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Fatigue Behavior of Polypropylene Fiber Reinforced Bituminous Concrete Mix

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***Abstract*—This Conventional bituminous mixes have performed satisfactorily well on a wide range of roads in the past, but it isseen that bituminous mixes are now exposed to greater stresses because of the increase in magnitude ofcommercial vehicles and higher tyre pressures. Increasing magnitude of wheel loads and tyre pressures of current traffic, the performance of neat bituminous mixes is generallyunsatisfactory for paving applications. The purpose of present work is to study the behaviour of fiber reinforced bituminous concrete mix on fatigue performance. Polypropylene fibers are extensively used in civil engineering applications for many years. Due to adhesion between polypropylene fibers and bitumen, the strengthening mechanism in bituminous concrete is somehow different. In this study, bituminous concrete specimens with polypropylene fibers were manufactured at the optimum bitumen content. It was observed for fiber-reinforced specimens that the Marshall Stability values increased and flow values decreased in a noticeable manner. The fatigue life of these specimens was also increased significantly. The improvement of the properties of bituminous concrete shows the positive effect of polypropylene fibers. The fiber-reinforced bituminous concrete mix exhibits prolonged fatigue life. Therefore it is concluded that the application of polypropylene fibers alters the characteristics of bituminous concrete mix in a very beneficial way.**

Keywords-Polypropylene fibers, Marshall Stability, Flow, Fatigue performance.

I. INTRODUCTION

Fatigue failure is one of the main distress mechanisms causing degradation of pavements. Fatigue is caused by repeated traffic loadings, which result in crack initiation, crack propagation and eventually catastrophic failure of the material due to unstable crack growth [2]. Fatigue cracking represents a major distress that affects the service life of flexible pavements. After the passing of a vehicle, the bituminous concrete layer tends to return to its original condition. But, due to the cycling nature of the loading, the bituminous concrete exhibits the fatigue cracking. Cracking usually starts from the bottom of the bituminous concrete layer, where the material is in tension when wheel loads are applied at the pavement surface, and propagates up to the surface. Once they reach the surface, the cracks represent avenues for water to enter the pavement and cause the deterioration of the foundation layers [8]. For thin pavements, fatigue cracking started at the bottom of the bituminous layer due to high tensile strains and migrated to the top surface. For thick pavements, cracks started on the surface of bituminous layer due to tensile strains at the surface and migrated to downward [1]. Polypropylene fibers are widely used as reinforcing agents and provide three dimensional reinforcement of the concrete. In this way, concrete becomes more tough and durable [9, 10]. Polypropylene fibers were used as modifiers in asphalt concrete in the United States. Ohio State Department of Transportation (ODOT) has published a standard for the use of polypropylene fibers in high-performance asphalt concrete [6]. Polypropylene fibers were used in a 1993 study by Yi and Mc Daniel in an attempt to reduce reflection cracking in an asphalt overlay. Although crack intensities were less on the fiber modified overlay sections, no reduction or delay in reflection cracking was observed [12]. The effect of polyester, polyacrylonitrile, lignin and asbestos fibers with different percentages were investigated on fatigue and rutting properties of asphalt concrete mixtures. It was investigated that addition of fibers into asphalt mixture resulted in increment of fatigue life [11]. The effect of carbon fiber with the percentage of 0.1, 0.2, 0.3, 0.4 and 0.5% by weight of mix on fatigue life of mixtures was studied. Carbon fibers have been prepared with two different lengths and it was observed that the specimens containing 20 mm fiber length had more fatigue life as compared to those mixtures containing 12.5 mm carbon fiber [7].

II. NEED OF STUDY

Fatigue cracking is an important deterioration mechanism of bituminous concrete surfaced pavements, because of the detrimental effect; these cracks have on the overall pavement life, reducing its durability and strength. Top-down fatigue cracks provide a path for moisture to readily infiltrate the underlying layers and subgrade soils of flexible pavements. The pavement structure, mixture composition and construction are major factors that have an effect both on the initiation and propagation of fatigue cracks with load repetitions. Environmental and climatic factors also play an influential role on the development of fatigue cracks with time. Fatigue is a major failure criterion for flexible pavements. Overloading of vehicles, wide range of temperature variation and properties of materials are some of the factors which influence and encourage the fatigue failure of a pavement.It is important to know the behavior of fatigue life of asphalt pavement by introducing the polypropylene fiber in the mix.

III. MATERIALS

A. Aggregate

The locally available aggregate was used in all the experiments. The physical properties of coarse aggregates are presented in Table1. The specific gravity of stone dust and cement as filler are 2.496 g/cc and 3.141 g/cc respectively.

TABLE 1THE PHYSICAL PROPERTIES OF AGGREGATES

S.N.	Property	Test Value	Standard
1.	Bulk specific gravity, g/cc	2.635	IS : 2386 (Part III)1963
2.	Apparent specific gravity, g/cc	2.704	
3.	Water absorption, %	0.975	

B. Bitumen and Fiber

Bitumen 60/70 grade and polypropylene fiber were used for preparation of the test specimens. The physical properties of bitumen and fiber are presented in Table 2 and Table3 respectively. Polypropylene fiber used in the present study is shown in figure 1.

TABLE 2PHYSICAL PROPERTIES OF BITUMEN

Property	Test Method	Test Result
Penetration 25 ^{0}C (100 g, 5 s),0.1mm	IS 1203-1978	65
Softening point(Ring & Ball), ^{0}C, Minimum	IS1205-1978	45.5
Ductility at 27 ^{0}C (5 cm/min pull), minimum	IS 1208-1978	83
Specific gravity (g/cc)	IS 1202-1978	1.01

TABLE 3PROPERTIES OF POLY PROPYLENE FIBER

S.N.	Property	Value
1	Type	Polypropylene wire
2	Shape	Straight Ends
3	Average Diameter	0.3 mm
4	Length	12 ± 2 mm
5	Specific Gravity	0.92 g/cc

Figure 1Polypropylene fiber used in the present study

IV. APPROACH

The aggregate gradation is satisfying the standard gradation as per the Ministry of Road Transport and Highways, Government of India required for the bituminous concrete. The final selected individual aggregate proportions for preparing Marshall Test specimens and fatigue test beams are presented in Table4.

TABLE 4COMPARISON OF SPECIFIED GRADING & GRADING OBTAINED

Nominal size of aggregate	Standard	Used in the study
	19 mm	19mm
Sieve size(mm)	Cumulative % by weight of total aggregate passing	
26.5	100	100
19	79-100	97
13.2	59-79	73
9.5	52-72	61
4.75	35-55	42
2.36	28-44	33
1.18	20-34	29
0.6	15-27	24
0.3	10-20	17
0.15	5-13	8
0.075	2-8	4

A. Preparation of Specimens and Fatigue Test

Appropriate quantity of aggregates was taken in a mixing bowl and heated to a temperature of 150-160°C. Appropriate quantity of 60/70 penetration grade bitumen by weight of aggregates was measured and heated separately to a temperature of 150°C. Aggregates and bitumen was mixed at a temperature of 155º C using a spatula till the aggregates were thoroughly coated with bitumen then add polypropylene fiber in the mix. The mix was then transferred to a pre-heated mould of size 20 x 4 x 3 inches in three layers, each layer being tamped 50 times by a 12 mm diameter rod. About 30 tone load was applied to the specimen by a hydraulic jack through small rectangular compaction plunger.

The beam was placed in Fatigue Testing Machine, which subjects the beam to a repeated load of 85 kg. The deflection caused by the loading is measured at the centre of the beam. The number of loading cycles to failure can then give an estimate the fatigue life of a particular bituminous concrete mix. The fatigue life can be determined as a number of load repetitions that cause the first crack.

V. DISCUSSION OF TEST RESULTS

Based on the volumetric properties of Marshall Specimens, the optimum bitumen content by weight of aggregate was found out to be 5.25 %. It was found that the unit weight of the polypropylene fiber-reinforced specimens is lower than that of plain specimens (Figure 3). The significant improvement in stability and flow values i.e. 27% increase in stability and 58% decrease in flow values for the specimens reinforced with 1.5 % of polypropylene fiber when compared with plain specimens (Figure 4 and Figure 5). The volume of air voids is increased with increase in the content of polypropylene fibers (Figure 6).This property is important for the pavements designed to serve in hot regions where the bitumen is suspected to flushing and bleeding where increased void ratio can be a solution for these problems. Investigated samples show completely different fatigue life behavior (Figure 7). It can be observed that addition of fibers provides longer fatigue life. However, in this study, the tests had been terminated at the point when the first visible crack was observed on the specimen surface and the fatigue life of the specimens is calculated on this basis. The significant improvement in fatigue life i.e. 113 % increase in number of cycles at failure for the specimens reinforced with 1.5 % of polypropylene fiber when compared with plain specimens (Figure 8).

Figure 2 Test setup for fatigue test on bituminous concrete beam

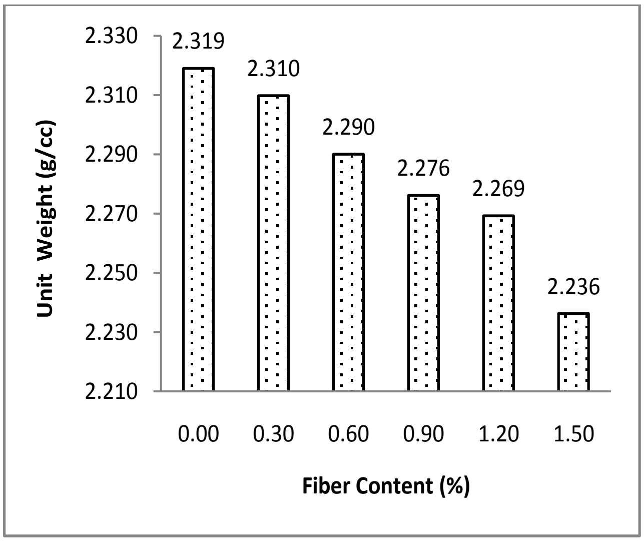

Figure 3 Effect of polypropylene fibers on unit weight

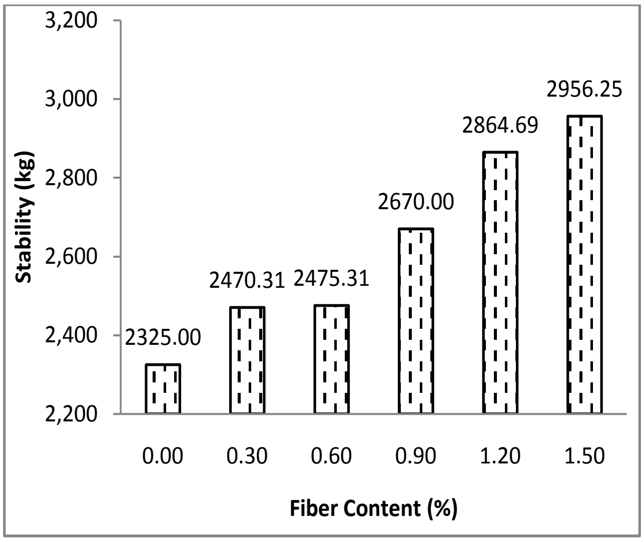

Figure 4Effect of polypropylene fibers on stability values

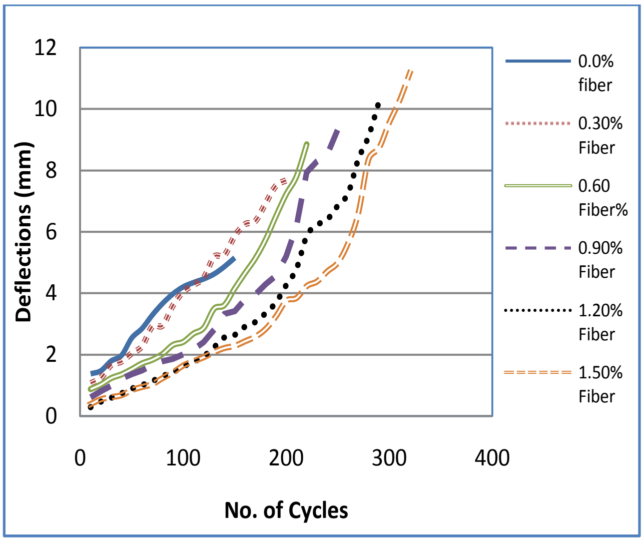

Figure 7 Behaviors of beams w.r.t. polypropylene fibers

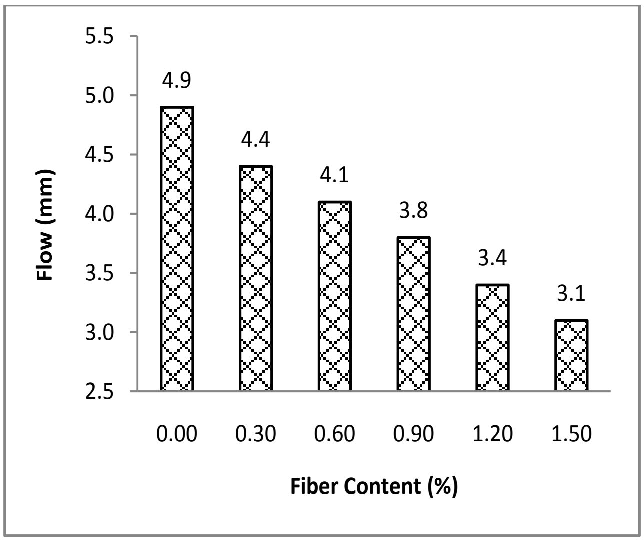

Figure 5 Effect of polypropylene fibers on flow values

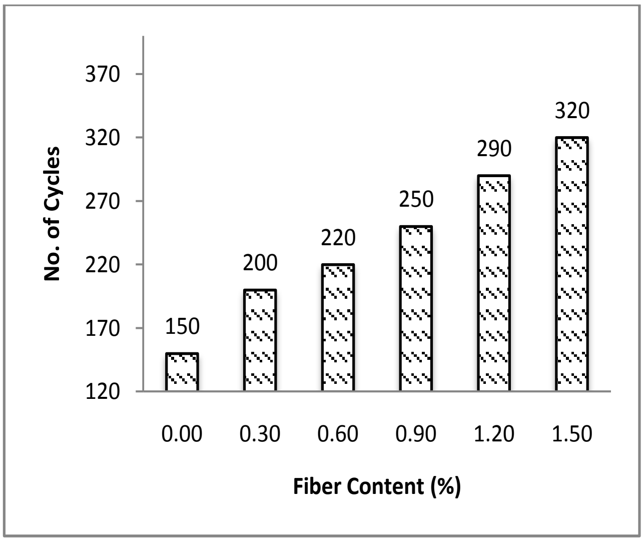

Figure 8Effect of polypropylene fibers on no. Of cycles at failure

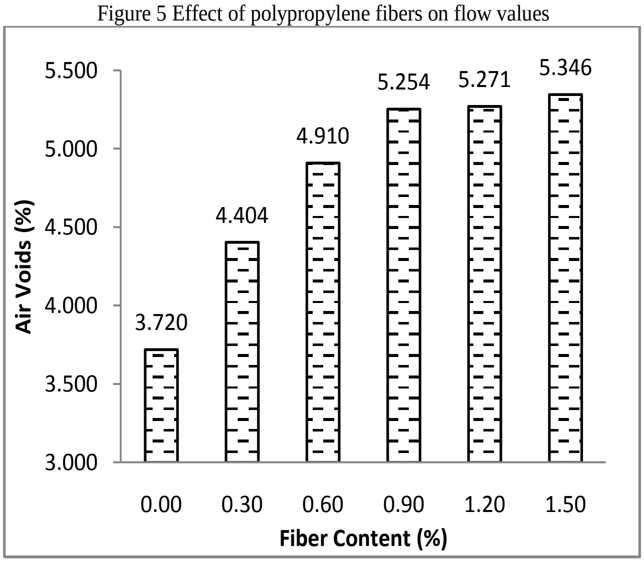

Figure 6 Effect of polypropylene fibers on air void

VI. CONCLUSIONS

The Marshall tests and fatigue tests have shown that the addition of polypropylene fibers considerably alters the behavior of bitumen concrete.When the polypropylene fiber content increases, an increase in the Marshall stability index was observed reaching 27 % for the specimens reinforced with 1.5 % of polypropylene fibers.The results from the analysis of the tested specimens show that the addition of polypropylene fibers improves the behavior of the specimens by increasing the life of samples under fatigue testing.According to the test results, the addition of 1.5 % of polypropylene fibers prolongs the fatigue life by 113 % in terms of number of cycles, in comparison to plain bituminous concrete beam.

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