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PERFORMANCE STUDY OF SEMI DENSE BITUMINOUS CONCRETE BY ADDING POLYMER FIBERS

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Abstract
Bitumen is a very complex material and durability of bitumen pavement depends upon selection of appropriate grade of bitumen to suit the climate conditions and traffic loading. Increase in traffic density, coupled with higher wheel loads and temperature variations lead to premature failure of bituminous course. The crack, once initiated, propagates up-wards causing gradual weakening of the pavement. Fiber Modified Binder has been found to improve the engineering properties of paving mixes.In the present study, tests are conducting on fibre modified and unmodified Semi Dense Bituminous Concrete (SDBC) and various inferences obtained from the experimental investigations are discussed. Bitumen of 60/70 penetration grade as binder and polymer fibres like polyester fibers and polypropylene fibres are used for the modification process. To study the efficiency of the fibre modified bituminous mixes, Marshall Stability test was conducted. Various tests were also performed on aggregate and bitumen to determine the engineering properties.The maximum Marshall Stability values obtained in case of Polyester Fibre Modified Bituminous Mix is 15.41 KN and polypropylene fibres is 14.18 at optimum fibre content and ordinary bituminous mix is 13.74 KN at optimum Bitumen content. From the Marshall Stability tests conducted, an optimum fibre content of 0.3% by weight of total mix was obtained. About 12% increase in stability values can be achieved by reinforcing the bituminous mix with polyester fibres and 3% increase can be achieved by polypropylene fibres compared with ordinary bituminous mix. Higher stability values indicate that the modified mixes would be less susceptible to cracking of flexible pavements. Permeability is directly proportional to the percentage of air voids so that if the air voids are more, then the permeability will be more.

INTRODUCTION

Polymer modified bituminous mix will have the acceptable permeability with respect to ordinary bituminous mix. The concept of using fibers to improve the behavior of materials is not new. The modern developments of fiber reinforcement started in the early 1960s. A multitude of fibers and fiber materials were introduced and are continuously being introduced in the market as new applications such as polyester fiber, asbestos fiber, glass fiber, polypropylene fiber, Carbon fiber, Cellulose fiber, etc. The principal functions of fiber as reinforcement material is to provide additional tensile strength in the resulting composite. This may increase the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix. Attempts of using non-synthetic fibers in pavement have been reported in the literature. Cotton fibers and asbestos fibers were used but these were degradable and were not suitable as long term reinforcement. Metal wires have also been proposed but they were susceptible to rusting with the penetration of water. Asbestos was also used until it was determined as a health hazard. This study investigates on the characteristics and properties of fiber modified bitumen, which may have the benefit of improving the performance of road pavement.

As to the modern highway transportation characterized with high speed, high traffic density, heavy load and channelized traffic, the technology of asphalt pavement has been changed greatly and many methods have been developed to improve the performance of asphalt pavement, such as the SuperpaveTM, the technology of modified asphalt, the SMA, etc. Among them, as a new additive, the fiber is a successful alternative in reinforcing asphalt pavement. Various types of fibers, i.e., mineral, cellulose and polyester fibers, are mixed with asphalt, and this mixture is called fiber modified asphalt binder. Studies show that different fibers offer different sets of toughening mechanisms to strengthen the asphalt composite and slow crack growth. Fibers also increase the available wetting surface area and behave as binder thickener which reduces asphalt bleeding and adds fiber toughening mechanisms. The mechanism of fibers affecting asphalt is complex, and its impact upon asphalt binder properties is profound. However, so far there is seldom research on the effect of fiber on asphalt binders, and fiber modified asphalt binder is also poorly characterized scientifically. The effect is an important issue that needs to be investigated. It helps the understanding of the properties of fiber modified asphalt binder.
Commonly, fibres reinforce the binder phase and optimal content depends on types of fibers used strongly. Furthermore, considering economic factors, it is also imperative to determine the optimal fiber content that improves bitumen properties to a satisfactory level at an effective cost.

The effects of polyester fiber on the rheological characteristics and fatigue properties of asphalt and its mixture are investigated in this paper. The viscosity, rheological and fatigue tests are conducted to characterize such related properties of asphalt binder and mixture with different fiber contents. Test results indicate that the viscosity of asphalt binder is increased with increasing polyester fiber contents, especially at lower temperature. With different polyester fiber contents, the complex modulus and loss modulus of asphalt binders are decreased. The dynamic modulus test results for asphalt mixture with 0.3% polyester fiber content also reveal that the dynamic modulus and phase angle are decreased at the same temperature, which leads to a decrease of fatigue parameter for asphalt mixture. The parameters of fatigue functions for asphalt mixture with or without fibers were obtained and compared, and it confirms that the fatigue property of asphalt mixture can be improved by fiber addition, especially at lower stress levels.

REVIEW OF LITERATURE

Tapkin (2007) conducted a study on “The effect of polypropylene on bituminous performance”. Marshall Stability and flow tests were used and indirect tensile tests were carried out in order to calculate the fatigue life of the bituminous specimens. The calcareous-based aggregate obtained from a quarry and 60/70 penetration bitumen was used in all the experiments. Preliminary experiments on Marshall Specimens (prepared with 50 blows on each side) established the mixture proportioning used in this study. In these experiments, the optimum bitumen content was determined as 5.5%. In this research, the bituminous concrete with 0.3%, 0.5% and 1% polypropylene fibres were investigated.

Mahrez, Karim and Katman (2005) conducted a study on “Fatigue and deformation properties of glass fiber reinforced bituminous mixes”. This study investigated the characteristics and properties of glass fiber reinforced stone mastic bituminous. To evaluate the effect of the fibre content on the bituminous mixes, laboratory investigations were conducted on the sample with and without fibres. The testing undertaken in this research comprise the Marshall test, indirect tensile test, creep test and resistance to fatigue cracking by using repeated load indirect tensile test. The glass fiber content in this research was varied between 0.1%, 0.2%, 0.3%, 0.4% and 0.5% by weight of mix. The optimum binder content for the original mix was 5.5% by weight of the mix, while the modified mixtures were prepared using the optimum binder content (5.6%, 5.7%, 5.8%, 5.9% and 6%) corresponding each fiber content (0.1%, 0.2%, 0.3%, 0.4% and 0.5%) respectively. The fiber length in the mixture was preserved as constant parameter with a value equal to 20 mm.

Wu, Ye and Li (2007) conducted a study on “Investigation of rheological and fatigue properties of bituminous mixtures containing polyester fibres” to investigate the effects of polyester fibre on the rheological characteristics and fatigue tests were conducted to characterize such related properties of bituminous binder and mixture with different fibre contents. The polyester fibre modified bituminous binder was obtained by a constant mixer at 165°C. Fibre contents of 0.1, 0.3 and 0.5% by weight of the bituminous. Standard super Pave mix procedures were employed to prepare the dynamic modulus test specimen. The results showed that the viscosity of bituminous mastic increase with the increase of polyester fibre contents. The contribution effects of polyester fibre to increase of viscosity are more significant at lower temperatures (60-135°C) than at higher temperature (135-180°C). Complex shear modulus of bituminous binder is decreased with the increase of fibre contents and frequencies, but the change of phase angles with or without fibres is limited. The loss modulus of bituminous binder is decreased with the increase of polyester fibre can be improved.

EVALUATION OF MATERIAL PROPERTIES

Most of the National Highways in India have flexible pavements with bituminous surfacing. The rapid growth of traffic loading intensity has put a heavy demand on the pavement to perform satisfactorily long periods. Bituminous surfaced pavements fail due to load associated distress and damage induced by air, temperature and moisture.
The individual material properties of each component may affect the overall performance of the pavement. If pavements are to perform long term and withstand specific traffic and loading, the materials making up the pavements are required to be of high quality.
This chapter explains in detail the material properties of aggregates, binder, filler and fibre that are necessary for high quality pavements.
The following materials were used for the preparation of bituminous mix:

- Crushed aggregate - Coarse,Fine,Filler
- 60/70 grade bitumen
- Fibers

Table 1 Physical properties of aggregates Used

S.No.	Property	Code	Value	MORTH limits
1	Specific gravity	IS 2386 part IV	2.69	2.5-3.0
2	Impact value	IS 2386 part IV	21.0%	<27
3	Crushing value	IS 2386 part IV	24.0%	<30
4	Los Angeles abrasion value	IS 2386 part IV	20%	<35
5	Flakiness and elongation index	IS 2386 part I	19.0%	<30

Table 2 Physical properties of 60/70 Grade bitumen

S.No.	Properties of binder	Value	Requirements as per IS: 73-1992
1	Penetration in mm @ 25^{0}C	65	60-70
2	Softening point, ^{0}C	49	45-55
3	Specific gravity	1.02	0.99 mini

PROPERTIES OF POLYPROPYLENE FIBRES

Table 3 Physical properties of the PP modified bitumen samples

Property	Test Value	Standard
Penetration at 25^{0}C, 1/10 mm	45.5	ASTM D 5-97
Penetration Index	-0.8	-
Ductility at 25^{0}C , cm	>100	ASTM D 113-99
Loss on heating, %	0.025	ASTM D 6-80
Specific gravity of 25^{0}C, kg/m^3	1015	ASTM D 70-76
Softening point, ^{0}C	52.1	ASTM D 36-95
Flash point, ^{0}C	292	ASTM D 92-02
Fire point, ^{0}C	345	ASTM D 92-02

Table 4 Gradation specified for SDBC mixes as per MORTH Specifications

Nominal aggregate size (mm)	13mm	
Layer thickness (mm)	35 – 40 mm	
S.No.	**IS Sieve (mm)**	**Cumulative % by weight of total aggregate passing**
1	19	100
2	13.2	90 – 100
3	9.5	70 – 90
4	4.75	35 – 51
5	2.36	24 – 39
6	1.18	15 – 30
7	0.6	-
8	0.3	9 – 19
9	0.15	-
10	0.075	3 – 8

Table 5 Composition of SDBC Mixture

Mix	0.1	0.25	0.3	0.35	**Gradation adopted**	**Specified gradation as per MORTH**
Sieve size (mm)	**20mm**	**11.2mm**	**6.7mm**	**Quarry dust**		
19	100	100	100	100	100	100
13.2	15.0	100	100	100	92	90-100
9.5	1.36	39.86	100	100	75	70-90
4.75	0	0	16.94	100	40	35-51
2.36	0	0	0.32	95.68	34	24-39
1.18	0	0	0	73.24	26	15-30
0.6	0	0	0	60.1	21	-
0.3	0	0	0	45.78	16	9-19
0.15	0	0	0	31.3	11	-
0.075	0	0	0	18.2	6	3-8

Table 6 Design Requirements for SDBC Mixtures

S.No.	**Design criteria**	**Plain Bitumen (MORTH)**	**PMB (IS: SP: 53-2002)**
1	Minimum stability (kN)	8.2	12.0
2	Flow (mm)	2 – 4	2.5 – 4.0
3	Air voids in percentage	3 – 5	3 – 5
4	Percentage of VMA	12 – 17	12 – 17
5	Percentage of VFB	65 – 75	65 – 75

Fig.1 Marshall Test specimen cast with 60/70 grade bitumen & with polyester & PP fibres

Table 7 Marshall Stability Test Results for Ordinary Bituminous Mix

S.No.	**Parameter**	**Bitumen Content (%)**				
		4	4.25	4.5	4.75	5
1	Marshall Stability (kN)	11.86	12.34	13.74	12.23	11.15
2	Flow (mm)	3.11	3.29	3.48	3.66	3.97
3	Marshall Density (g/cc)	2.373	2.39	2.417	2.414	2.413
4	Percentage air voids (%)	5.97	4.96	3.5	3.26	2.93
5	Percentage voids in Mineral Aggregates, VMA (%)	15.28	14.92	14.17	14.5	14.76
6	Percentage voids filled with Bitumen, VFB (%)	60.89	66.71	75.25	77.52	80.11

The variations of stability, Flow value, Marshall Density, Percentage of air voids, Percentage voids in Mineral Aggregates and Voids filled by Bitumen with the bitumen content are shown in Figs

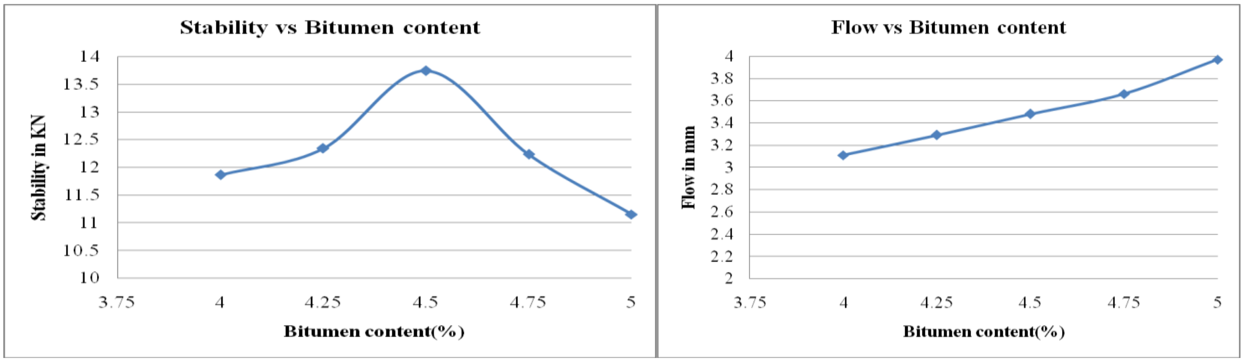


Fig. 2 Marshall Stability Vs Percentage of bitumen content

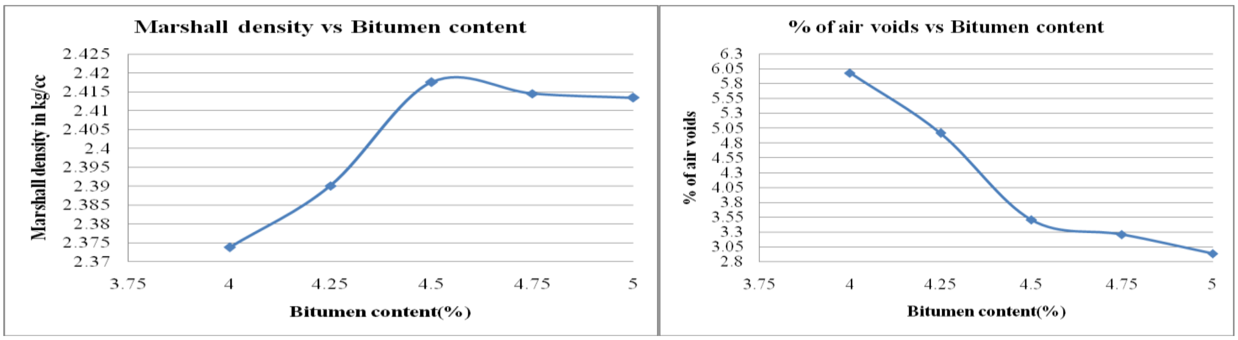
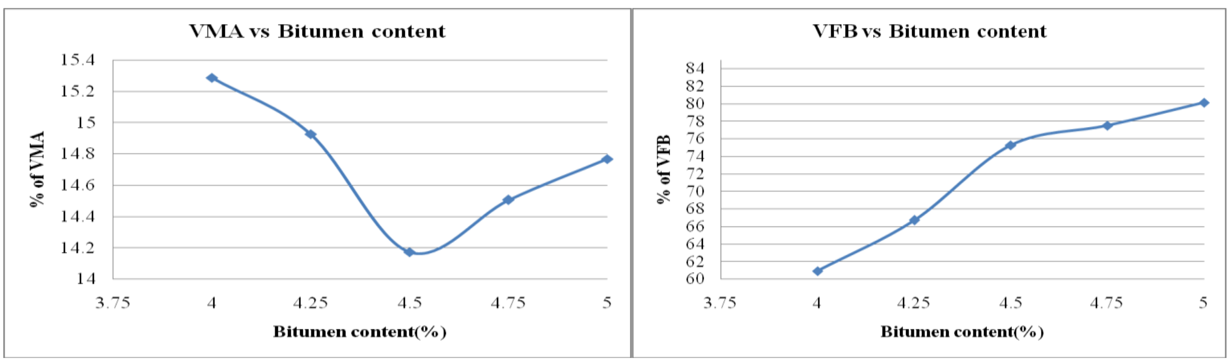


Fig. 3 Flow Vs Percentage of Bitumen



Above Figs. represents graphs of Marshall Stability vs. Bitumen content, Flow vs. Bitumen content, and Density vs. Bitumen content respectively, the Optimum Bitumen Content (OBC) obtained for ordinary bituminous mix is 4.5%.

Polyester Modified Bituminous Mix

The Results obtained for Polyester Modified Bituminous mixes are shown in Table 8. At a Fibre Content of 0.3% (Percentage of total mix), Marshall Stability value increased and then there is a decrease in the value.

Table 8 Marshall Stability Test Results for Polyester modified Bituminous Mixes

S.No.	Parameter	Fibre Content (%)				
		0.1	0.2	0.3	0.4	0.5
1	Marshall Stability (kN)	13.87	14.44	15.41	14.98	14.69
2	Flow (mm)	3.22	3.46	3.63	3.88	3.97
3	Marshall Density (g/cc)	2.37	2.385	2.413	2.395	2.365
4	Percentage air voids (%)	5.44	4.91	3.84	4.63	5.89
5	Percentage voids in Mineral Aggregates, VMA (%)	15.67	14.97	13.78	14.26	15.17
6	Percentage voids filled with Bitumen, VFB (%)	65.25	67.16	72.08	67.51	61.12

The variations of stability, Flow value, Marshall Density, Percentage of air voids, Percentage voids in Mineral Aggregates and Voids filled by Bitumen with the Fibre content are shown in Figs. below .

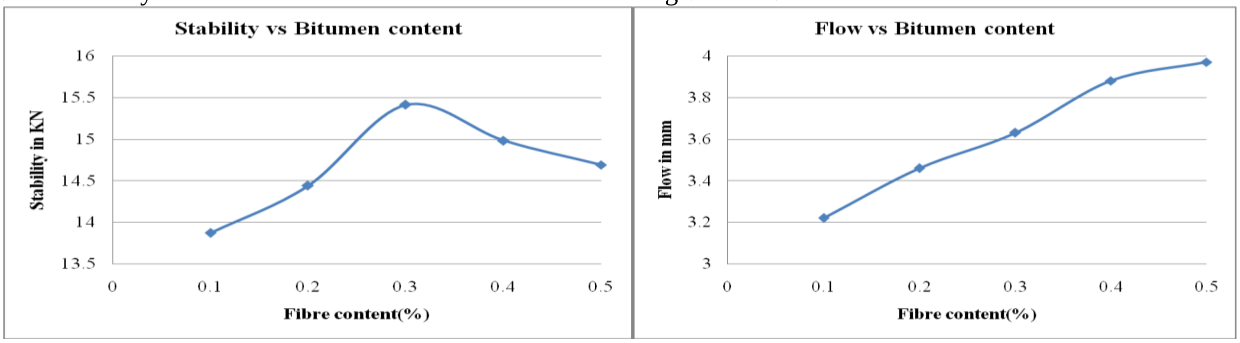


Fig. 4 Marshall Stability Vs % of Fibre Content & 12 Flow value Vs % of Fibre Content

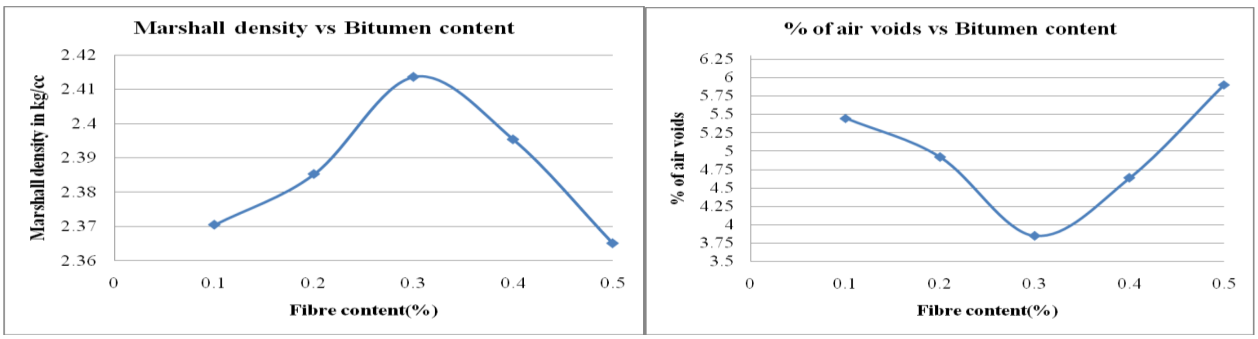


Fig. 5 Marshall Density Vs % of Fibre Content & % of Air voids Vs % of Fibre Content

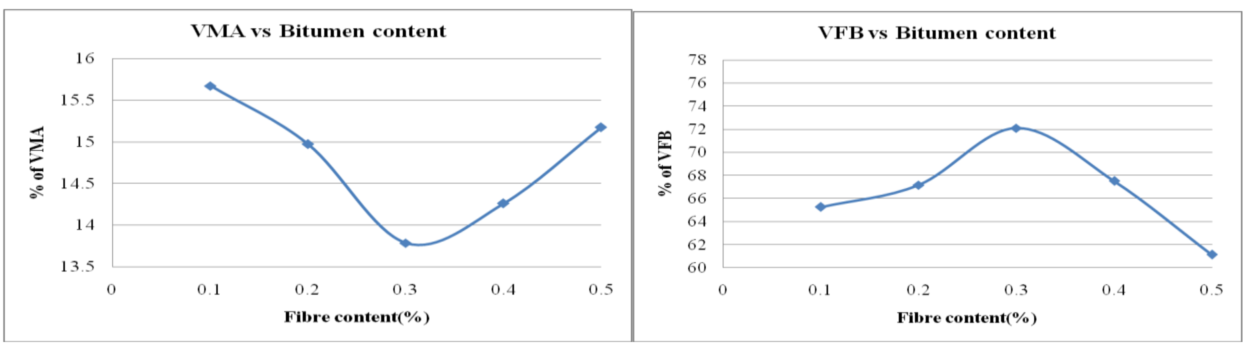


Fig. 6 % of VMA Vs % of Fibre Content & % of VFB Vs. % of Fibre Content

Above figures are representing graphs of Marshall Stability vs. Fibre content, Flow vs. Fibre content, and Density vs. Fibre content respectively, the Optimum Fibre Content (OFC) obtained is 0.3%.

Polypropylene Modified Bituminous Mix

The Results obtained for Polypropylene Modified Bituminous mixes are shown in Table 9. By increase in Fibre Content, The Marshall Stability value increases and the flow value decreases.

Table 9 Marshall Stability Test Results for Polypropylene Bituminous Mixes

S.No.	Parameter	Fibre Content (%)				
		0.1	0.2	0.3	0.4	0.5
1	Marshall Stability (KN)	12.56	13.24	14.18	14.61	15.02
2	Flow (mm)	3.34	3.18	3.02	2.56	2.20
3	Marshall Density (g/cc)	2.345	2.364	2.401	2.433	2.395
4	Percentage air voids (%)	6.4	5.64	4.16	2.88	4.4
5	Percentage voids in Mineral Aggregates, VMA (%)	16.51	15.6	14.05	12.66	13.79
6	Percentage voids filled with Bitumen, VFB (%)	61.24	63.85	70.36	77.21	68.09

The variations of stability, Flow value, Marshall Density, Percentage of air voids, Percentage voids in Mineral Aggregates and Voids filled by Bitumen with the Fibre content are shown in Figs below.

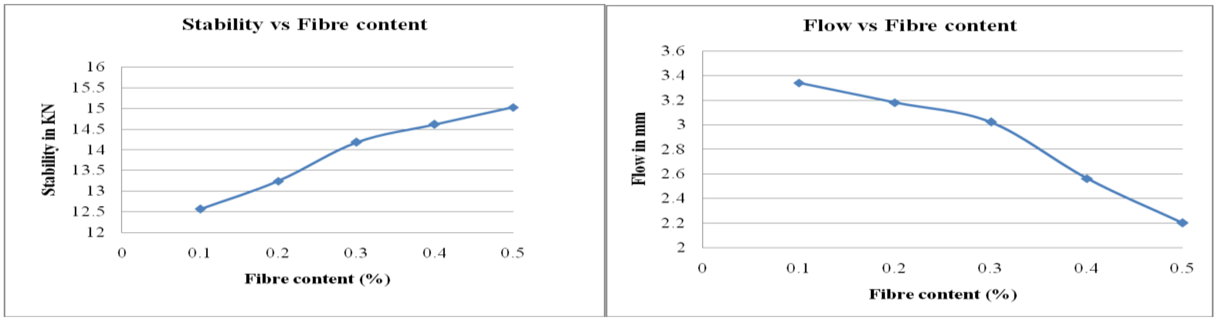


Fig. 7 Marshall Stability Vs % of Fibre Content & Flow value Vs % of Fibre Content

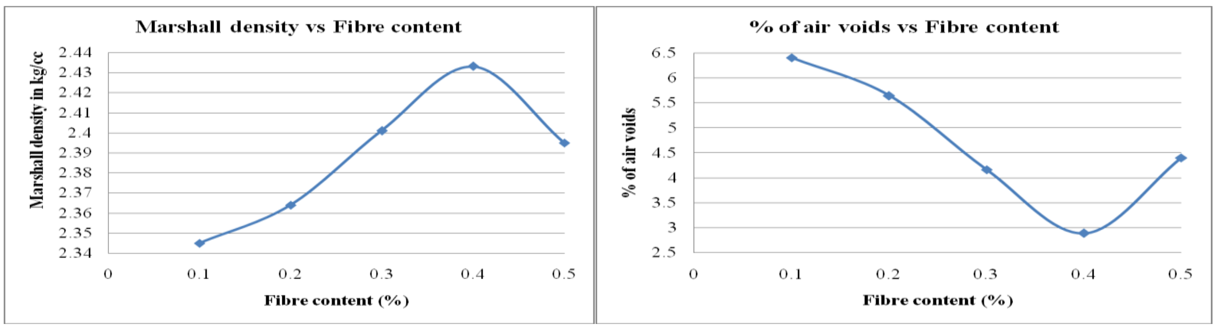


Fig. 8 Marshall Density Vs %of Fibre Content % of Air voids Vs % of Fibre Content

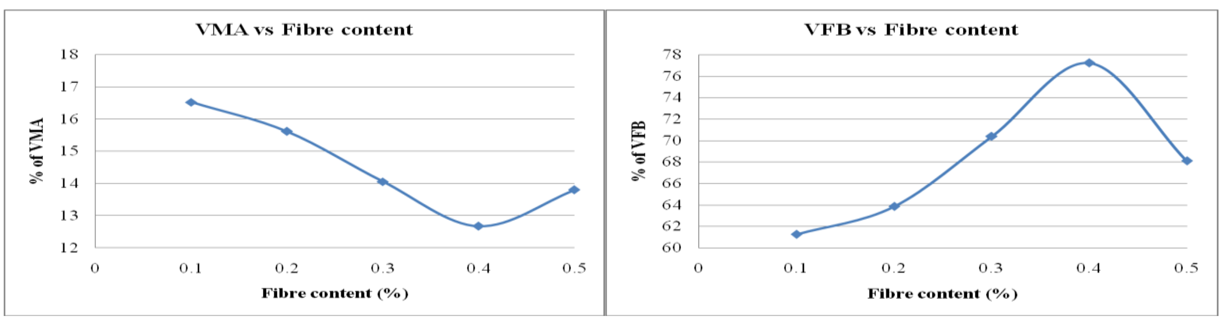


Fig. 9 % of VMA Vs % of Fibre Content & % of VFB vs. % of Fibre Content

From the Figs. it is clear that 0.3% of fibre content got much improvement effect by taking the design requirements, So that the Optimum Fibre Content (OFC) obtained is 0.3%.

Comparison of SDBC by adding Polyester and Polypropylene Fibres

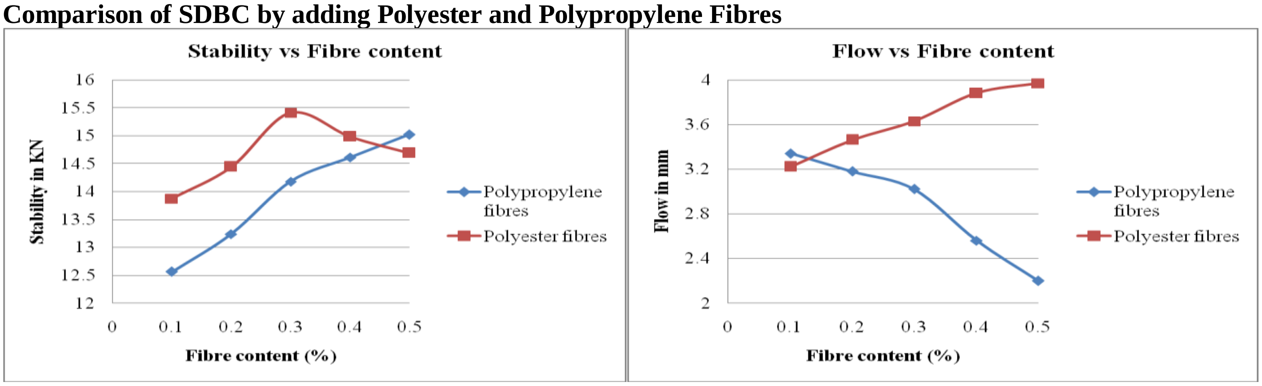


Fig. 10 Marshall Stability Vs % of Fibre Content & Flow value Vs % of Fibre Content

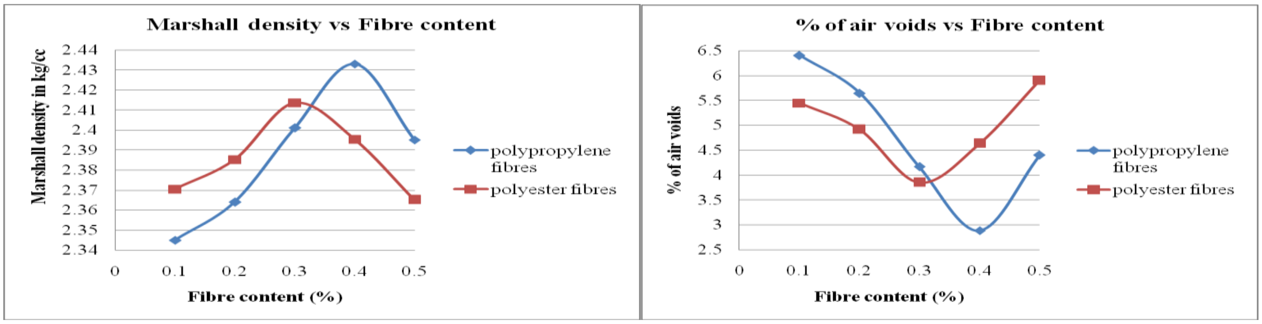


Fig. 11 Marshall Density Vs % of Fibre Content % of Air voids Vs % of Fibre Content

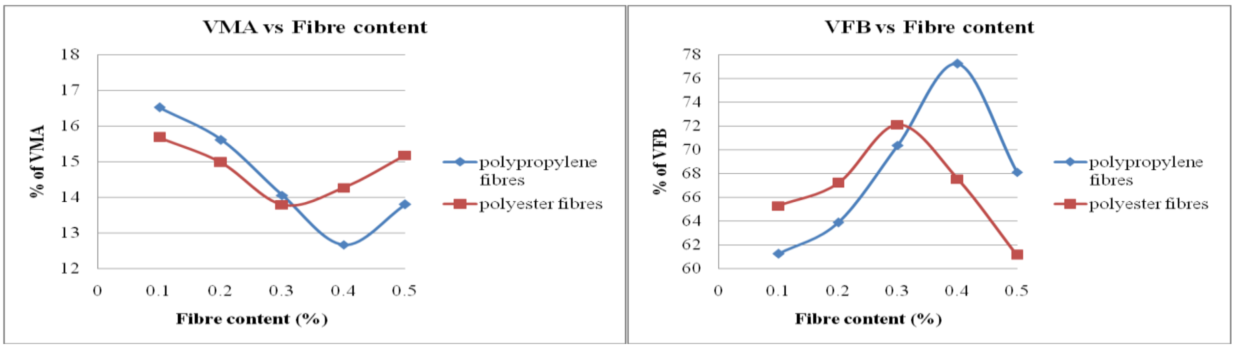


Fig. 12 % of VMA Vs % of Fibre Content & % of VFB vs. % of Fibre Content

From the test Results, it is clear that the Marshall Stability value and Marshall Density Value is maximum for a binder content of 4.5%. The other values which are in design requirements were satisfied by 4.5%. Therefore the Optimum Bitumen Content is 4.5%. The Fibre Content 0.3% which satisfies all design requirements so that the optimum fibre content is 0.3%. From the graphs it is observed that polyester fibres got much improvement effect compared with polypropylene fibres.

CONCLUSION

The objectives of the study were to evaluate the performance of fibre modified bituminous mixes reinforced with Recron 3S fibre through laboratory investigations. Aggregate and binder tests were conducted to assess the suitability of the materials used in the study. Marshall Stability test is used to evaluate the characteristics of bituminous mixes.
Based on the laboratory test results, the following conclusions are drawn.

- From the Marshall stability tests conducted, an optimum Bitumen content of 4.5% by weight of total mix was found for SDBC.
- From the Marshall stability tests conducted, an optimum fibre content of 0.3% by weight of total mix was found.
- At the optimum fibre content For Polyester Fibres the maximum stability value is found to be 15.41 KN.
- At the optimum fibre content For Polypropylene Fibres the maximum stability value is found to be 14.18 KN
- A stability value of 13.74 KN is obtained without adding fibres at Optimum Bitumen Content.
- About 12% increase in stability values can be achieved by reinforcing the bituminous mix with Polyester fibres and 3% increase can be achieved by Polypropylene fibres. Higher stability values indicate that the modified mixes would be less susceptible to cracking of flexible pavements.
- Polyester Fibres got much improvement effect where compared with Polypropylene Fibres.

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