seasonal temperature of the pavement have been always responsible for early development of distress symptoms like raveling, undulations, rutting, cracking, bleeding, shoving and potholing of bituminous surfacing. The objective of the paper is to highlight to road engineers the effect that their decision regarding maintenance and rehabilitation of road surfacing may have on the tyre life of road users. Since Indian continent lies in the tropical region the prediction of weather is different and hence need for pavement is very essential.

1.1 Warm Mix Ashphalt (WMA) [3]

Warm Mix Asphalt is new in India in which an additive is mixed with hot asphalt mixes in desired proportion so as to lower down the hot mix temperature from 160°C to 135°C- 140°C for the preparation of workable mix laying. Sasobit Additive is described as an "Asphalt Flow Improver", during lay operations, due to its ability to lower the viscosity of the asphalt binder. This decrease in viscosity allows working temperature to be decreased by 18-54°C. At temperature below its melting point, Sasobit reportedly forms a crystalline network structure in the binder that leads to the added stability. During, the production of HMA, Sasol recommends that Sasobit is added at a rate of 0.8% or more by mass of the binder but not exceeding 4%.

1.2. Objectives of the Present Study

- To know the Optimum Binder Content required by each binder for a given WMA and HMA bituminous mix.
- To determine the number of passes required by various bituminous binders, in attaining 20mm rut depth.
- To evaluate the rutting performance of Bituminous concrete (BC) Grade-2 mix at varying tyre pressure and temperature on a casted slab specimen with WMA as Sasobit additive and HMA mix
- To have comparative evaluation of grade bitumen VG-20 and VG-30 prepared specimen with WMA as Sasobit additive and HMA mix.
- To identify the bituminous binder that shows high resistance to temperature and tyre pressure prepared specimen with WMA and HMA mix which are the key parameters in causing rutting of the pavement.

2.0. LITERATURE REVIEW

2.1. General

Flexible pavements with bituminous surfacing are used in India. The high traffic intensity in terms of commercial vehicles, over loading of trucks and significant variation in daily and seasonal temperature of the pavement have been responsible for early development of distress like raveling undulations, rutting, cracking, bleeding, shoving and pot holing of bituminous surfacing[2].

Hot mix asphalt (HMA) is produced at temperature ranging from 160°C to 190°C. The high temperature is used to dry the aggregates and to decrease the viscosity of the asphalt binder. It also produces the desired workability and provides time to compact the HMA while begins to cool. Some techniques have been used since the 1970's to decrease the production and compaction temperature of HMA, benefits of lowering the production and compaction temperature include reduced energy consumption, reduced asphalt emissions and improved performance of pavement.

2.2. Sasobit [2]

Sasobit is a product of Sasol wax of South Africa. Sasobit is a Fischer-Tropsch (FT) or synthetic wax that is created in the coal gasification process. These organic waxes have longer chemical chain lengths and are different from petroleum or paraffin waxes. The longer chain helps to keep the wax in solution, and it reduces binder viscosity at typical asphalt production and compaction temperatures. The Sasobit has been used as an aid and temperature reducer. The Sasobit process incorporates a low melting point organic additive that chemically changes the temperature-viscosity curve of the binder. Both these additives produce a reduction in the binder viscosity by providing liquids in the binder above their melting points. Blending 3 to 4% Sasobit by weight allows a reduction in production temperature of minus 7.77° C to 12.22°C [2].

2.3 Hamburg Wheel-Tracking Device [10]

The HWTD was developed by Helmut-Wind Incorporated of Hamburg. It is used as a specification requirement for some of the most traveled roadways in Germany to evaluate rutting and stripping. Tests within the HWTD are conducted on a slab that is 260mm wide, 320mm long, and typically 40 mm high (10.2”x 12.6”x 1.6”). These slabs are normally compacted to 7±1 percent air voids using a linear kneading compactor. Testing in the HWTD is conducted under water at temperatures ranging from 25°C to 70°C, with 50°C being the most common temperature. Loading of samples in the HWTD is accomplished by applying a 705-N (158-lb) force onto a 47mm-wide steel wheel. The steel wheel is then tracked back and forth over the slab sample. Test samples are loaded for 20,000 passes or until 20mm of deformation occur. The travel speed of the wheel is approximately 340mm per second. The results obtained from the HWTD consist of rut depth, creep slope, stripping inflection point, and stripping slope. The creep slope is the inverse of the deformation rate within the linear region of the deformation curve after post compaction and prior to stripping (if stripping occurs). The stripping slope is the inverse of the deformation rate within the linear region of the deformation curve, after the onset of stripping. The stripping inflection point is the number of wheel passes corresponding to the intersection of the creep slope and the stripping slope. This value is used to estimate the relative resistance of the hot mix sample to moisture-induced damage. A slight modification of the HWTD was made by the Superfos Construction, U.S. (previously Couch, Inc.). This device was referred to as the Superfos Construction Rut Tester (SCRT). The SCRT used slab specimens with similar dimensions as the HWTD. The primary difference between the two was the loading mechanism. The SCRT applied an 82.6 kg (180lb) vertical load onto a solid rubber wheel with a diameter of 194mm and width of 46mm. This loading configuration resulted in a contact pressure of approximately 940kPa (140Psi) and contact area of 8.26cm^2 (1.28 in 2) which was applied at a speed of approximately 556mm per second. Test temperatures ranging from 45°C to 60°C (113°F to 140°F) has been used with the SCRT. Recent research with the SCRT has used 60°C as the test temperature. An air void content of 6 percent was generally used for dense-graded hot mix samples. Results from the SCRT are identical to those from the HWTD and include rut depth, creep slope, stripping slope, and stripping inflection point. Another slight modification of the HWTD is the Evaluator of Rutting and Stripping (ERSA) equipment. This device was built by the Department of Civil Engineering at the University of Arkansas. Testing of cylindrical or beam samples in the ERSA can be conducted in either wet or dry conditions. A 47mm wide steel wheel is used to load specimens with 705N (160lb) for 20,000 cycles or a 20mm rut depth, whichever occurs first.

3.0 MATERIAL AND SAMPLE PREPARATION

3.1. Aggregate

Virgin aggregate and 30 percent recycled aggregate have been selected for preparation of samples and it has satisfied the requirements of MoRT&H specifications.

3.2. Bitumen

Modified bitumen materials have been used in this research and all the basic test have been conducted as per MoRT&H specification. The bitumen samples used in this study are VG-20 and VG-30

3.3. Design methodology for Bituminous Concrete (BC) Grade

For the purpose of the study, the applicability of different binders was studied for BC course. This study was carried for 550 – 600 mm thick layer of BC (Grade-2) including base and sub base layer as per IRC37-2012 design specification.

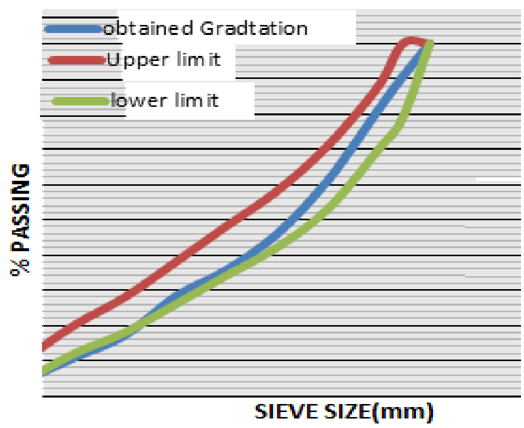

Figure 1: Showing Adopted Gradation

The designed gradation obtained along with specified limit is shown in Figure 1. A Job Mix Formula (JMF) was prepared and obtained grading is shown in the Table 1. Compaction for mix design was done using a Rolling Compactor cum Rut Analyzer (RCRA). The Optimum Binder Content (OBC) of different binder’s

VG-20 and VG-30 were 5.6 and 5.7 % respectively by weight of aggregate shown in table 2 and table 3.

Table 1.0 Bituminous Concrete (BC) Grade-2 Job Mix Formula Indicating Mix Proportion

Bituminous Concrete with Nominal Maximum Aggregate of Size of 19 mm								
Sieve	**40 mm**	**20 mm**	**10 mm**	**4.75 mm**	**Stone Dust**	**Combined Grading**	**MoRT&H Specifications**	
Size in mm	**Aggregate Proportions**							
	0	**0.28**	**0.45**	**0.22**	**0.05**	**1**	**Lower Limit**	**Upper Limit**
26.5	0	28	45	22	5	**100**	**100**	**100**
19	0	23	45	22	5	**95**	**79**	**100**
13.2	0	10	45	22	5	**82**	**59**	**79**
9.5	0	5	24	21	5	**55**	**52**	**72**
4.75	0	0	10	21	5	**36**	**35**	**55**
2.36	0	0	0	21	5	**26**	**28**	**44**
1.18	0	0	0	18	5	**23**	**20**	**34**
0.6	0	0	0	10	5	**15**	**15**	**27**
0.3	0	0	0	4	5	**9**	**10**	**20**
0.15	0	0	0	2	5	**7**	**5**	**13**
0.08	0	0	0	0	3	**3**	**2**	**8**

Table 2.0 Optimum Binder content (OBC) For VG-20 grade Bitumen

S. N.	Properties	Obtained binder content (from graph)	Average OBC (%)
1	Max stability, Kg	6.0	5.6
2	Max. density, g/cc	5.5	
3	Air voids (%)	5.5	

Table 3.0 Optimum Binder content (OBC) For VG-30 grade Bitumen

S. N.	Properties	Obtained binder content (from graph)	Average OBC (%)
1	Max stability, Kg	5.8	5.7
2	Max. density, g/cc	5.7	
3	Air voids (%)	5.7	

4.0 TECHNICAL SPECIFICATION OF RUTTING TEST USING ROLLING COMPACTOR CUM RUT ANALYSER

Specimens were casted using VG-20 and VG-30 at their OBC's and was subjected to rutting test using an indigenously designed by Dr. B.V Kiran Kumar called Rolling Compactor cum Rut Analyzer (RCRA). The unique features of this compactor is it can apply a constant pressure of 600 kPa and if required the pressure can be applied up to 3000 kPa. Similarly the rolling speed in the compactor can be varied. It has a temperature control unit which maintains the pre-selected compaction and test temperature. With this the equipment is also capable of noting the densification data of the mix while compaction of mix. Using these measurements the specimen's compaction characteristics can be developed. The compactor is also capable of producing the vibrations in range of 0.5 to 1.5 Hz during compaction. The compactor is an hydraulically operated with twin non return valve system and has a Programmable Logical Circuit (PLC) which is in-turn connected to vertical and horizontal transducers and capable of recording minute change in mm. The Figure 2.0 shows the picture of Rolling Compactor cum Rut Analyzer. The rutting test was conducted on the casted specimens at its OBC for HMA mix and WMA mix by adding sasobit additive 4 % and was conditioned at 30⁰C, 50⁰C and 70°C, tyre pressures of 7.1Kg/cm^2 was maintained throughout the test.

Figure 2: Rolling Compactor cum Rut Analyser

4.1 Procedure for Preparation of the Specimen

- Weigh the required, sizes and quantities of aggregates, according to Rothfutch's.
- Method (Graphical procedure) [for this thesis work we have taken.
- 20mm down size (15% of total Quantity).
- 13.2mm down size (30% of total Quantity.
- 4.5mm down size and Filling Material (55% of total Quantity.
- Bitumen content (OBC) 5.6% for VG-20, 5.7% for VG-30 for HMA mix and WMA mix by adding 4 % Sasobit additive.
- Pour all the weighed and mixed aggregate in the pan and heat the aggregate up to 175⁰C.
- Add bitumen and mix it (the temperature should be between 121⁰C to 145⁰C, depending on type of binders).

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- The mix is poured in a pre-heated mould (pouring temperature should be between100⁰C to 145⁰C, depending on type of binders).
- Then the mix is compressed using Rolling Compactor cum Rut Analyser equipment up to a required thickness.

4.2 Procedure for Conducting Rutting Test

- The pre-cast slab specimen for which the rutting test is to be conducted is placed in the mould and then the mould along with the slab specimen is placed on the rut analyzer machine which is connected to the thermostat and heater.
- Using quick panel in rut analyzer the requisite test temperature is keyed in. Later the required rut depth measurement is entered in the system.
- Later using the auto cycle option in the quick panel the equipment hydraulic connections and other functions are turned on.
- The program in the programmable logical circuit is done in such way that only when the pre-selected temperature is obtained uniformly throughout the mould then rutting test is initialized and the pre-selected temperature is maintained throughout test period.
- The data of deformation per millimeter and number of passes taken to cause the deformation is recorded in a memory card. Later the data can is downloaded into a system and a graph indicating number of passes versus deformation is plotted.

5.0 ANALYSIS AND DISCUSSIONS

5.1 General

The test results for BC mix for HMA and WMA mix with different type of binder viz., VG-20 and VG-30 for BC Grade 2 mix are analysed for the rut depth of 20mm at a tyre pressure of 7.1kg/cm^2 and temperatures varying from 30°C, to 70°C with an increment of 20°C. The results here in are represented graphically.

Table 4.0 Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 30°C temperature for Bitumen for VG-20 grade For HMA and WMA

Rut Depth in mm	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm²	7.1 kg/cm²
0	0	0
-2	9.250	9.568
-4	19.45	19.856
-6	35.262	36.155
-8	50.635	51.025
-10	65.256	65.896
-12	85.652	86.225
-14	95.786	96.35
-16	98.265	98.885
-18	100.581	100.992
-20	102.756	103.254

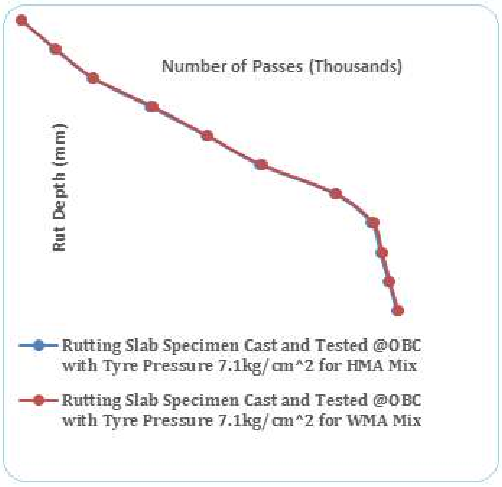

Figure 3: Relation between number of passes and Tyre pressure at 7.1 kg/cm2 for 20mm rut depth at 30°C temperature for Bitumen for VG-20 grade For HMA and WMA.

Table 5.0 Relation between number of passes and Tyre pressure at 7.1 kg/cm2 for 20mm rut depth at 500C temperature for Bitumen for VG-20 grade For HMA and WMA

Rut Depth in mm	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm²	7.1 kg/cm²
0	0	0
-2	7.4	7.6544
-4	15.56	15.8848
-6	28.2096	28.924
-8	40.508	40.82
-10	52.2048	52.7168
-12	68.5216	68.98
-14	76.6288	77.08
-16	78.612	79.108
-18	80.4648	80.7936
-20	82.2048	82.6032

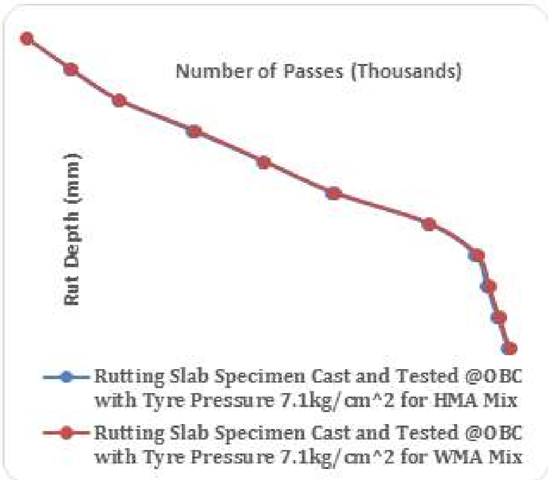

Figure 4: Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 50⁰C temperature for Bitumen for VG-20 grade For HMA and WMA

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Table 6.0 Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 70⁰C temperature for Bitumen for VG-20 grade For HMA and WMA

Rut Depth in mm	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm²	7.1 kg/cm²
0	0	0
-2	2.775	2.8704
-4	5.835	5.9568
-6	10.5786	10.8465
-8	15.1905	15.3075
-10	19.5768	19.7688
-12	25.6956	25.8675
-14	28.7358	28.905
-16	29.4795	29.6655
-18	30.1743	30.2976
-20	30.8268	30.9762

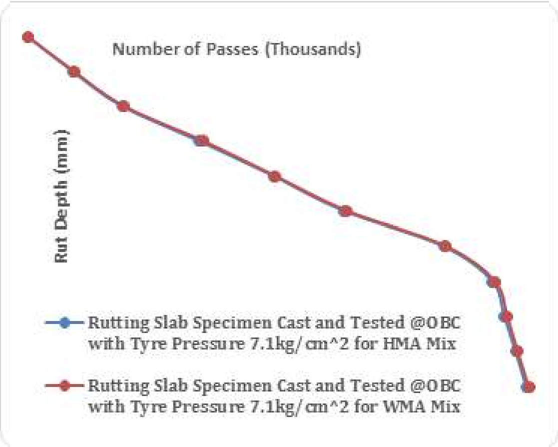

Figure 5: Relation between number of passes and Tyre pressure at 7.1 kg/cm² for20mm rut depth at 70⁰C temperature for Bitumen for VG-20 grade For HMA and WMA

Table 7.0 Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 30⁰C temperature for Bitumen for VG-30 grade For HMA and WMA

Rut Depth in mm	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm²	7.1 kg/cm²
0	0	0
-2	10.125	10.568
-4	20.256	20.986
-6	35.896	36.258
-8	51.258	51.896
-10	65.895	66.542
-12	86.369	86.98
-14	96.358	96.895
-16	98.986	99.568
-18	100.887	101.268
-20	103.165	103.986

Figure 6: Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 30⁰C temperature for Bitumen for VG-30 grade For HMA and WMA

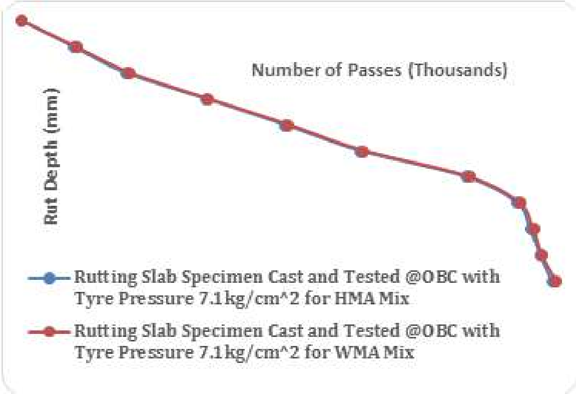

Table 8.0 Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 50⁰C temperature for Bitumen for VG-30 grade For HMA and WMA

Rut Depth in mm	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm²	7.1 kg/cm²
0	0	0
-2	8.1	8.4544
-4	16.2048	16.7888
-6	28.7168	29.0064
-8	41.0064	41.5168
-10	52.716	53.2336
-12	69.0952	69.584
-14	77.0864	77.516
-16	79.1888	79.6544
-18	80.7096	81.0144
-20	82.532	83.1888

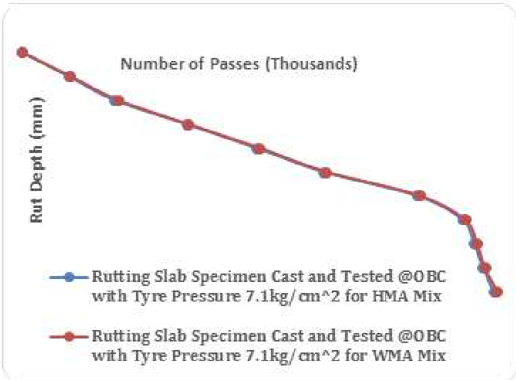

Figure 7: Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 50⁰C temperature for Bitumen for VG-30 grade For HMA and WMA

Table 9 Relation between number of passes and Tyre pressure at 7.1 kg/cm² for 20mm rut depth at 70⁰C temperature for Bitumen for VG-30 grade For HMA and WMA

Rut Depth in mm	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm^2	7.1 kg/cm^2
0	0	0
-2	3.0375	3.1704
-4	6.0768	6.2958
-6	10.7688	10.8774
-8	15.3774	15.5688
-10	19.7685	19.9626
-12	25.9107	26.094
-14	28.9074	29.0685
-16	29.6958	29.8704
-18	30.2661	30.3804
-20	30.9495	31.1958

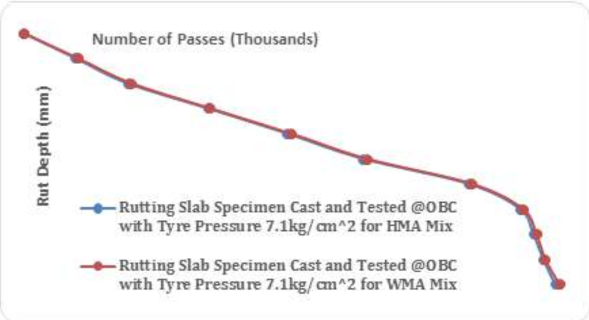

Figure 8: Relation between number of passes and Tyre pressure at 7.1 kg/cm^2 for 20mm rut depth at 70^{0}C temperature for Bitumen for VG-30 grade For HMA and WMA

Table 10 Relations between Number of Passes at Varying Temperature and Tyre Pressure for Bitumen of V-20

Temperature (°C)	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm^2	7.1 kg/cm^2
30	102756	103254
50	82205	82603
70	30827	30976

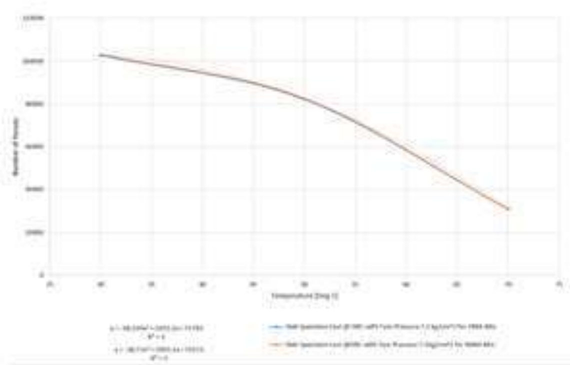

Figure 9: Relation between Number of Passes at Varying Temperature and Tyre Pressure for Plain Bitumen VG-20.

Table 11 Relations between Number of Passes at Varying Temperature and Tyre Pressure for Bitumen of V-30

Temperature (°C)	Number of Pass in Thousand	
	Tyre Pressure	
	HMA	WMA
	7.1 kg/cm^2	7.1 kg/cm^2
30	103165	103986
50	82532	83188
70	30949	31196

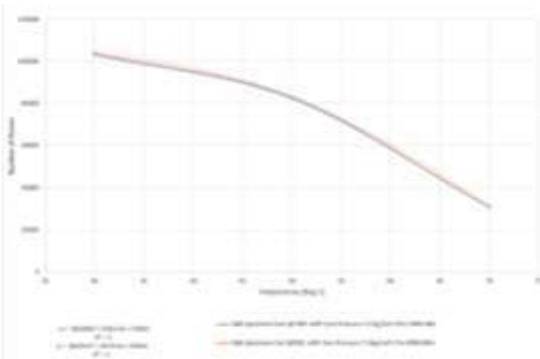

Figure 10: Relation between Number of Passes at Varying Temperature and Tyre Pressure for Plain Bitumen VG-30.

5.2 Criteria for Number of Pass to failure with respect to various Temperature and Tyre Pressures

- For BC mix with HMA mix for VG-20 grade bitumen at tyre pressure 7.1kg/cm^2, number passes for 20mm rut depth was 102756 at 30°C and the number passes were reduced to 82205 at 50°C and further the number passeswere reduced to 30827 at 70°C.
- For BC mix with HMA mix for VG-30 grade bitumen at tyre pressure 7.1kg/cm^2, number passes for 20mm rut depth was 103165 at 30°C and the number passes were reduced to 82532 at 50°C and further the number passeswere reduced to 30949 at 70°C.
- For BC mix with WMA mix for VG-20 grade bitumen at tyre pressure 7.1kg/cm^2, number passes for 20mm rut depth was 103254 at 30°C and the number passes were reduced to 82603 at 50°C and further the number passeswere reduced to 30976 at 70°C.
- For BC mix with WMA mix for VG-30 grade bitumen at tyre pressure 7.1kg/cm^2, number passes for 20mm rut depth was 103986 at 30°C and the number passes were reduced to 83189 at 50°C and further the number passeswere reduced to 31196 at 70°C.

6.0 CONCLUSIONS

The laboratory investigations carried out on BC Grade-II mix for rutting characteristics using Rolling Compacting cum Rut Analyser (RCRA) Equipment are summarised as follows

1. The relation between number of passes and rut depth at 30^0 C and tyre pressure of 7.1 kg/cm^2 was obtained for both plain bitumen with HMA and WMA , the rut depth observed after 102756 passes was 20mm for VG-20 bitumen for HMA mix and The rut depth was observed to after 103254 passes was 20 mm for VG-20 for WMA mix , As the temperature increases to 50^0 C ,the rut depth observed after 82205 passes was 20mm for VG-20 for HMA mix and the rut depth observed after 82603 passes was 20mm for VG-20 for WMA mix. Further as increase in temperature to 70^0 C the rut depth observed after 30827 passes was 20mm for VG-20 for HMA mix and the rut depth observed after 30976 passes was 20mm for VG-20 for WMA mix. This shows the WMA mix improves the resistance property of the mix due to better shear strength of mix.
2. The relation between number of passes and rut depth at 30^0 C and tyre pressure of 7.1 kg/cm^2 was obtained for both plain bitumen with HMA and WMA , the rut depth observed after 103165 passes was 20mm for VG-20 bitumen for HMA mix and The rut depth was observed to after 103986 passes was 20 mm for VG-20 for WMA mix , As the temperature increases to 50^0 C ,the rut depth observed after 82532 passes was 20mm for VG-20 for HMA mix and the rut depth observed after 83189 passes was 20mm for VG-20 for WMA mix. Further as increase in temperature to 70^0 C the rut depth observed after 30949 passes was 20mm for VG-20 for HMA mix and the rut depth observed after 31196 passes was 20mm for VG-20 for WMA mix. This shows the WMA mix improves the resistance property of the mix due to better shear strength of mix.
3. The number of passes required for all the binders at 30°C and at 7.1 kg/cm^2 tyre pressure is worked out as 100 percent and when the temperature is increased to 50°C the performance of the binder in relation with the number of cycle reduces to 80 percent and this reduces to 30 percent at 70°C. This shows that temperature plays a vital role in causing rutting.
4. The study on rutting characteristics for WMA mix binder at 70°C temperature and at tyre pressures of 7.1kg/cm^2 has showed better performance than HMA mix
5. At 70°C for tyre pressures of 7.1kg/cm^{2}the number of wheel passes decreases dramatically for all binders.
6. From the laboratory studies it is evident that there is a significant improvement in the performance related property of the binder course (BC) by using WMA mix.

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