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Influence of Mineral Fibers on Asphalt Concrete

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Abstract— If we need to work on highway pavements asphalt concrete has great importance. For the construction of highways our first choice has always been the basic material for pavement engineering i.e. asphalt concrete. Thus it is need to improve the standards of asphalt concrete for finer performance and to last longer as compared to the current asphalt mix. It has been experimented that the addition of fibers to asphalt improves the concrete strength and other physical characteristics. As we seen, in some experiments mineral fibers like carbon fibers offer better characteristics for binder due to their inherent compatibility with asphalt and excellent mechanical properties. Mineral fibers like mineral steel fibers are also impounds good tensile influences in the asphalt and it is realized that the combination of steel and carbon fibers create an excellent influences in the internal structure of asphalt resulting in asphalt concrete more durable .

In the current study, an approach was developed to mix carbon fibers and mineral steel fibers with blending of asphalt. Using Marshall Procedure, Optimum carbon Fibers Content and Optimum steel fibers Content for Dense Bituminous Macadam (DBM) are to be calculated. An attempt has been made to study the effects of increasing the tensile strength of asphalt mix concrete mineral with fibers called Carbon and mineral steel fibers is used as an additive in (DBM of hot mix asphalt). An experimental study is performed on conventional asphalt and fibers modified asphalt concrete.

Keywords— Asphalt Concrete, Mineral Fibers, Steel Fiber, Carbon Fibers, Dense Bituminous Macadam, Marshal Stability Test.

I. INTRODUCTION

Bituminous concrete is commonly used as surface course for high traffic roads. Bituminous concrete is a mixture of well-graded aggregates from size less than 25 mm, while the fine filler that is smaller than 0.075 mm. Coarse aggregates which employed high compressive strength and shows high interlock properties, Fine aggregates that is use to fill voids in the coarse aggregate and stiffens the binder. E.g. Sand, Rock dust, Fillers used to fill the voids, stiffens the binder and offers impermeability E.g. cement, lime, fly-ash, Binder to fills voids, cause particle strength. E.g. Asphalt, Tar. Adequate amount of asphalt is add to the mix so that the compacted mix which is effectively impervious and impose adequate elastic property. The asphaltic mix design concentrates to determine the proportion of asphalt, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical. The properties of a asphalt mix can be as it is an economical mix, Stability to meet the high traffic demand, Asphalt content to ensure good binding and moisture proofing, Voids to accommodate compaction due to heavy traffic, Flexibility to meet traffic loads in cold region, Sufficient workability for construction.

A. Objective of Current Investigation

In the previous investigation we found that carbon fiber was added onto the bituminous mix in the amount of small percentage of 1.5% which was accounted as the optimum carbon fibers content. In some investigation we seen that mineral steel fibers was added into the bituminous mix separately. In the present investigation we are intent about the addition of mineral fibers i.e. carbon fiber 1.5% and mineral steel fibers in combination, the quantity of mineral steel fibers that is added to the bituminous mix design modified with carbon fiber and which will offer better tensile strength expecting an increase in durability of dense bituminous concrete is use in our investigation. Mineral steel fibers content varies between(1% - 4%). In the current study 60/70 penetration grade asphalt is used as binder. The whole effort is carried out in different stages which are listed below.

1) Investigation on Marshall Properties of DBM mixes using lime as filler and different percentages of Asphalt content to determine **Optimum Asphalt Content.**
2) Study on Marshall Properties of DBM mixes with optimum carbon fiber(1.5%) and different percentages of steel are added to the weight of the bitumen in Dry Process to find **Optimum mineral steel fibers Content.**

II. PROPERTIES OF MATERIALS USED IN BITUMINOUS MIX

A. Mineral Aggregate

There are various types of mineral aggregates which can be used in bituminous mixes. The aggregates used to manufacture bituminous mixes can be obtained are termed as natural aggregates. Broken bituminous pavement is also an important source of aggregate for bituminous mix. Aggregates play a very important role in providing strength to asphalt mixtures. In BC the mineral aggregates content varies from 70-80%. The aggregates must possess a highly cubic shape and rough texture to resist rutting and movements, a hardness which can resist fracture under heavy traffic loads, a high resistance to polishing, and high resistance to abrasion. Specific gravity of coarse aggregates was found as 2.75. specific gravity of Fine aggregates was found as 2.6 Aggregate passing through 0.075 mm IS sieve is filler. Lime is used as filler with specific gravity of 2.3. Standard tests were conducted to determine their physical properties.

B. Binder

Asphalt acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Binder is good to provide durability to the mix. The characteristics of asphalt which affects the bituminous mixture behavior are temperature propensity, visco-elasticity and age. The behavior of asphalt depends on temperature as well as on the time of loading. It is stiffer at lower temperature and under shorter loading period. Asphalt must be treated as a visco-elastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. Though at low temperature it behaves like an elastic material and at high temperatures its behavior is like a viscous fluid.

C. Stabilizing Additives

The concept of using mineral fibers improve the behavior of materials. The modern developments of fibers reinforcement have been extensively improve rheological properties of engineering materials. It is well known that modified asphalt significantly increases rheological properties of asphalt used within bituminous pavements suffering from different kinds of problems like cracking, rutting, fatigue, etc.

D. Types of Fibers

The fibers are broadly classified as three types as

- Natural Fibers (e.g. Cellulose, Coconut, Lignin, Sisal, Jute, Banana fibers etc.)
- Synthetic Fibers (e.g. Polypropylene, Polyester, Aramid fibers etc.)
- Mineral Fibers (e.g. Carbon, Basalt, Glass, Steel, Asbestos fibers etc.)

This paper highlights the erstwhile research works that were carried out in laboratory on asphalt mixes reinforced with the addition of Steel and Carbon fibers as additives to improve the results.

1) *Carbon Fibers:* Carbon fibers are thought to tender advantages over other fibers types for the alteration of asphalt binder. Since the fibers are composed of carbon and asphalt is a hydrocarbon, they are thought to be inherently compatible. Because carbon fibers are produced at extremely high temperatures (over 1000°C), fibers melt due to high mixing temperatures is not an issue. Carbon fibers are produced from either polyacrylonitrile (PAN) or pitch precursors. These precursors are processed into carbon fibers in similar ways. The high tensile strength of mineral carbon fibers increases the tensile strength and related properties of mixtures, including fighting against to thermal cracking. The stiffening effect showed by the addition of other fibers should also occur in carbon fibers modified mixtures, increasing the fatigue life of pavements. For these reasons it was hypothesized that carbon fibers should be the most compatible, best performing fibers type available for modification of asphalt binder.
2) *Mineral steel fibers:* Modified bitumen concrete is made up of fine and coarse aggregate and discontinuous discrete mineral steel fibers. Means of strengthening of fibers reinforcement is extending in mineral mineral steel fibers crack arrest mechanism is based on fracture system. Mineral steel fibers are defined as short discrete with length to diameter from 20 to 100mm. Steel with aspect ratio more than 100 tend to interlock to form a ball after shaking thus avoided. And mineral steel fibers with aspect ratio less than 50 are able to disinterlock and can easily be discrete by vibration. Addition of these fibers will increase toughness much more than that first crack strength in these tests. Bond due to mineral steel fibers is depending upon aspect ratio

E. Selection of Binder

Different type of binder like conventional penetration grade asphalt of 60/70 or 80/100 asphalt are use as modified binder like Polymer Modified Asphalt (PMB), Crumb Rubber Modified Asphalt (CRMB), Natural Rubber Modified Asphalt (NRMB) in used by numbers of researcher for their research effort. Some researcher also used high grade binder like PG 76-22 with asphaltic mixture such as Bituminous Concrete (BC). In this study 60/70 penetration grade asphalt is used as the purpose of binder.

F. Selection of Stabilizing Additive

Different stabilizing additive like fibers such as natural fibers, mineral fibers etc. polymer, plastic, waste material like carpet fibers, waste tyres, polyester fibers are added to asphaltic mix mainly with Stone Natural fibers as like jute fibers and coconut fibers are also used by many researchers. Here an attempt has been made in this research work to utilize available mineral fibers carbon and steel fibers in mix with Dense bituminous mixture.

Figure 3.1 Carbon fiber


Figure 3.2 Steel fibers

III.METHODOLOGY

VOLUMETRIC PROPERTIES OF BITUMEN MIX

A. Theoretical Maximum Specific Gravity

Loose DBM mixtures were prepared to determine their theoretical maximum specific gravity (Gmm) values. Test was conducted as per ASTM D 2041.

1. The DBM mixture was prepared using oven-dry aggregates, and placed in a pan and the particles of mix were separated by hand, taking care to avoid fracturing the aggregate, so that the fine aggregate portion were not larger than about 6 mm. The sample was cooled to room temperature.
2. The sample was placed directly into a cylindrical container and net mass (mass of sample only) weighed and was designated as A.
3. Sufficient water was added at a temperature of approximately 25°C to cover the sample completely. The cover was placed on the container.
4. The container was placed with the sample and water, and agitation was started immediately to remove entrapped air by gradually increasing the vacuum pressure (by vacuum pump) for 2 min until the residual pressure manometer read 3.7 ± 0.3kPa, vacuum and agitation was continued for 15 ± 2 min.
5. The vacuum pressure was gradually released using the bleeder valve and the weighing in water was done. For determining the weight in water, the container and contents were suspended in water for 10 ± 1 min, and then the mass was determined. The mass of the container and sample under water was designated as C.

The maximum specific gravity of the sample was calculated as follows:

$$G_{mm} = \frac{A}{[A - (C - B)]}$$

Where: G_{mm}= Maximum specific gravity of the mixture,

A = Mass of dry sample in air, gm,

B = Mass of bowl under water in gm

C = Mass of bowl and sample under water, gm.

B. Method of fibers addition

Various methods of joining together carbon fibers and asphalt binder were attempted. The goal was to find a method that would uniformly disperse fibers during the binder. Small trial blends of asphalt binder and 0.5 to 2.5 percent carbon fibers by weight of bitumen are made. After each trial mix was completed, the hot, modified binder was poured onto a square paper and allowed to cool.

After many trails the dry mix process is taken into thought and the mix is prepared and trial blends of steel fibers of 1 to 5 percent by weight of bitumen are made.

Mineral steel fibers has more advantages as additive with carbon fiber like as
1) Random distribution of steel Leeds to distributed cracking with reduced crack size.
2) First crack tensile strength and ultimate tensile strength of the concrete may be increased by the fibers.
3) Shear frictional strength is increased
4)Addition of mineral steel fibers is not going to decrease amount of shrinkage but it can increase the number of cracks and thus reduce the average crack width. Mineral steel fibers can reliably detain cracking and to improve resistance to weakening as a result of fatigue, impact and shrinkage of pavement. Mineral steel fibers are also effective in supplementing or replacing the stirrups in beams.

TABLE 3.1 GRADATION OF AGGREGATES IN ASPHALT CONCRETE

Sieve size	Aggregates (% finer)	Aggregates % used in mix	Mineral Carbon fiber content	Mineral steel fibers content
19 mm	90-100	25%	0.5%	1%
13.2 mm	75-90		1.0%	2%
9.5 mm	62-75	20%	1.5%	3%
4.75 mm	45-62	54%	2.0%	4%
2.36 mm	30-42		2.5%	5%
1.18 mm	18-34			
600 micron	12-25			
300 micron	10-15			
150 micron	5-10			
75 micron	1-6	1%		

IV. EXPERIMENTAL PROCEDURE

1) Preheating of the weighed aggregates and bitumen separately up to 170 °C and 163°C respectively.
2) Bitumen mix of carbon fiber is mix thoroughly with varied proportion (1%,2.%,3%,4%,5%) of mineral steel fibers of 12mm and 15mm transfer the mixed material to the compaction mould arrange on the compaction pedestal.
3) Give total 75 number of blows on the upper side of the samples mix with a standard hammer (45cm, 4.86 Kg). Reverse the samples and give 75 blows again on other side. Take the mould with the samples and cool it for a few minutes.
4) Remove the samples from the mould by tender pushing, Mark the samples and cure it at room temperature overnight.
5) Number of batches of samples are prepared by varying quantities of bitumen with variance of 0.5%.
6) Before testing of the samples, keep the samples in the water bath having a temperature of 60 °C for around 40 minute.
7) Check the stability of the samples on the Marshall Stability apparatus.
8) The binder content, corresponding to the specified air voids (4.5%) was found in previous investigation.

A. Marshall Stability Test

Marshall Stability test was conducted on cylindrical DBM samples to find out their stability and flow values. The principal features of the method were a density-voids analysis and a stability-flow test of compacted samples. The samples was kept in thermostatically controlled water bath maintained at 60 ±10C for 30 to 40 minutes. Then it was placed in Marshall Test machine and experimented to determine Marshall Stability value of strength of the bituminous mixture. It was the maximum resistance in kilo Newton, which it would develop at 600C when tested in the standard Marshall equipment. The flow value was the total deformation in units of mm, occurring in the samples between no load and maximum load during the test. The test samples were prepared with varying asphalt content in 0.5 per cent increments over a range that gives a well-defined maximum value for samples density and stability.

Figure 4.1 Performing Marshall Test

All the compacted specimens are subject to the following tests:

- Bulk Density Determination.
- Specific Gravity Analysis
- Stability of Bituminous Mix
- Flow value of bituminous mix
- Percentage of Air Voids

V. OPTIMUM ASPHALT CONTENT

Graphs were plotted for asphalt content against bulk density, air voids, Marshall Stability and Flow. The Optimum Binder Content (OBC) for DBM mixtures is usually preferred to produce the specified air voids. All the values are compared with the specification values to check whether they were in specified limits.

VI. ANALYSIS OF RESULT

A. Aggregate Properties

Particle shape, strength tests, specific gravity and water absorption tests have been conducted and data is as follows:

TABLE 5.1 PHYSICAL PROPERTIES OF COARSE AGGREGATE

S. N.	Property	Name of the Test	Test Result	Specified Limit (MORT& H)	Test Method
1	Particle Shape	Flakiness (13.65%)	28.45 %	Max. 35 %	IS:2386 Part-1
		Elongation (14.80%)			
2	Strength	Aggregate Impact Value	23.30 %	Max.27 %	IS:2386 Part-4

TABLE 5.2 SPECIFIC GRAVITY OF AGGREGATES

Size	Bulk Sp. Gravity G_{sb}	Apparent Specific gravity G_{sa}	Water Absorption (%)
40 mm	2.656	2.610	0.1
20 mm	2.654	2.609	0.1
10 mm	2.656	2.606	0.1

TABLE 5.3 – RHEOLOGICAL PROPERTIES OF BINDER

Property Tested	Test Method	Result Obtained	Requirement as per IS-73
Penetration (100 gram, 5 seconds at 250C) (1/10th of mm)	IS 1203-1978	64.43mm	50-70
Softening Point ^{0}C (Ring & Ball Apparatus)	IS 1203-1978	51.00°C	Min 47
Specific gravity	IS:1203-1978	1.02	0.95

INVESTIGATION ON THE EFFECT OF BINDER (BITUMEN) PERCENTAGE, CARBON FIBER PERCENTAGE AND STEEL FIBER PERCENTAGES ON DBM

Prepare Graphical Plots Between the different bitumen content and properties the following graphical plots are prepared:

Binder content versus Marshall stability value
Binder content versus Marshall flow value
Binder content versus unit weight/bulk specific gravity
Binder content versus percentage of void inmix

Optimum Binder Content **-** Optimum Binder Content is bring into being out by taking average value of following three bitumen Content found from above graph i.e.

I. Bitumen content corresponded to maximum stability value of mix
II. Bitumen content corresponding to maximum unit weight of mix
III. Bitumen content equivalent to the median of designed limits of percentage air voids in total mix.

From above result it has been observed that BC mixes with all three types of filler produce satisfactory result as suggested as in MORTH. Here mixes with cement filler gives higher stability and other improved characteristics followed by stone dust filler and then fly ash filler. Here LIME has been selected as filler material for further investigation considering its wide availability, low cost price and environment protection.

B. Effect Of Binder (Bitumen) Percentage On DBM

Variation of Marshall Properties of Dense bituminous Macadam (DBM) with different percentages of bitumen content is explained below.

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TABLE 5.4 EFFECT OF BINDER (BITUMEN) PERCENTAGE ON DBM

Percentage	G_{mm}	G_{mb}(mean density value)
0.5	2.4734	2.323
1.0	2.4651	2.329
1.5	2.4532	2.354
2.0	2.4329	2.343
2.5	2.4200	2.34

1) *Marshal Stability:* It is observed that stability value increases with increase in binder content up to certain binder content; then stability value decreases. Variation of Marshall Stability value with different binder content with different filler is given fig 5.1

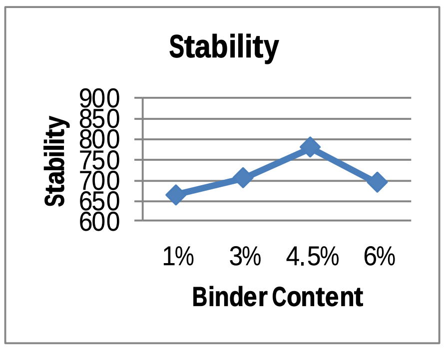

Figure 5.1-Variation of Marshal Stability Different Binder Content

2) *Flow Value:* With the increase in the binder content the marshall flow value increases to certain limits.

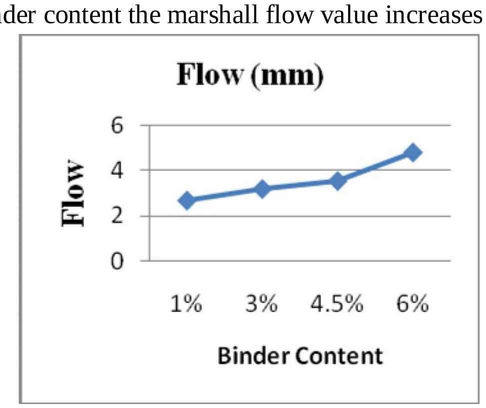

Figure 5.2 – Variation of Flow value with Different Binder Content

3) *Unit Weight:* It is observed that unit weight increases with increase binder content up to certain limits binder content; then decreases. Variation of unit weight value with different binder content with different filler is given figure 5.3.

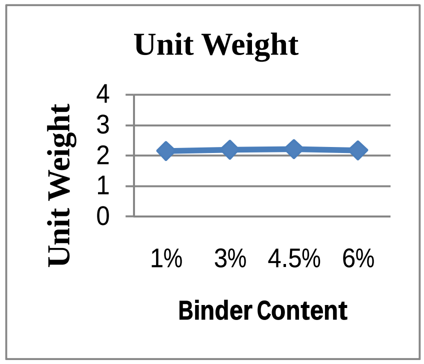

Figure 5.3 Variation of Unit Weight with Different BC

4) Air Voids: It is observed that with increase binder content air void decreases. Variation of air void with different binder content MORTH recommended it should be lies between 3 to 6%. Hence the binder content at 4.5% value of air void given below.

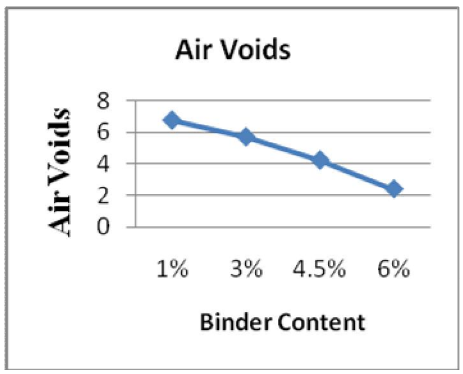

Figure 5.4 -Variation of air void in BC with different binder content

C. Effect Of Carbon Fiber On DBM

For preparation of mix, binder content at 4.5% and carbon fiber content vary from 0.5% to 2.5%. Here optimum carbon fiber content and other Marshall properties are calculated by Marshall Method.

1) *Marshal Stabilty:* It is observed that stability value increases with increase of carbon fiber content and further addition decreases stability. Variation of Marshall Stability value with different carbon fiber content increases with increase binder content. Variation of stability with different binder content is shown in Figure below.

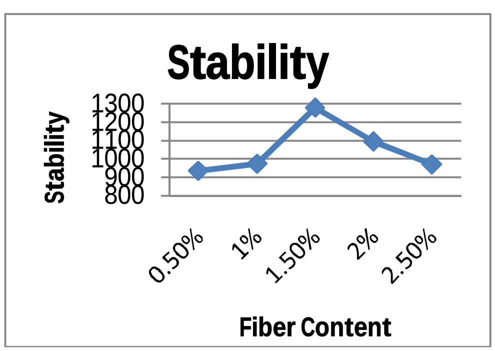

Figure 5.5- Variation of Marshall Stability of BC with different Carbon Fiber Content

2) *Flow Value :* It is observed that with increase binder content flow value increases.

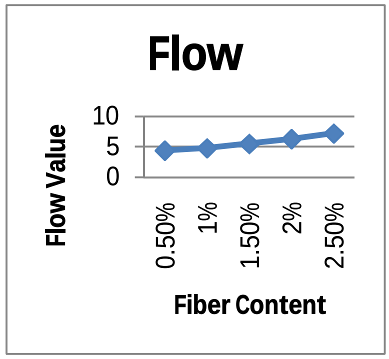

Figure 5.6- Variation of Flow Value with different Carbon fiber Content

3) *Unit Weight:* The unit weight increases with increase binder content up to certain binder content; then decreases is observed.

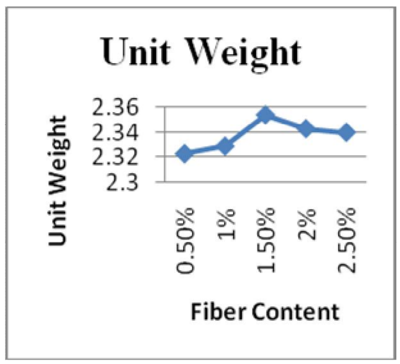

Figure 5.7- Variation of Unit Weight with different Carbon fiber Content

4) *Air Void:* Variation of air void content with different carbon fiber content of mix is given in 5.8 between 3 to 6%.

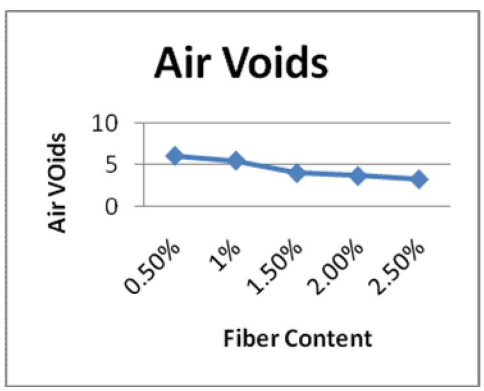

Figure 5.8- Variation of Air Voids with different Carbon fiber Content

D. Effect Of Steel Fiber On Carbon Fiber Modified Dbm

For preparation of mix, binder content at 4.5%, carbon steel fiber content of 1.5% and steel fiber content vary from 1%-4%. Here optimum steel fiber content and other Marshall properties are calculated by using Marshall test Method.

1) *Marshal Stability:* It is observed that stability value increases with increase of steel fiber content and further addition of steel fiber it decreases. Variation of Marshall Stability value with different steel fiber content increases with increase binder content. Variation stability with different binder content is shown in Figure below.

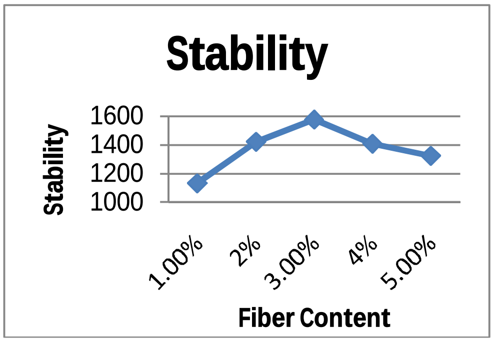

Figure 5.9- Variation of Marshall Stability of BC with different Steel fiber Content

2) *Flow Value:* It is observed that with increase binder content flow value increases. Variation of flow value with different binder content of BC with different steel fiber content is shown in fig.

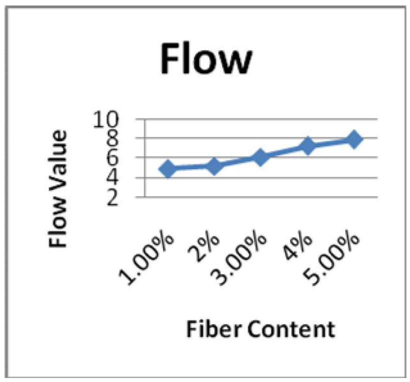

Figure 5.10- Variation of Flow Value with different Steel fiber Content

3) *Unit Weight:* It is observed that unit weight increases with increase binder content up to certain binder content; then decreases. Variation of unit weight value with different steel fiber content with different steel fiber is given fig.

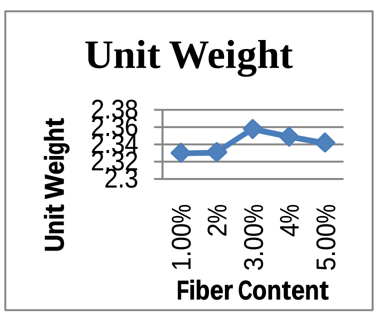

Figure 5.11- Variation of Unit Weight with different Steel fiber Content

4) *Air Void:* It is observed that with increase binder content air void decreases. Air void content with different steel fiber content should be lies between 3 to 6%. Hence the values of binder content at 4.5% of air void given below table.

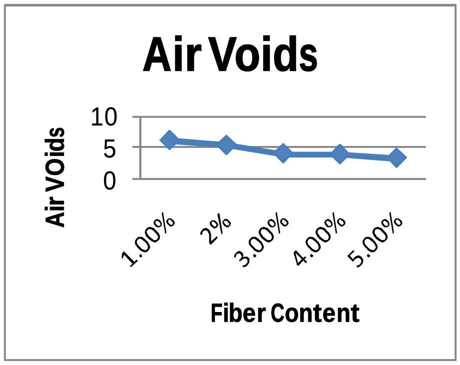

Figure 5.12- Variation of Air Voids with different Steel fiber Content

E. Detailed Comparison Between Standard Mix And Modified Bitumen Mix

TABLE 5.5 DETAILED COMPARISON BETWEEN STANDARD MIX AND MODIFIED BITUMEN MIX

PARTICULARS	Percentage of Optimum Binder Content (4.0%) BC	Percentage of Optimum Carbon Fiber Content (1.5%) CFC	Percentage of Optimum Steel fiber Content (3.0%) SFC
Stability (kg)	780	1280	1578
Flow Value (mm)	3.55	5.5	6.4
Unit Weight	1.95	2.354	2.358
Air Voids (%)	4.32	4.04	4.06

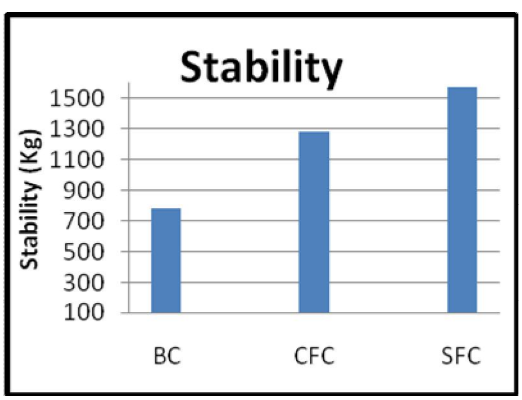

Figure 5.13 Comparison of Stability value Between Standard Mix and Fiber Modified Mix

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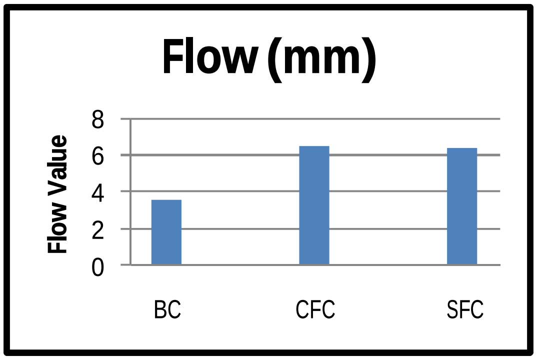

Figure 5.14 Comparison of Flow Value Between Standard Mix and Fiber Modified Mix

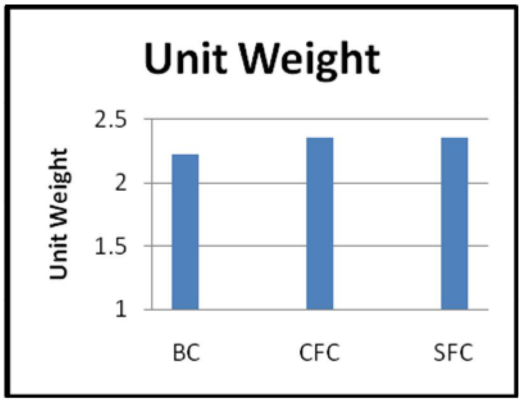

Figure 5.15 Comparison of Unit Weight Between Standard Mix and Fiber Modified Mix

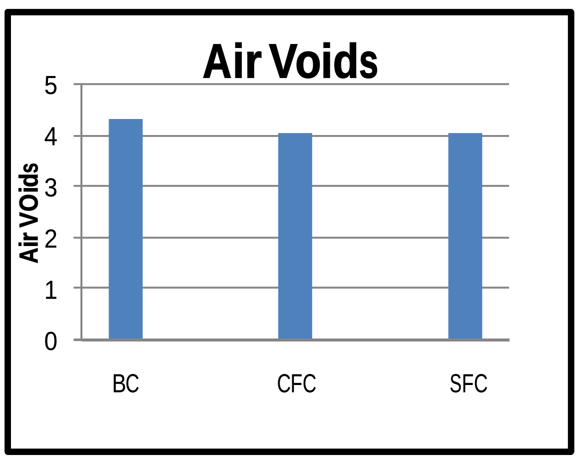

Figure 5.16 Comparison of Air Voids % Between Standard Mix and Fiber Modified Mix

VII. CONCLUSION

The primary purpose of this report was to develop information about the addition of carbon fibers in dry process in different percentages. This study was intended to provide information that would validate the recipes to use in DBM and provide data to indicate why these recipes are successful. This study looked at the effect of asphalt content and amount of fibers to it. The use of carbon fibers showed consistency of results in the current study. It was observed that the addition of fibers favorably affects the properties of bituminous mixtures by increasing its stability and voids and decreasing the flow value. As such, it can be said that carbon fibers has the potential to improve structural resistance to distress occurring in road pavement due to traffic loads. Compared to the control mixture, the fibers content of 1.5% by weight of total mix resulted in highest performance in terms of stability;

however, some mechanical properties of the same mix may be compromised when the fibers content exceeds 1.5% level. Since the length of the fibers is a critical factor affecting the performance of carbon fibers modified asphalt mixtures it must be ensured that individual fibers keep their linear configuration intact after the mixing process. To achieve these improvements, proper attention must be paid to ensure that the fibers are uniformly dispersed in the mixture.

A. Optimum Binder Content

Optimum Binder Content is found out by taking average value of following three bitumen Content found from above graph i.e.

I. Bitumen content correspond to maximum stability

II. Bitumen content correspond to maximum unit weight

III. Bitumen content associated to the limits of percentage air voids in mix the optimum binder content is taken as 4.5%.

B. Optimum Mineral Fiber Content

The value of carbon fiber content corresponding to 4.5% of binder, is designated as Optimum Carbon fiber Content and in the present case it is 1.50%. From the Marshall data of 4.5% bitumen content, it was observed that the stability and unit weight or bulk density of the mass observed to be the maximum.

C. Optimum Mineral Fiber Content

The values of steel fiber content corresponding to 4.5% of bitumen and Optimum Carbon fiber Content of 1.5% is designated. From the Marshall data of 4.5% bitumen content, and 1.5% carbon fiber content it was observed that the stability and unit weight or bulk density of the mass is obtained at the steel fiber percentage of 3.0%.

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