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A LABORATORY STUDY ON REINFORCED HMA MIX AND EVALUATION OF RUT DEPTH USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Asphalt pavement undergoes distresses as rutting and fatigue. Rutting is observed as one of the most prominent distresses in flexible pavement which occurs as depression along the wheel path. In this article rutting characteristics of bituminous mixture was studied with placement of steel grid at different height and inclusion of fibre with varying proportions. The laboratory results exhibits that fibre has more resistance towards rutting when compared to steel grid placed at h/3 height in Hot Mix Asphalt (HMA) mixture. Finite Element Method (FEM) was carried on HMA layer with the placement of steel grid and fibre at different proportions. The model considered as asphalt layer to follow viscose-elastic behaviour by depending on dynamic modulus. The laboratory test results of above mix combination were verified in simulation test and the test data was observed to be adjoining with the simulated values. This reveals that non-linear model is applicable for simulating bituminous performance mixture when reinforced with fibre and steel grid.

Keywords: *Rutting, Viscose-elastic, Non-linear, ANSYS and Simulation.*

I. INTRODUCTION

Asphalt is used as binder in construction of HMA layers. Asphalt concrete is a composite material combination of aggregates with different sizes together with asphalt binder. Pavement failures happen when a black-top surface never again holds its unique shape and creates material pressure which causes issues. Failure includes cracking, depression, rutting, and raveling. Among all those failures, rutting and cracking are very common. Rutting is because of continues loading under the wheel path and occurs inside the initial couple of years after opening. Rutting occurs because of the plastic development of asphalt mixture in high temperature or deficient compaction during development. In order to improve the HMA performance against the failure numerous industrial accessible support items are used as steel mesh, glass fibre grid, carbon fibre web etc as reinforcement. In HMA layers when reinforced with Steel grid it showed better performance than the Geosynthetics [2]. The rutting resistance decreases with increasing in temperature prediction of rut resistance with different temperatures [12]. A two-dimensional model was developed and investigated to predict the black-top material characteristics and tire black-top contact restricted segment was used to develop simulation model influence on black-top failure [11]. The stress level and vertical deformation of base course was investigated in FEM model with the reinforcement of Geogrid in HMA layers. The reinforcement has improved performance of HMA layers [3]. Air voids content plays a vital role in the behavior of rutting under wheel load. The rut depth has reduced at optimum air void content [16]. Basalt fibre to bituminous mix gives the higher stability strength. The addition of fibre as reinforcement in HMA layer increased in G* value [15].

In the present study an attempt carried with reinforcement of HMA layer and predicting the rutting characteristics when simulated in FEM for field observations.

The main objectives of this study are

1. To investigate the effectiveness of reinforcement at optimum height in HMA layer.
2. To estimate the influence of fibre in bituminous mixes and evaluate performance characteristics of HMA layer and is verified through FEM.

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II. METHOD & MATERIAL

2.1 Mix information

In the current research, steel grids are placed at different heights (1/3H, 2/3H, 1/2H) of marshal mould to obtain optimum height and different percentages of fibre added to bitumen.

2.2 Methodology

The current study has been carried out in 6 phases as listed below

Stage-1: Collection of Literature and Materials.

Stage-2: Conventional mix evaluation and Modification of mixes by using steel grid and fibre with different properties.

Stage-3: To evaluate the rutting program of modified bituminous mixes through finite element techniques.

Stage-4: Performance characteristics of modified and conventional mixes for modulus rutting characteristics.

Stage-5: The finite element technique with non-linear properties of conventional and modified mixes is used for predicting the rutting potential and comparing laboratory results.

Experimental program

In present research, steel grid is placed at varying height in marshal mould. The optimum percentage of basalt fibre is carried for Marshall Test.

a. Materials

The crushed stone aggregates and stone dust is collected from local quarry. VG 30 grade bitumen attain from Indian Oil Corporation Limited (IOCL). Tests were conducted in the laboratory to confirm the grade of bitumen.

b. Steel grid

Configuration of current reinforcement consists of square shape, galvanized steel wire setting. These meshes are available in local market and proposed to be used in this study as a reinforcement interlayer. The properties of steel grid were arrived from laboratory test and are tabulated in table 1.

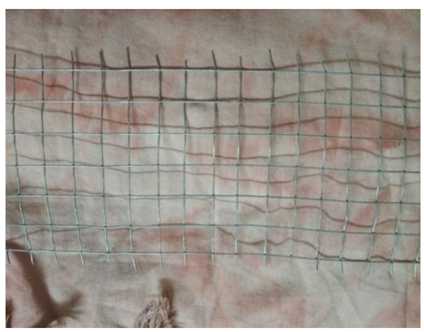

Fig. 1 Configuration of steel grid used in this research.

TABLE 1 Steel grid properties

Sample	Dia. (mm)	Area (mm2)	Tensile load(N)	Tensile strength(N/mm2)	Elongation %
Steel grid	1.060	0.882	0.538	613.636	7.2

c. Basalt fibre

Basalt fibre was provided by local suppliers and the properties are shown in Table 2.

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Table 2 Properties of Basalt Fibre

Property	Value
Tensile strength	2.32 GPa
Elastic modulus	86.3 GPa
Elongation at break	2.84%
Density	2.67g/cm3

a) Source -Yongchun Cheng, et al, "Laboratory Study on Properties of Diatomite and Basalt Fibre Compound Modified Asphalt Mastic",2017 [18].

2.4 Gradation of mix
Bitumen Concrete grade I was selected in the present study (MORTH specifications). Gradation of aggregates is an important factor which affecting permanent deformation of hot mix asphalt. Aggregate grading and binder content when tested in accordance with MORTH. The combined grading of the coarse and fine aggregate and added filler shall fall within the limits as shown in table .The combined gradation range for the different size of aggregates as

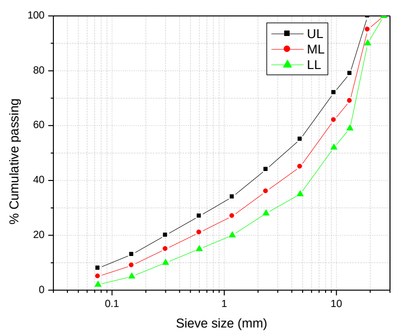

Fig. 2 Gradation of aggregates

2.5 Marshall specimen preparation
Marshall Specimens were prepared according to [6] OBC (optimum bitumen content), optimum height of grid and optimum percentage of fibre to be included as additive. 1200 grams of blend is required to set up the sample. Aggregates were preheated before blending. The mix is set up fit as a shape of 100mm in estimation and compacted with 4.54kg rammer, tumbling from a height of 45.7 cm with 75 blows on each face of the sample. The compacted specimen will have a thickness of 63.5 mm. Dependability adjustments were connected for variety in thickness. The sample is allowed to cool for several hours and after that removed using a sample extractor**.**

The specimen is set in the testing get together and the load is connected on to it at the rate of 50.8mm/minute. The sample is tested at a temperature of 60 °C. A load cell is utilized to apply the load on the sample and a LVDT (Linear Variable Displacement Transducer) was utilized for recording the flow values. The peak load was recorded by the DAS (Data Acquisition System) alongside the flow values. Three samples were set up for every level of bitumen. The peak load opposed by the specimen is named as Marshall Stability value as sketched out in [7]. The flow is noted down as far as mm or units (1 unit=0.25 mm) MORTH.

2.6 Specimen for Rutting Test
The specimen is made in a slab compactor otherwise called roller compacting device appeared in Fig.3. The sampler has a volume of around 6000 cc. Total weight of the specimen was around 13.5kgs, in that weight of filler 732.9gms and 717gms of bitumen is used. One slab is prepared with Steel grid included at optimum height and another slab is prepared with 0.6% of basalt fibre. The specimens were set up with densities connected from Marshall Stability test. The specimen was compacted utilizing hydraulic pressure in oscillatory movement. It is compacted until the point that the moment that needed densities of mix are expert as cleared up in [8].

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Fig. 3 Automatic compactor

2.7 Immersion type of wheel tracking device

Accelerated test performed in the lab for estimation of rutting obstruction was utilized and is displayed through Fig.4.The wheel used in the examination is steel wheel of 47 mm wide and the total weight of the wheel utilized including surcharge charge is 710N. LVDT is utilized to quantify the trench profundity. Specimens were tested in completely merged condition in water at a temperature of 50 °C. Immersion test is passed on for understanding the stripping impediment of mixes. The moment of the wheel way is 230 mm and the speed of the wheel for one pass is about 1.46 kmph (72 wheel passes for every min). B.C grade I according to MORTH is embraced for the present examination in readiness of specimen. 24102 passes will mimic movement of 30 msa in the field [16].

Fig. 4 Wheel tracking device

2.8 Finite element analysis

Finite element analysis, used to simulate rut depth of field and lab. The model created and aligned in this exploration was actualized in ANSYS (version 19.1). The material properties load and limit conditions, element type and geometry of the model was provided to give sensible outcome. A rectangular model of 400mm*300mm*50mm bituminous model was produced to relate the wheel tracking test of laboratory. A single axle with single tire was utilized to give loading condition. The load magnitude was 710N with 745 kPa tire pressure. The base and the four surrounding vertical limits were set to be kept with confined with restricting displacement in all directions. A three-dimensional, demonstrate was created in finite element analysis. The extent of limited component work was fluctuated by the loading impact. The best work was utilized to enhance the accuracy of estimation as shown in fig 5.

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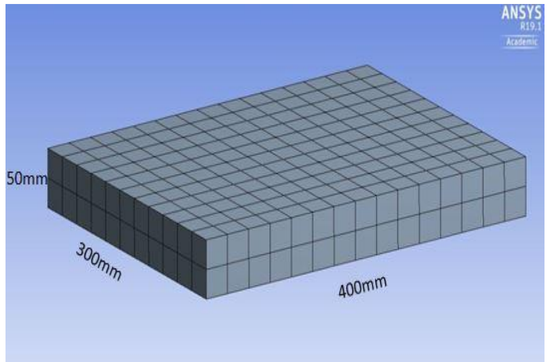

Fig. 5 Bituminous concrete slab used in Analysis

III. RESULTS

3.1 Physical Properties of Aggregates

Tests were carried out on aggregates and bitumen for the preparation of the mixes. Aggregates were tested for strength, toughness, hardness, shape and the results were shown in Table 3.

Table 3 Physical properties of aggregates

Test conducted	Results (%)	MORTH Specification (%)	Test code
Aggregate crushing value	23	Max 30	IS:2386(IV)
Aggregate Impact Value	20	Max 30	IS:2386(IV)
Combined Elongation & Flakiness Indices	3.61&7.57	<15	IS:2386(I)
Water absorption	0.4	0.1-2	IS:2386(III)
Specific Gravity	2.6	2-3	IS:2386(III)
Los Angeles abrasion value	23	Max 30	IS:2386(IV)

From the test results it is observed all the values are obtaining as per MoRTH specifications for BC grade-1

3.2 Bitumen Physical Properties

Bitumen properties were arrived in the laboratory and are tabulated in table 4

Table 4 Physical properties of bitumen

Consistency Characteristics	VG-30	Specifications of VG-30	Test standards
Penetration at 25^0C	55	50-70	IS:1203
Softening point(^{0}C)	47.5	Min 47	IS:1205
Ductility(cm)	50.33	Min 50	IS:1208
Absolute Viscosity (Poise)	2567	Min 2400	IS:1206(II)
Kinematic Viscosity (cSt)	358.67	Min 350	IS:1206(II)

From the test results it confined that bitumen grade is of VG-30 as per IS-73:2013

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3.3 Marshall stability test results

In order to achieve the stated objectives in the present study Marshall Parameters with placement of grid and fibre, was studied and tabulated in table 6.

Table 5 provides codes used in the study.

Table 5 Sample codes for different mixes

Mix No	Description	Code
1	Conventional mix	CG
2	Conventional mix with grid	SG
3	Conventional mix with fibre	BF

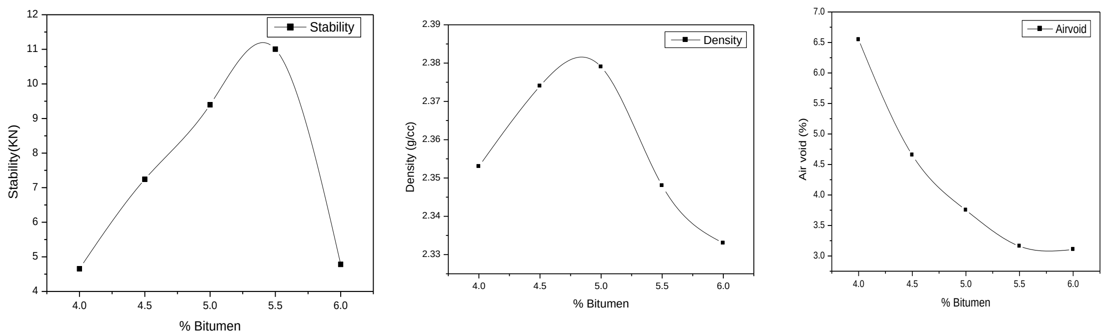

Fig. 6 Conventional Stability, Density and Air voids graphs.

Table 6 Marshall Stability test results for steel grid

Depth of SG	Stability (KN)	Flow (mm)	Air voids (%)	Density (g/cc)	VMA (%)
H/3	30.958	7.917	3.654	2.325	14.536
H/2	17.042	13.824	3.012	2.103	15.032
2H/3	16.032	13.787	3.962	2.205	14.259

From the Marshall test results it is observed that stability value is maximum at H/3 height when placed in HMA layer. But VMA has not improved consider there is improvement in density parameter when compared with conventional mix.

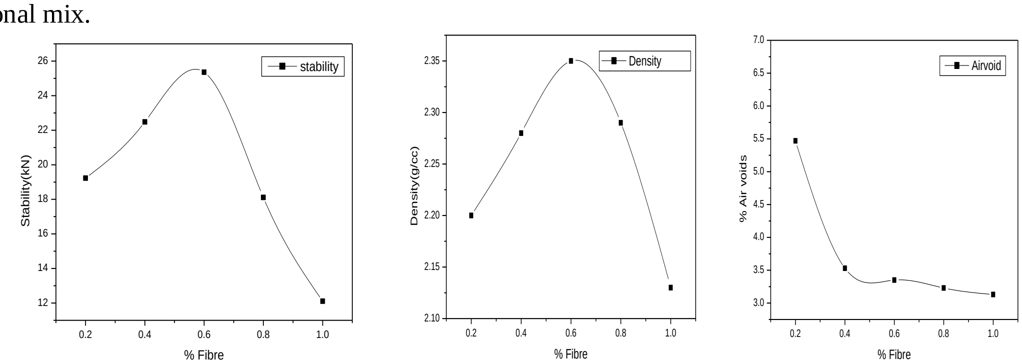

Fig. 7 Modified Stability, Density and Air void graph

From these graphs it is observed that stability has increased. At 0.6% of fibre highest stability was obtained which is 25.361 KN.

Table 7 Results of Marshall's test

Mix Type	Max Stability (KN)	4% Volume of Voids (%)	Max Bulk Density (g/cc)
CG	11.005	7.40	2.143
BF	25.361	6.45	2.3
SG	24.958	4.40	2.243

Once the optimum results were found for above mixes, investigations were extended further.

3.4 Indirect tensile strength characteristics

The Indirect tensile strength test (IDT), circumstantial in [4], is utilized to decide the tensile properties of the bituminous mixes which can additionally be identified with the cracking properties of the asphalt. The formula for assessing the indirect tensile strength is presented below.

$S_t = 2P/\pi D t$

Where

S_t = IDT strength, MPa

P = maximum load at failure, N

t = specimen height just before the test, mm

D = specimen diameter, mm

The indirect tensile strength for conventional, reinforced and fibre with the same percentage of fibre is presented below.

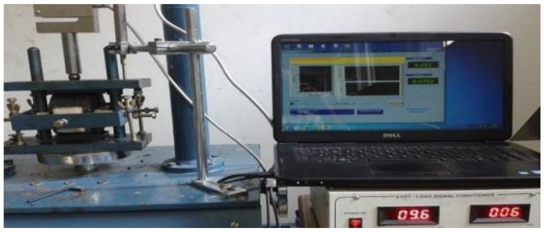

Fig.8 Installation of IDT-setup

3.5 Tensile strength ratio

Tensile strength ratio (TSR) is a measure of water sensitivity. It is the ratio of the tensile strength of water conditioned specimen to the tensile strength of unconditioned specimen which is expressed as a percentage. The laboratory results of mix combinations are tabulated in Table 8.

TSR= S_1/ S_2

S_1 - Tensile Strength of Conditioned sample (MPa); S_2-Tensile Strength of Unconditioned sample (MPa). The TSR values for all the four mixes are summarised and presented in Table 8.

Table 8 Tensile Strength Ratio for Different Mix Combination

Mixture combination	Conditioned (S_1) MPa	Un-conditioned (S_2) MPa	TSR(S_1/S_2)
CG	0.796	0.95	0.84
SG	0.631	0.72	0.876
BF	0.982	1.100	0.892

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The tensile strength ratio results explain the BF mix has better moisture sustainability compared to other mix combination.

3.6 Resilient Modulus

Repeated load test was carried as [8] for determining resilient modulus for different mix types in the study. Test results were presented in Table 9.

Table 9 Repeated Load Test Results

Mix	Binder Content (%)	Load (KN)	Horizontal Deformation (μm)	Tensile stress (MPa)	Resilient modulus (MPa)	Initial tensile strain (μm)
CG	5	950	0.006282	0.95	2416	0.000806
SG	5	722	0.002262	0.72	2680	0.000550
BF	5	1100	0.001965	1.100	2782	0.000810

BF mix has higher stiffness compared to other mix combination because of random distribution of fibre.

3.7 Immersion Wheel Tests

The rutting test is led as per [9]and utilized for assessment of rutting qualities of the mix. Rectangular slab as appeared in Fig.4.a were threw of size 400mm X 300mm X 50mm and are tried for assessment of rutting qualities utilizing Immersion compose wheel rutting mechanical assembly. The slab were set up with built up OBC, with ideal height of grid and optimum percentage of fibre for all samples composes as exhibited in Table 5. A LVDT is additionally given to the side of wheel for observing trench profundity to relating number of wheel passes. Conventional mix was tried at first and it is trailed by all different mixes. Blend with fibre demonstrated preferred resistance towards rutting over the steel grid at ideal height and conventional mix.

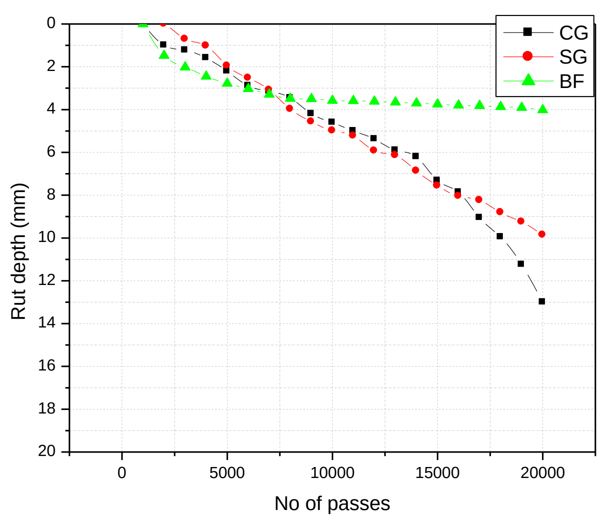

Fig.9 rutting performance of different mix combination

From fig 9 it is observed that better resistance towards rutting and stripping characteristics when compared to other mix combination .for 20,000 number of wheel passes BF has rut depth of 4.56mm when compared with SG mix rut depth of 9.86mm and CG mix rut depth of 13.66mm.

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3.8 Finite element simulation

Table 10 Input Parameters and Rut depth for different models

Model	**Density (g/cc)**	**Poisson's ratio**	**Rut depth (mm)**	**Vertical deformation(µm)**
CG	1655	0.35	6.512	0.000862
SG	1655	0.35	3.006	0.000542
BF	1655	0.35	1.022	0.000982

The outcome examination of equivalent stresses and principle stresses for the instance of conventional, fibre and reinforced models with the thickness of 50mm appeared in beneath figures 10-15.

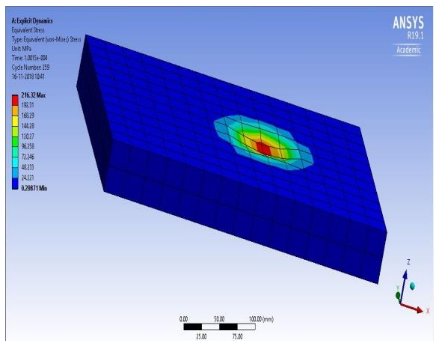

Fig.10 CG Equivalent stress in N/mm²

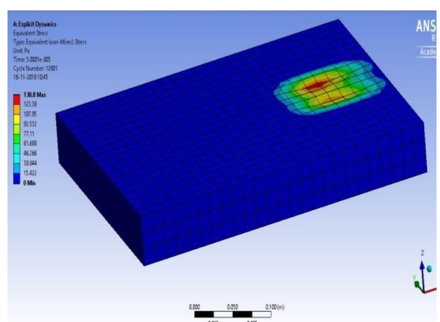

Fig.11 SG Equivalent stress in N/mm²

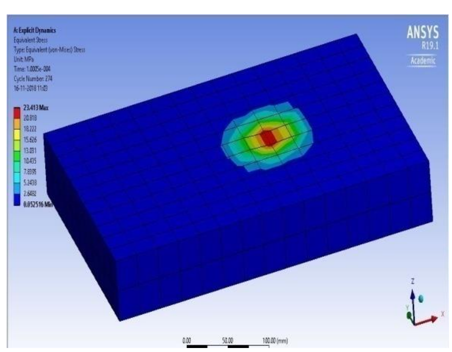

Fig.12 BF Equivalent stress in N/mm²

The above figures show equivalent stress of different models. Stress is observed at different places for different models. The Stress decreased when it is compared with the conventional model.

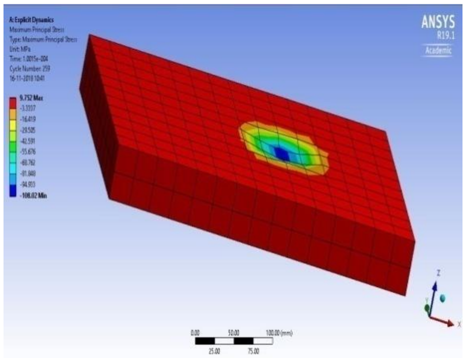

Fig.13 CG Principle stress in N/mm²

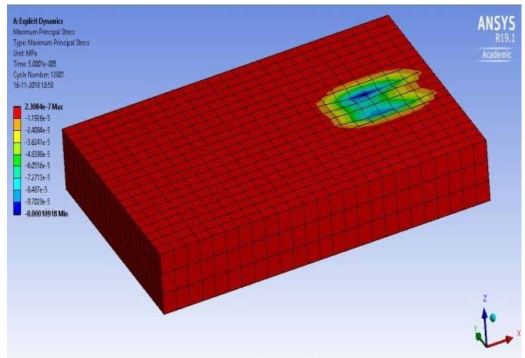

Fig.14 SG Principle stress in N/mm²

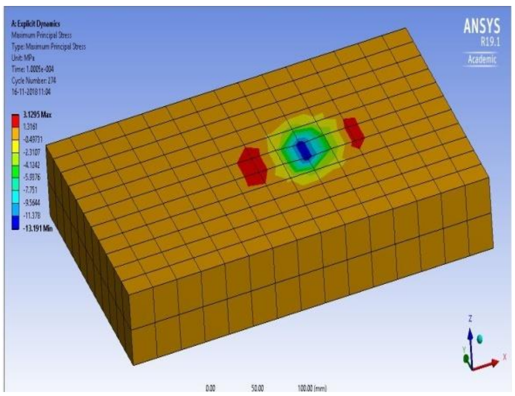

Fig.15 BF Principle stress in N/mm²

For SG mix the rut depth is observed more than BF because of VMA component. The rut depth is less for BF mix compared with other mix combination because of less air void content and VMA.

IV. CONCLUSION

Concerning the above experimental observations from Marshall Test, Indirect Tensile Test, Resilient Modulus Test and Immersion wheel Rutting Test

1. The Marshall Stability results of SG and BF shows effective increase in density and stability decrease in void ratio compared with conventional mix.
2. The stability value of SG is 30.985 KN and for BF is 25.361 KN which is more than CG mix.
3. The bulk density is found maximum at 1/3rd height and 2.3gm/cc at 0.6% of fibre at 5% OBC.
4. The laboratory test results were verified in the simulation test and the results were observed in the same pattern.
5. The simulation result also shows that fibre has less rut depth compared to the reinforced and plane model.
6. The indirect tensile strength value of unsoaked specimens has an increment for Modified mixes.
7. Mixes has good resistance to moisture damage as the tensile strength ratio is meeting the requirement.
8. Resilient modulus for each mix combination was found using repeated load test. Test result shows that BF mix has higher stiffness compared to other mix combinations.

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REFERENCES

1. *Abed, A., H. And Al-Azzawi, A., A., "Evaluation of Rutting Depth in Flexible Pavements by Using Finite Element Analysis and Local Emperical Model", American Journal of Engineering and Applied Sciences, pp. 163-169,2012.*
2. *Ahmed Mohamady, Abu-Bakr M. Elhady and Mohamed S. Eisa., "Improving of asphalt pavement performance using steel wire grid reinforcement''', International Journal of Inventions,Volume 2, Issue 10.pp. 12-20,2013.*
3. *Adel A. Al-Azzawi., "Finite Element Analysis of Flexible Pavements Strenghted with Geogrid'', ARPN Journal of Engineering and Applied Sciences,2012.*
4. *AASHTO T 283, Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage.*
5. *AASTHO T-19, Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate.*
6. *ASTM D 6926-04, Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus.*
7. *ASTM D 5581-07, Standard test method for conduct of resistance of plastic flow of bitumen mixes.*
8. *ASTM D4123-82, Standard Test Method For Indirect Tension Test for Resilient Modulus of Bituminous Mixtures, 1995.*
9. *AASHTO T 324 – Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA).*
10. *BS EN 12697 33, Standard Test methods for hot mix asphalt Bituminous mixtures- Specimen prepared by roller compactor,.*
11. *Loay Akram Al-Khateeb, Andrews Saoud & Mohammad Fawaz Al-Msouti."Rutting Prediction of Flexible Pavements Using Finite Element Modeling'', 2011.*
12. *Mohammed Salih Abd-Ali., "A Finite Element Model for Rutting of Flexible Pavement Considering Temperature Effect'', 2013.*
13. *Mulungye, R.M, P.M.O Owende, K.mellon.,"Analysis of Response of Flexible Pavements Using Finite Element Method", 2005.*
14. *Nahi, Ismail and Ariffin., "Analysis of Asphalt Pavement Under Non Uniform Tire-Pavement Contact Stress Using Finite Element Method'', Journal of applied sciences, 11(14), 2562-2569,.*
15. *P. Sateesh & T.Anith Kumar.,"Performance Of Basalt Fibre Modified Bitumen In Dense Bitumen Macadam", International Journal of Research, 2017.*
16. *Zhi suo and Wong, W., G., "Nonlinear Properties analysis on Rutting Behaviour of Bituminous materials with different Air Void contents", Construction and Building Materials 23, pp. 3492-3498, 2009.*
17. *IRC SP 53, guidelines on use of modified bitumen in road construction.*
18. *Yongchun Cheng, Chunfeng Zhu, Guojin Tan, Zehua Lv, Jinsheng Yang1 and Jiansheng Ma., "Laboratory Study on Properties of Diatomite and Basalt Fiber Compound Modified Asphalt Mastic''., Advances in Materials Science and Engineering, Article ID 4175167.,2017.*