3rd Conference of Transportation Research Group of India (3rd CTRG)

A study on improvement in engineering properties of dense grade bituminous mixes with coal ash by using natural fiber

Saswat Biswapriya Dash[a] and Mahabir Panda[b]

[a]Ex-Post graduate student, Department of Civil Engineering, National Institute of Technology, Rourkela, 769008, India, E-mail: saswat.dash91@gmail.com
[b]Professor, Department of Civil Engineering, National Institute of Technology, Rourkela, 769008, Odisha, India, E-mail: panda.mahabir@gmail.com

Abstract. Coal-based thermal power plants have been a major source of power generation in India. The prime waste products of a coal thermal power plant are fly ash and bottom ash. Heavy dumping of these waste products causes fatal environment pollution to air, water, and land, besides impairing human health. This research work is done to explore the optimum use of ash, namely bottom ash (as fine aggregate) and fly ash (as mineral filler) along with natural fiber (such as sisal fiber) used to improvise the engineering properties of bituminous paving mixes. For national interest, these waste products that are available easily and abundantly can be used economically for bituminous paving applications which ultimately help in saving the natural aggregate resources of the nation.

In the present study, dense graded bituminous mix specimens were prepared using natural aggregates as coarse aggregates, bottom ash as fine aggregates, fly ash as filler and sisal fiber as additive. The grading of aggregates was chosen for dense graded bituminous macadam (DBM) mixes with nominal maximum aggregates size (NMAS) of 26.5 mm as per MORTH (2013). To strengthen the mix, slow setting emulsion (SS1) coated sisal fiber was added in varying percentages such as 0%, 0.25%, 0.5%, 0.75%, and 1% by weight of the mix, with different length variations such as 0 mm, 5 mm, 10 mm, 15 mm and 20 mm. At the initial stage of the research, specimens were prepared with two types of paving bitumen i.e. VG-30 and VG-10.The initial trials resulted better Marshall characteristics with VG-30 bitumen and hence was considered for subsequent studies. The most suitable composition (such as optimum bitumen content and optimum fiber content including the optimum length of fiber of the mix) was selected based on the results of the Marshal tests. Marshall stability as high as 15 kN was obtained with optimum bitumen content of 5.6% and optimum fiber content of 0.5% with optimum fiber length of 10 mm. Further, for justifying the performances of the paving mix, tests such as indirect tensile strength (ITS) test and moisture susceptibility test in form of retained stability test and tensile strength ratio (TSR) of bituminous mixes were also conducted. It was finally observed that the paving mixes formed with bottom ash as part of fine aggregate and fly ash as filler, stabilized with natural sisal fiber duly coated with SS-1 emulsion were not only satisfactory, but also yielded much improved engineering properties.

From the above it is observed that waste materials such as coal ash and locally available natural fiber such as sisal fiber can together be used in an appropriate way for bituminous paving mixes. Thus, this may not only help to find a new way of construction of bituminous pavement, but may also help evading the problems such as huge space required for dumping and environmental pollution.

Keywords: Fly ash, Bottom ash, Sisal fiber, Dense Graded Bituminous Mix (DBM), indirect tensile strength.

1. Introduction

For preparation of bituminous mixes, normally aggregates in form of coarse, fine and filler fractions are used. In many construction sites, aggregates in different size fractions are not easily available, necessitating their procurement from long distances thereby causing exorbitant increase in cost of construction. On the other hand, a number of coal based thermal power plants have been set up in several parts of the country. It is reported that around 120 million tons of ashes are produced per year from nearly forty major thermal power plants in India. Such a huge quantity of this type of waste material does pose challenging problems, in the form of land usage, health hazards and environmental dangers. Hence to suppress the wretched effects of these materials, a good number of studies have been made to utilize them in a productive way which will satisfy the needs of the society. This particular work is an attempt to utilize these waste materials to some extent by replacing the filler and some fractions of fine aggregates in bituminous paving mixes. In order to enhance the properties of the paving mixes, their modification with different types of fibers is also done. In order to offset the possible drawbacks of using the coal ashes, unlike conventional fibers, naturally, locally and abundantly available sisal fiber has been tried in possible development of sustainable bituminous paving mixes to improve the pavement performance. From the fiber point of view sisal fiber is one of the most widely used and locally available natural fiber. This is obtained from a plant with a botanical name *Agave sisalana*.

Ali et al. observed through an experimental study on the outcome of fly ash on the mechanical properties of bituminous mixtures, that fly ash as mineral filler can be used to increase resilient modulus characteristics and stripping resistance [1]. As per Churchill and Amirkhanian, partial substitution of fine aggregates by coal ash had a moderate detrimental effect on short-term tensile strengths. Results of a limited field study showed that 3 months after placement, metal concentrations in soils were not substantially altered [2]. Colonna et al. studied the feasibility of bottom ash for HMA mix used in the intermediate courses of flexible pavements. Their results show that the mixtures perform better when 15% of bottom ash was added to the mixture in replacement of correspond amount of sand [3]. Kar studied the effect of sisal fiber on SMA and BC mixtures and he concluded that the optimum bitumen contents for BC and SMA mixes were 5% and 5.2% respectively whereas optimum fiber content for each mix was 0.3% [11]. From the scanty literature available, it is observed that there is no study on utilization of bottom ash and fly ash together in the same bituminous mix and the use of a natural fiber in SMA and BC mixes. Hence, this was the main motivation of the present research work.

In the present study, dense graded bituminous mix specimens were prepared using natural aggregate as coarse aggregates, bottom ash as partial replacement of fine aggregates and fly ash as mineral filler with sisal fiber as a stabilizing additive. Design of the mixtures was done as per Marshall procedure. For characterization of the mixes, various tests such as indirect tensile strength (ITS) and moisture susceptibility test in terms of tensile strength ratio (TSR) and retained stability were taken up.

2. Objectives of Study

The prime objective of this study is to use waste materials such as bottom ash and fly ash along with some locally available natural or vegetative fibers in bituminous paving mixes. To achieve this objective, the optimum mix design conditions such as optimum fiber content, optimum fiber length and optimum bitumen content in addition to the appropriate replacement of bottom ash and fly ash are decided as per Marshall method of mix design. Further, the bituminous mixes thus developed have been evaluated in terms of the engineering properties.

3. Materials

3.1. Bitumen

Initially, two bitumen grades such as VG-30 and VG-10 (Viscosity Grade) were tried with certain assumed mix compositions and test conditions to study the Marshall characteristics of mixes. The initial trials showed better and satisfactory Marshall characteristics when mixes were made up with bottom ash, fly ash and emulsion coated fiber with VG-30 bitumen as binder. The physical characteristics of VG-30 bitumen used in this study are given in Table1.

Table 1 Physical properties of bitumen used

SL. No.	Physical Properties	IS Code / ASTM Code	Test Result
1	Penetration at 25^{o}C/ 100gm/ 5sec, 0.01mm	IS:1203-1978	46
2	Softening Point, ^{o}C	IS:1205-1978	46.5
3	Specific gravity, at 27^{o}C	IS:1203-1978	1.01
4	Absolute viscosity, Brookfield at 160^{o}C, cP	ASTM D 4402	200

3.2. Aggregate

For this study, stone chips comprising coarse aggregate fractions and fine aggregate fractions ranging from 26.5 mm to 0.3 mm were used. For lower fractions of fine aggregates and mineral filler, bottom ash and fly ash were respectively used to the extent of 9% and 5% by weight of total mix. Bottom ash procured from the nearby NSPCL thermal power plant and fly ash collected from the nearby Adhunik Metaliks Power plant were used in this study. The physical properties of natural aggregates and bottom ash are given in Table 2.

Table 2 Physical properties of natural aggregate and bottom ash used

SL. No.	Property	Code specification	Test Result	
			Natural aggregate	Bottom ash
1	Aggregate impact value, %	IS:2386 part-IV	14	-
2	Aggregate crushing value, %	IS:2386 part-IV	13.5	-
3	Los Angles abrasion value, %	IS:2386 part-IV	18	-
4	Soundness test result (5 cycles in sodium sulphate), %	IS:2386 part-V	3	8.2
5	Flakiness index, %	IS:2386 part-I	11.9	-
6	Elongation index, %	IS:2386 part-I	12.5	-
7	Water absorption, %	IS:2386 part-III	0.14	10.75
8	Specific gravity	IS:2386 part-III	2.7	2

3.3. Additives (Sisal Fiber)

The sisal fiber, a naturally and locally available product which is produced from a plant has been used as a stabilizing additive for improving the engineering properties of conventional DBM mixtures. In this experimental work, sisal fibers were coated with slow setting emulsion (SS-1) and stored at 110°C in hot air oven for 24 hours [4]. Emulsion coating was made considering the organic nature of the material. Sisal fiber is a cellulose fiber having soft yellowish color. The sisal fiber used in this study is shown in Figure 1. It is durable, anti-static and recyclable. The chemical composition and physical properties of sisal fiber are given in Table 3.

Figure 1 Sisal fiber used.

Figure 2 Sisal fiber plant (Agave sisalana).

Table 3 Chemical composition and physical properties of sisal fiber used.

Chemical composition [10]		
SL. No.	Composition	Test result
1	Cellulose, %	65
2	Hemicellulose, %	12
3	Lignin, %	9.9
4	Waxes, %	2
Physical property		
SL. No.	Property	Test result
1	Density, gm/cc	1.5
2	Tensile strength, MPa	511-635
3	Young's modulus, MPa	9.4-2.0
4	Elongation at break, %	2.0-2.5

4. Experimental Design

The DBM samples were prepared with aggregates as per gradation specified in MORTH (2013) [5] given in Table 4 and Figure3. The following tests were performed.

- *Marshall tests of mixes*
- *Static indirect tensile test*
- *Resistance to moisture damage in form of Tensile strength ratio (TSR) and Retained stability test*

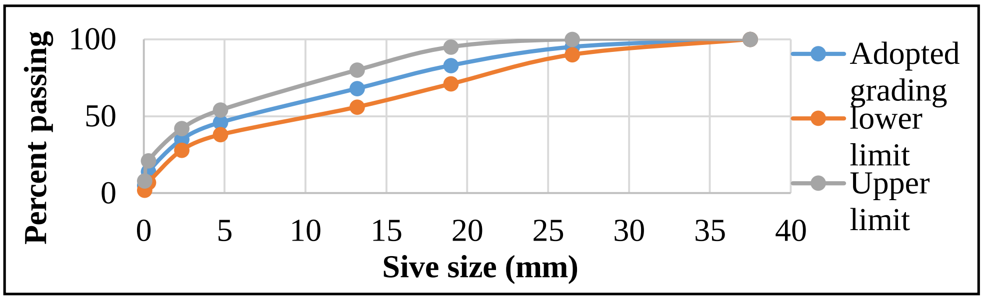

Figure 3 Aggregate gradation curve.

Table 4 Gradation of aggregate.

Sieve size (mm)	Adopted gradation (% Passing)	Specified limit (% Passing)	
37.5	100	100	Natural aggregate
26.5	95	90-100	Natural aggregate
19	83	71-95	Natural aggregate
13.2	68	56-80	Natural aggregate
4.75	46	38-54	Natural aggregate
2.36	35	28-42	Natural aggregate
0.3	14	7-21	Bottom ash
0.075	5	2-8	Fly ash

4.1. Design Mix

The DBM mixtures were prepared in accordance with the Marshall procedure specified in ASTM D6927-15 [8]. All ingredients of the mixture, such as coarse aggregates, fine aggregates, filler, sisal fibers and VG-30 bitumen were mixed in a specified procedure developed after several trials. Before preparing the samples, fibers were coated with SS-1 emulsion and stored in a hot air oven at 110^{o}C for 24 hours [4] as shown in Figure 4 (a and b) and Figure 5 respectively to drain away the excess emulsion after coating. Then the fibers were cut into specified lengths of about 5 mm, 10 mm, 15 mm and 20 mm as given in Figure 6. The aggregates and bitumen were heated separately and maintained at the mixing temperature of 150^{o}C to 160^{o}C. The temperature of the aggregates was maintained 10^{o}C higher than that of the binder. Required quantities of bitumen VG-30 and coated emulsion fiber pieces were added to the pre-heated aggregates and thoroughly mixed as shown in Figure 7 (a and b). The quantity of binder to be added was calculated from subtracting the coated emulsion fiber weight from design binder weight. Then thorough mixing was done manually till the colour and consistency of the mixture appeared to be uniform.

Figure 4 Coating of emulsion on fiber.

Figure 5 Oven dry coated fiber.

The mixing time and temperature was maintained, i.e. 2 to 5 minutes and 150^{o}C to 160^{o}C respectively. The mixture was then poured in to a pre-heated Marshall mould and compacted using Humboldt Automatic Marshall Compactor with 75 compaction blows on each side as shown in Figure 8.

Figure 6 Cutting of coated fiber.

Figure 7 Addition of bitumen and fiber followed by thorough mixing.

The Marshall samples were extracted from the mould after the specimens were brought to room temperature and thereafter tested in accordance with ASTM D6927-15 procedure [8] as shown in Figure 9 and 10.

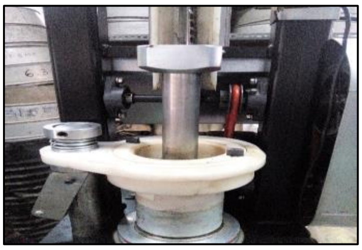

Figure 8 Compaction of a Marshall specimen in progress.

Figure 9 A view of DBM samples before Marshall testing.

Figure 10 Marshall test of a DBM sample in progress.

4.2. Static Indirect Tensile Test

Static indirect tensile strength (ITS) test of bituminous mixes was performed in accordance with ASTM D 6931-12 [7] to assess the resistance to thermal cracking. In this test, Marshall specimens were prepared at optimum composition and loaded in vertical diametrical plane as shown in Figure 11 (a, b, c and d). The test temperature was varied from 5^{o}C to 40^{o}C at an increment of 5^{o}C. The tensile strength values of three mix samples were calculated from Equation 1 and then the average of results of three samples was reported. The effects of temperature on the ITS of mixes with and without fiber were also studied.

Figure 11 Loading of a specimen during ITS test and different views of specimens after ITS test.

$$St = \frac{2000 \times P}{\pi \times D \times T} \quad \ldots (1)$$

Where S_t= Indirect Tensile strength, MPa
P = Maximum Load, kN

T = Specimen height before testing, mm
D = Specimen Diameter, mm

4.3. Resistance to Moisture Induced Damage

The resistance to moisture susceptibility of bitumen mixes was measured in terms of tensile strength ratio (TSR) and retained stability value.

4.3.1 Tensile strength ratio (TSR)

In this test, conducted in accordance with the ASTM D4867/D4867M–09 [6], the specimens of 100 mm diameter and 62.5 mm height were prepared in gyratory compactor with 7% air voids as shown in Figure 12. Six samples of equal average air voids were prepared and divided into two subsets. Samples of one subset were conditioned in water at 60$^{\pm}$1°C for 24 hours followed by soaking in water bath at 25$^{\pm}$1°C for 1 hour prior to testing and the other set were cured in water bath for 20 minutes at 25$^{\pm}$1°C. The ITS test was performed at 25$^{\pm}$1.0°C temperature as shown in Figure 13 for samples of each set. Figure 14 gives a view of some failed specimens with tensile cracks.

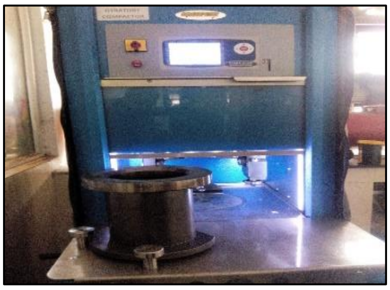

Figure 12 A Sample under preparation in a gyratory compactor.

Figure 13 Moisture susceptibility test in progress.

Figure 14 View of cracks in DBM sample after failure.

The tensile strength ratio of each sample was calculated from Equation 2 and the average of results of three samples was reported.

$$\text{Tensile strength ratio (TSR), \%} = \frac{S_{tm}}{S_{td}} \times 100 \qquad \ldots (2)$$

Where S_{tm} = average tensile strength of the moisture-conditioned subset, kPa
S_{td} = average tensile strength of the dry subset, kPa.

4.3.2 Retained stability test

The loss of stability in bituminous mixes due to penetration of moisture was measured in the form of Retained stability test. This test was conducted in accordance with the STP 204-22 procedure [9]. In this test, six Marshall specimens were prepared with 4% air voids and were divided into two sets. Samples of one set were conditioned with water at 60$^{\pm}$1^{o}C for half an hour (unconditioned) and the other set for 24 hours (conditioned). Following the conditioning, each sample was tested for Marshall stability value. The retained stability of each sample was calculated from Equation 3 and the average of three samples of each set was reported.

$$\text{Retained stability, \%} = \frac{S_2}{S_1} \times 100 \qquad \dots (3)$$

Where S_1= Unconditioned Marshall stability, kN

S_2= Conditioned Marshall stability, kN

5. Results and Discussion

5.1. Mixture Design

From the results of the Marshall tests as presented in Figure 15 through 26, it is observed that with increase in fiber content and fiber length, optimum binder content is increased. The mixtures are more consistent and offer higher stability values with other satisfactory Marshall characteristics when fiber length varies from 5 mm to 20 mm. With increase in fiber content beyond 0.5% and fiber length beyond 10 mm in the mixture, the stability decreases. This is corroborated from the experimental observation that during the mixing process, beyond the said fiber conditions, the mixture does not become homogenous enough to result in an appropriate mix.

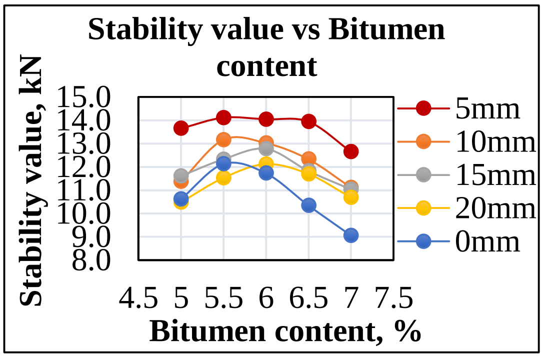

Figure 15 Stability value vs Bitumen content (0.25% fiber).

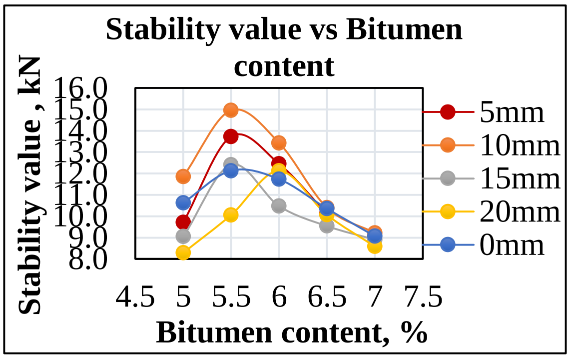

Figure 16 Stability value vs Bitumen content (0.5% fiber).

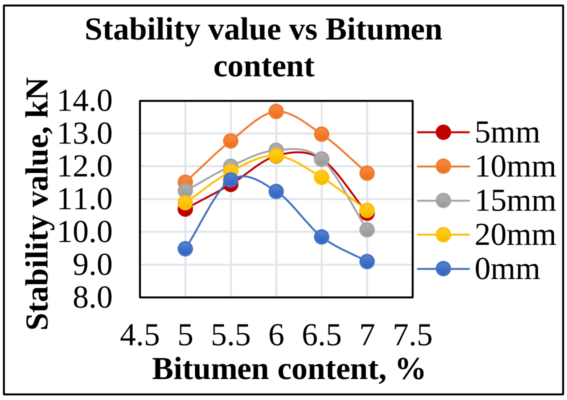

Figure 17 Stability value vs Bitumen content (0.75% fiber).

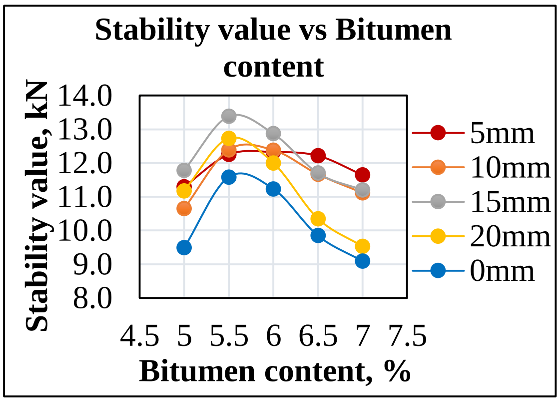

Figure 18 Stability value vs Bitumen content (1% fiber).

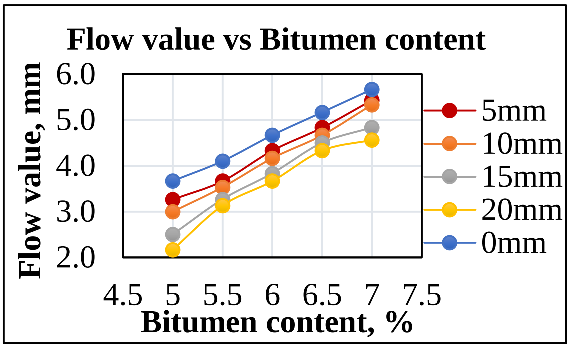

Figure 19 Flow value vs Bitumen content (0.25% fiber).

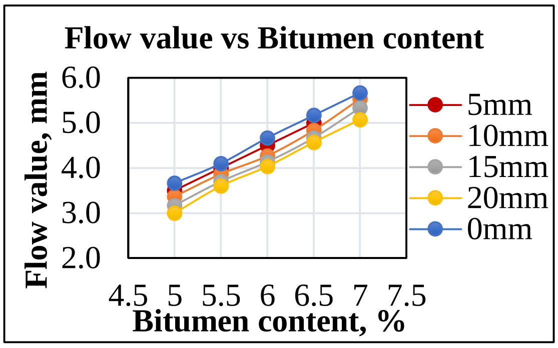

Figure 20 Flow value vs Bitumen content (0.5% fiber).

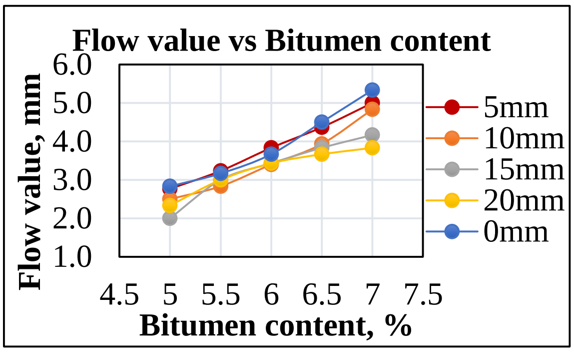

Figure 21 Flow value vs Bitumen content (0.75% fiber).

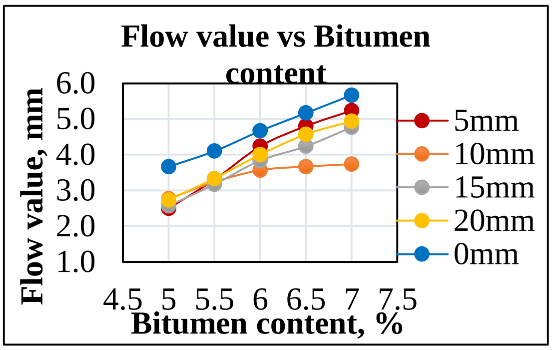

Figure 22 Flow value vs Bitumen content (1% fiber).

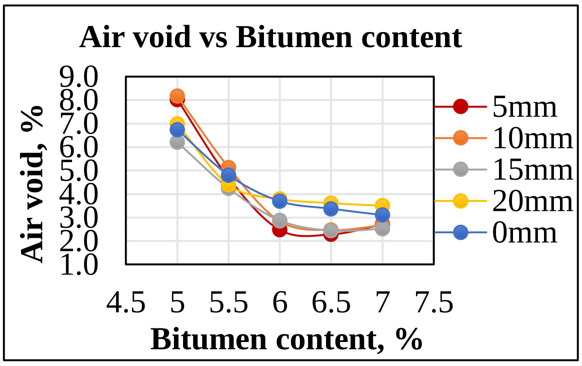

Figure 23 Air void vs Bitumen content (0.25% fiber).

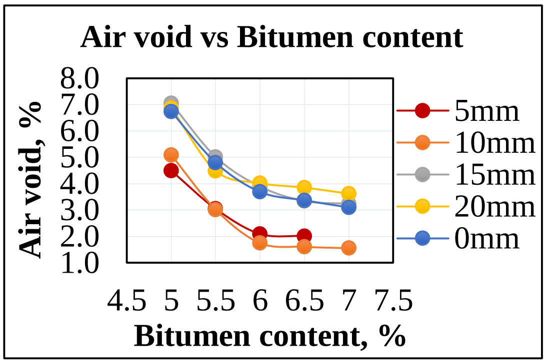

Figure 24 Air void vs Bitumen content (0.5% fiber).

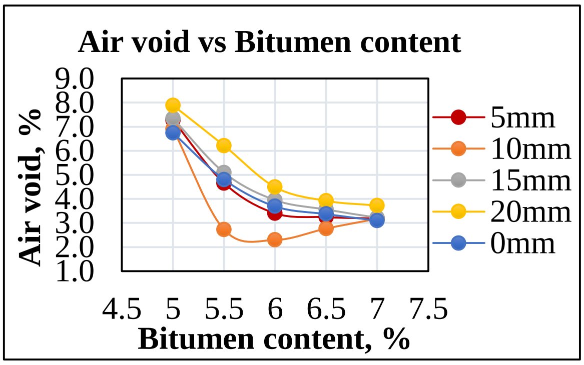

Figure 25 Air void vs Bitumen content (0.75% fiber).

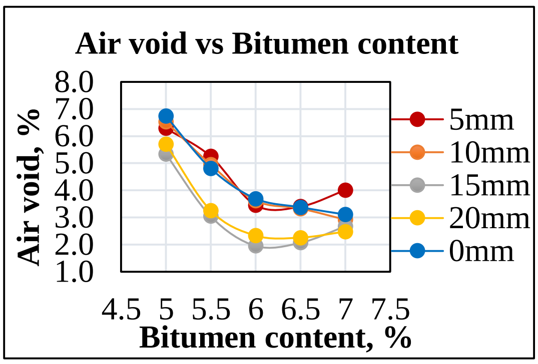

Figure 26 Air void vs Bitumen content (1% fiber).

From the Marshall stability and other characteristics reported above, it is found that the optimum bitumen content of 5.57% with optimum fiber content of 0.5% by weight of mixture along with fiber length of 10 mm, offers maximum stability value of 15 kN satisfying other Marshall criteria. The bitumen requirement is generally observed to be higher as the fine aggregates (partly) and filler comprise of coal based bottom ash and fly ash in addition to the use of fibers in the paving mixes.

The summary of results of other Marshall tests not presented above is given in Table 5. Increase of Marshall quotient up to fiber content of 0.5% indirectly indicates higher resistance to permanent deformation characteristics of bituminous mixes.

Table 5 Marshall test results.

SL. No.	Item/ Property	Test Results				
	Fiber content, %	0	0.25	0.5	0.75	1
	Fiber length, mm	0	5	10	15	20
1	Bulk specific gravity, kN/m^3	23.3	22.8	23.0	23.0	22.8
2	Marshall Quotient, kN/mm	3.62	3.55	4.29	4.29	4.19
3	Voids in mineral aggregate (VMA), %	15.30	16.70	15.80	15.90	16.10

5.2. Static Indirect Tensile Test

The variations of indirect tensile strength with temperature in respect of DBM mixes with or without coal ash and fiber are shown in Figure 27. As usual, the indirect tensile strength of any bituminous mix decreases with increase in temperature. But with addition of coal ash along with emulsion coated fiber, the indirect tensile strength of DBM sample at any test temperature is higher compared to an un-modified mix. This may be possible due to the criss-cross pattern of fibers present in various parts of the mixture resulting in higher strength in tension. It is also observed that the coal ash contributes to a marginal increase in the tensile strength compared to an un-modified conventional mix, which is an advantage. This may be due to the higher bitumen content in the mix with coal ash.

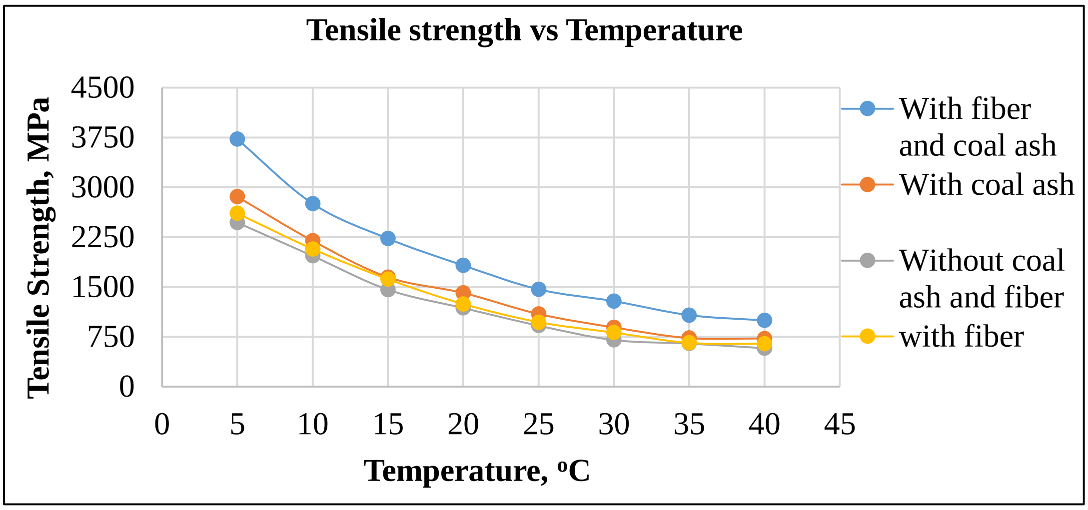

Figure 27 Relationship between Indirect Tensile strength and Temperature.

5.3. Resistance to Moisture Damage

5.3.1. Tensile strength ratio (TSR)

The results of tensile strength ratio (TSR) with respect to different types of mixes considered are presented in Table 6. It is observed that with addition of both fiber and coal ash together, resistance to moisture induced damages improves marginally as compared to the conventional DBM mixture. However, the un-modified mixes satisfy the minimum TSR requirements.

Table 6 TSR of mixes with and without fiber and coal ash.

Tensile strength ratio			Remarks
Type of mixes	DBM With coal ash	DBM Without coal ash	Minimum 80% (as per MORTH specification)
DBM With fiber	84.77%	82.04%	
DBM Without fiber	82.35%	80.26%	

5.3.2. Retained stability test

The results of retained stability values for un-modified and various modified mixes are presented in Table 7. It is observed that the mix containing both emulsion coated fiber and coal ash results higher retained stability values as compared to the un-modified mix. But the sample prepared only with coal ash and conventional aggregate has shown less resistance to moisture and hence given reduced stability than design requirement.

Table 7 Retained stability of mixes with and without fiber and coal ash.

Retained stability (%)			Remarks
Type of mixes	DBM With coal ash	DBM Without coal ash	Minimum 75% (as per MORTH specification)
DBM With fiber	84.05	79.94	
DBM Without fiber	73.21	77.03	

6. Conclusions

Based on the results of a laboratory study the following conclusions are drawn.

1. From the results of the Marshall tests, it is observed that the DBM mixes prepared with bottom ash and fly ash used respectively in 300-75 micron sizes and passing 75 micron resulted best mixes satisfying the Marshall criteria when bitumen content, fiber content and fiber length were 5.6%, 0.5% and 10mm respectively. A higher value of bitumen content is observed in contrast to the normal requirement of 4.5% for DBM mix; this is due to the increase in fiber content and fiber length and also due to the use of coal ash in aggregate mixture in the present work.

2. It is also observed that with increase in fiber content and fiber length upto a given level, air-void and flow value decreases whereas Marshall quotient increases. The latter is a good indication of rutting resistance of bituminous paving mixes in case of the recommended mix composition.

3. From the indirect tensile strength test it is observed that the indirect tensile strength of sample increases due to the addition of emulsion coated fiber and coal ash which gives an excellent engineering property for DBM samples to endure thermal cracking.

4. It is further observed the use of either emulsion coated fiber or coal ash or both in DBM mix, increases the resistance to moisture induced damages as determined in terms of the tensile strength ratio and retained stability value.

Acknowledgments:

The authors record appreciation of sincere cooperation provided by the staff and PG & research students of the Transportation Engineering section of NIT Rourkela for conduct of this research work.

The authors acknowledge the opportunity to present the research work that forms the basis of this article at the 3rd Conference of the Transportation Research Group of India (TRG) held at Kolkata (India) during 17-20 December, 2015.

7. References

1. Ali N, Chan JS, Simms S, Bushman R and Bergan AT (1996) Mechanistic evaluation of fly ash asphalt concrete mixtures. Journal of Materials in Civil Engineering, ASCE, Vol. 8, No. 1, pp.19-25. ISSN 0899-1561196/0001-0019-0025.
2. Churchill EV and Amirkhanian SN (1999) Coal ash utilization in asphalt concrete mixtures. Journal of Materials in Civil Engineering. ASCE, Vol. 11, No. 4, pp.295-301.
3. Colonna P, Berloco N, Ranieri V and Shuler ST (2012) Application of bottom ash for pavement binder course. Elsevier Procedia-Social and Behavioral Sciences, 53, pp.961-971. doi: 10.1016/j.sbspro.2012.09.945
4. Lei X, He X, Guan P and Deng P (2010) Effect of sisal fiber on anti-slide performance for asphalt pavement surface. Seventh International Conference on Traffic and Transportation Studies, pp. 1310-1319. doi: 10.1061/41123(383)125
5. MORTH, Ministry of Road Transport and Highways, Specification for Road and Bridge Works, 5th Edition, 2013.
6. Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures, D4867/D4867M−09
7. Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures1 ASTMD 6931 – 12.
8. Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures, ASTM D6927 – 15.
9. Standard Test Procedures Manual for Retained Marshall Stability, STP 204-22, Saskatchewan Highways and Transportation.
10. http://textilelearner.blogspot.in/2013/01/sisal-fiber-properties-of-sisal-fiber.html, last accessed April 08, 2015
11. Kar D (2012) A laboratory study of bituminous mixes using a natural fiber. Dissertation, Department of Civil Engineering, NIT Rourkela.