JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# A STUDY ON THE ENHANCEMENT OF ENGINEERING PROPERTIES OF DENSE GRADE BITUMINOUS MIXES WITH COAL ASH VIA NATURAL FIBRE INCORPORATION

**Vibha Gajendra** [1] **Akhand Pratap Singh** [2]

**M.Tech Scholar, Assistant Professor**

Department of Civil Engineering Shri Rawatpura Sarkar University, Raipur

**Abstract**

Coal-based thermal power plants have been a significant source of power generation in India, resulting in the generation of vast amounts of waste products, namely fly ash and bottom ash. Improper disposal of these waste materials leads to severe environmental pollution and adverse effects on human health. This research focuses on utilizing bottom ash as fine aggregate and and fly ash as a mineral filler, along with the incorporation of natural fiber (such as sisal fiber), to enhance the engineering properties of bituminous paving mixes. The aim is to economically utilize these readily available waste products of bituminous pavement construction, thereby conversing the nation's natural aggregate resources.

In this study, dense graded bituminous mix specimens were prepared using natural aggregate as coarse aggregates, bottom ash as fine aggregate, fly ash as filler, and sisal fiber as an additive. The proportions of aggregate followed the specifications of the Ministry of Rod Transport and Highways (MORTH, 2013) for dense graded bituminous macadam (DBM) grading, with a nominal maximum aggregate size (NMAS) of 26.5 mm. To improve the mix, slow-setting emulsion (SS1) coated sisal fibers were added at varying percentages (0%, 0.25%, 0.5%, 0.75%, and 1 % by weight of the mix) and different fiber lengths (5mm, 10mm, 15mm, and 20mm). Initial trials using two types of paving bitumen (VG30 and VG10) revealed better Marshall Characteristics with VG30 bitumen, which was consequently selected for further investigation. The Marshall Test results were analyzed to determine the optimal binder content, fiber content, and fiber length. An optimal bitumen content of 5.57%, fiber content of 0.5% and fiber length of 10 mm yielded Marshall Stability of 15 kN. Additionally, various performance tests such as moisture susceptibility, indirect tensile strength (ITS), creep, and tensile strength ratio were conducted to evaluate the pavement's performance. The findings indicated satisfactory and significantly improved engineering properties when coal ash was used as fine aggregate and filler, stabilized with natural sisal fiber coated with SS-1 emulsion.

The utilization of non-conventional aggregates like coal ash and natural fiber together opens up new possibilities for bituminous pavement construction. This approach provides an economical solution for the disposal of coal ash, addressing concerns related to environmental pollution, while also reducing the consumption of natural sand and stone dust.

**Keywords**: ***Bottom ash, Fly ash, Sisal fiber, Emulsion, Indirect tensile strength, Static creep test, Tensile strength ratio.***

## 1. Introduction

### 1.1 Background of the Study

Pavements or highways or roads are regarded as country's backbone, upon which its upswing andprogress depend on. All countries normally have a series of programs for building a new road infrastructures or emerging the existing one. Construction of both flexible and rigid pavement include a gross amount of investment to reach better performance oriented and smooth quality of pavement that will endure for long time. In India, where highways are considered as the primary function of transportation, Government of India has been investing a huge amount of money for developing the pavement construction and maintenance. A detailed engineering study may retain significant amount of investment and pavement materials, which in turn achieve a reliable performance of the in-service highway. Regarding flexible pavement, two major facts are taken into considerations i.e. pavement design and mix design. The present research study is focused on engineering property of bituminous mixes prepared from alternate or nonconventional materials.

### 1.2 Bituminous Mix Design

#### 1.2.1 Overview on Bituminous Mix Design

From the review of Das et al. (2004); it is known that the bituminous paving technique was first introduced on rural roads during 1900's. The formal mix design method was first made possible by Habbard field method, which was originally developed for the sand-bituminous mixture. But one of the focal limitations of this technique was its incompatible of handling large aggregates. Later on, a project engineer Francis Hveem of California Department of Highways, developed an instrument called Hveem stabilometer to calculate the possible stability of the mixture. At the earlystage, Hveem did not have any experience to estimate the amount of optimum bitumen that will just be right for mix design. He adopted the surface area calculation concept used for cement concrete mix design, to assess the quantity of bitumen vital for the mixture. On the other hand,
Bruce Marshall developed equipment to test stability as well as deflection of the bituminous mixture. It was adopted by the US Army Corpse of Engineers in 1930's and successively adaptedin 1940's and 50's.

### 1.3 Problem Statement

For preparation of bituminous mixes, commonly aggregates, inform of coarse, fine and filler fractions are used. In many locations, the aggregates in different size fractions are not easily available, use of which needs procurement from long distances and hence increases the cost exorbitantly. On the other hand, a number of coal-based thermal power plants have been set up tosomewhat cater to the power supply requirement. It is reported that around 120 Million Tons of ashes are producing from forty major thermal power plants per year in India. Most of the coal ash has likely to dispose of either dry or wet to open areas, which are available near the factory or by grounding into artificial lagoon or dumping yards. Such a vast quantity of this type of waste material does pose challenging problems, in the form of land usage, health hazards, and environmental dangers. Both in disposal as well as in utilization, utmost care has to be taken to safeguard the interest of human life, wildlife and environment. Hence to suppress the wretched effect of these materials, a detailed study is necessary to utilize them in a productive way that willsatisfy the society need.

### 1.4 Objectives of Research

This experimental study has done to enable the most appropriate use of coal ash as nonconventional aggregate along with natural fiber (Sisal fiber) as an additive by ensuring the adequate performance result in the field of fatigue, moisture susceptibility, and creep value. Againthe possible effects of fiber on bitumen mixes are also taken into consideration, and comprehensive study was done to find the optimum fiber content and fiber length that will increase the engineeringproperty of bituminous mix.

### 1.5 Scope of the Study

- The significant scope of this study is to use coal ash as a fine material in HMA mix designand thus producing a good quality and smooth surface road which may be commercially acclaimed and can with stand in any possible environment condition.
- Again Utilization of non-conventional materials like coal ash and natural fibers together thus may help to find a new way of bituminous pavement construction. The coal ash dumping which is a serious concern to everyone in respect of its disposal and environmental pollution, can find one way for its reuse in an economical way by substituting natural resources of sand and stone dust.

## 3. Raw Materials

### 3.1 Mixture Constituent

A bituminous mix is made from aggregate, graded from maximum fraction to smaller fraction (usually less than 25mm IS sieve to the mineral filler, smaller than 0.075mm IS sieve), which are blended with bitumen binder to form a consistent mixture. This mixture is then laid and compacted to achieve an elastic body which is seamlessly impervious and hard. The study of mix design is toattain the suitable proportion of aggregate, bitumen and other additives if added.

#### 3.1.1 Aggregates

Aggregates play an important part in bituminous mix. Maximum aggregate by weight of mixture is added to take the maximum load bearing & adding strength characteristics to the mixture. Hence, the physical properties and quality of the aggregates are considerably important to pavement. There are three types of mineral aggregates used in bituminous mixes, which are given below.

**Coarse Aggregates**

Aggregates which are retained on 4.75 mm IS sieve are called as coarse aggregates. A good qualitycoarse aggregate should have physical characteristic like hardness, angular in shape, toughness, durability, free from dust particles, clay, vegetation and organic matters. Aggregate with these above physical properties offers quite good compressive strength and shear strength and shows good interlocking characteristic.

**Fine Aggregates**

Aggregates size ranging from 4.75 mm to 0.075 mm IS sieves are called Fine aggregates. As with course aggregate, Fine aggregate should be free from dusts, clay, vegetation, loam or organic matter. Fine aggregate fills the voids between the coarse aggregate and stiffens the binder.

**Mineral Filler**

Aggregates those are smaller than 0.075 mm IS sieve is called as mineral filler. Filler are used to fills the voids in mix, which cannot be filled by fine aggregates. And also used to increase the binding property between the aggregates in the preparation of specimens.

### 3.1.2 Bitumen

Bitumen is essential in bituminous mix because of its visco-elastic and adhesive property. It bindsthe aggregate and fills the small voids which offer impermeability in mixture. At low temperatureit acts like an elastic body and at high temperatures it behaves like a viscous liquid [22].

### 3.1.3 Additives

Additives are used in the mixture to provide better strength characteristic and engineering property. Now a day's different additives such as fibers, polyethylene, minerals, polyester etc. are added either to stabilize or to improve performance property of the pavement.

### 3.1.4 Bitumen Emulsion

A bitumen emulsion is two phase system in which a significant amount of finely divided bitumen is suspended over an aqueous medium and stabilized by one or more suitable material. When the bitumen emulsion is applied on aggregate, it breaks down and starts binding the aggregate. The firstsign of break down occur when the color of bitumen emulsion film change from chocolate brownto black. Bituminous emulsions are especially used in patch and maintenance work [22]. Three types of emulsion are there i.e. (i) Rapid setting (RS), (ii) Medium setting (MS), and (iii) Slow setting (SS)

## 3.2 Materials Used in Study

In this study following materials are taken in to consideration to prepare the bituminous mix.

- Stone chips (as coarse aggregate)
- Bottom ash (as fine aggregate)
- Fly ash (as mineral filler)
- VG-30 (as bitumen binder)
- Sisal fiber (as additives)
- SS-1 emulsion (as fiber coating agent)

### 3.2.1 Aggregate

Coarse aggregates comprised of stone chips were procured from a nearby crusher and were stored by sieving in to different sizes. For this study, stone chips comprising coarse aggregate fractions and upper size fractions of fine aggregates ranged from 26.5 mm to 0.3 mm were used as shown in Figure 3.3. For lower fractions of fine aggregates and mineral filler, bottom ash and fly ash wererespectively used to the extent of 9% and 5% by weight of total mix. Bottom ash was procured from the nearby NSPCL thermal power plant (shown in Figure 3.2), while fly ash was collected from the nearby Adhunik Metaliks Power plant (shown in Figure 3.1). The physical properties ofcoarse aggregates and fine aggregates which are primarily required for paving are given in Table3.1.

*Figure 3.1 Fly Ash*

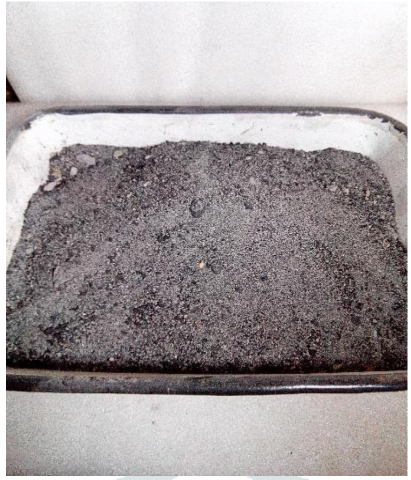


*Figure 3.2 Bottom Ash*

*Figure 3.3 Stone Chips*

## 4 Expérimental Work

The adopted gradation for DBM sample has been considered as specified in MORTH (2013) and is given in Table-4.1. Throughout the experimental study the aggregate gradation given in Table 4 was followed, and the following tests were performed. The aggregate gradation curve is shown infigure.4.1.

| Sieve Size(mm) | Adopted Gradation (% Passing) | Specified Limit (as per MORTH, 2013) (% Passing) |
|---|---|---|
| 37.5 | 100 | 100 |
| 26.5 | 95 | 90-100 |
| 19 | 83 | 71-95 |
| 13.2 | 68 | 56-80 |
| 4.75 | 46 | 38-54 |
| 2.36 | 35 | 28-42 |
| 0.3 | 14 | 7-21 |
| 0.075 | 5 | 2-8 |

**Natural Aggregate**

Bottom ash

Fly ash

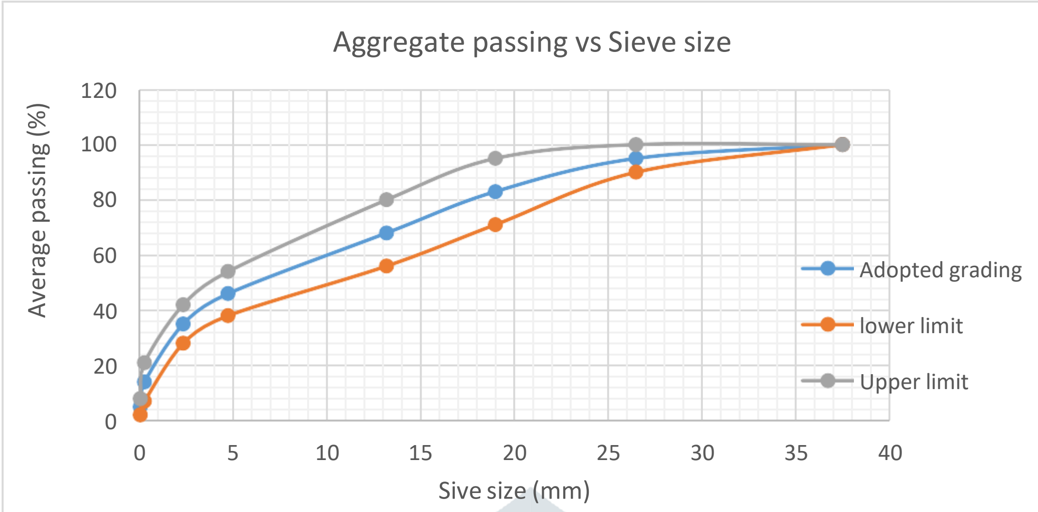



***Figure 4.1 Aggregate Gradation Curve.***

After adopting the above aggregate gradation the subsequent test were made to ensure the performance characteristics.

- Marshall test of mixes to evaluate volumetric analysis
- Static indirect tensile test
- Resistance to moisture damage (Tensile strength ratio)
- Retained stability test
- Static creep test

**4.2. Design Mix**

The DBM mixtures were prepared in accordance with the Marshall procedure specified in ASTMD6927-2015. All ingredients of mixture, such as coarse aggregates, fine aggregates, filler, fiber and VG-30 bitumen were mixed in a specified procedure. Before preparing the samples, fibers were coated with SS-1 emulsion and stored in a hot air oven at 110$^0$C as shown in Figure 4.3. Coated fiber are stored for 24 hours to ensure proper coating around each fiber and to drain downextra bitumen that may adhere to fiber, as shown in Figure 4.3 [26 and 27]. Then the fibers were cut into specified lengths of about 5mm, 10mm, 15mm and 20mm as given in figure 4.4. The aggregates and bitumen were heated separately to the mixing temperature of 155$^0$C to 160$^0$C. Thetemperature of the aggregates was maintained 10$^0$C higher than that of the binder. Required quantities of bitumen VG-30 and coated emulsion fiber pieces were added to the pre-heatedaggregates and thoroughly mixed as shown in Figure 4.5.

*Figure 4.2 Coating of Emulsion On Fiber.*

*Figure 4.3 Oven Dry Coated Fiber.*

*Figure 4.4 Cutting Of Coated Fiber.*

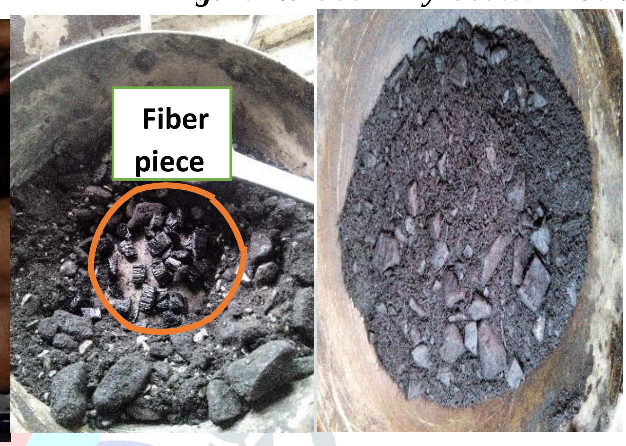



*Figure 4.5 Addition And Mixing Of Fiber*

(a) (b) (c) (d)

***Figure 4.6***
***(a) Pouring of Mixture In Mould, (B) Compaction of Mixture In Progress, (C) DBM Samples, (D) Marshall Test in Progress***

The quantity of binder to be added was calculated from subtracting the weight of emulsion coatedfiber from weight of design binder. Proper mixing was done manually till the colour andconsistency of the mixture appeared to be uniform. The mixing time and temperature was maintained within 2-5 minutes and $150^0$C-$160^0$C respectively. The mixture was then poured in toa pre-heated Marshall mould and compacted using Humboldt Automatic Marshall Compact with75 compaction blows on each side. The specimens were kept 24 hours for cooling to a temperatureof

$25^{\pm}1^{0}C$ (as shown in Figure 4.6 (a), (b), (c) respectively).

In this experiment, the resistance to deformation of a Marshall cylindrical specimen of DBM mixture is measured. The specimen is loaded diametrically at a deformation rate of 50 mm/min asshown in Figure 4.6(d). Here are two major features of the Marshall method of mix design are given below.

1. Stability and flow values
2. Voids analysis.

The Marshall stability for bituminous mix is defined as the maximum resistance carried by specimen at a standard temperature of 60°C. The flow value is recorded when the specimen deformed under maximum. The Marshall Voids analysis was done before the Marshall Stability test. In this voids analysis bulk specific gravity ($G_{mb}$), air voids (VA), voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and Marshall Quotient were determined, that are discussin next chapter.

## 4.3 Static Indirect Tensile Test

Static indirect tensile test of bituminous mixes was performed in accordance to ASTM D 6931 (2007) to assess the resistance to thermal cracking for a Marshall cylindrical specimen that is loaded in vertical diametrical plane as shown in figure 4.7. This tests were carried out on DBM specimen which were prepared at their optimum binder content, optimum fiber content and optimum fiber length as calculated from Marshall properties analysis. The effect of temperature onthe Indirect Tensile Strength (ITS) of mixes with and without fiber was also studied. The load at which tensile crack were develop in the specimen were noted down from the dial gauge of the proving ring and was calculated.

*Figure 4.7 Loading And Failure Pattern of Indirect Tensile Strength Test.*

### 4.4 Resistance to Moisture Damage (Tensile Strength Ratio (TSR)

The resistance to moisture susceptibility of bitumen mixes was measured by tensile strength ratio.The test is similar to Static Indirect Tensile test only the specimen were prepared in gyratory compactor with 7% air void and 150 mm diameter to 62.5 mm height specimen dimension as shown in figure 4.8. Six sample of equal avg. air void was prepared and divided into two subset. One subset was partially saturate to be moisture conditioned with distilled water at room temperature using a vacuum chamber by applying a partial vacuum of 70 kPa or 525 mm Hg (20 in. Hg) for a short time such as five min. after that the partially saturated samples are cured to be moisture conditioned in distilled water at 60±1.0°C for 24 hour.

## 5 Analysis of Results and Discussion

### 5.1 Introductions

This chapter deals with results analysis and discussion for test that are carried out for DBM sample in previous chapter. This chapter is divided into three sections. In first section the parameter and the equation used for Marshall Property's analysis are given below. Second section deals with calculation and comparison of optimum binder content, optimum fiber content and optimum fiberlength of DBM mixes with and without coal ash used as fine aggregate and filler. Third section deals with analysis made from the experiment such done in previous chapter static indirect tensile, static creep test at $40^0$C, moisture susceptibility test (Tensile strength ratio), and retained stabilitytest.

### 5.2 Parameters Used in the Study

All the Marshall propeties properties were calculated as per Das A. and Chakraborty P. (2010). The concern equation and other formulae used in calculations are given below.

### 5.3 Effect of Coal Ash (Bottom Ash and Fly Ash) On DBM Mix

At the initial stage of experiment bottom ash and fly ash was used as fine replacement in DBM mix. In this experiment the total coal ash content is taken as 35% by weight of the total mix, fromwhich the percentage of fly ash as mineral filler is fixed, i.e. 5% of weight of the mix. The bottomash content is varied according to the DBM gradation specified in MORTH (2013), which is givenin chapter 4.

#### 5.3.1 Marshall Stability

It is seen from the figure 5.1 that using of coal ash in DBM mix is not satisfactory with respect to stability value, when compared with conventional mix. The maximum stability value of 11.83 kN was achieved when 14% of coal ash by weight of the mix was mixed for preparing DBM samples.

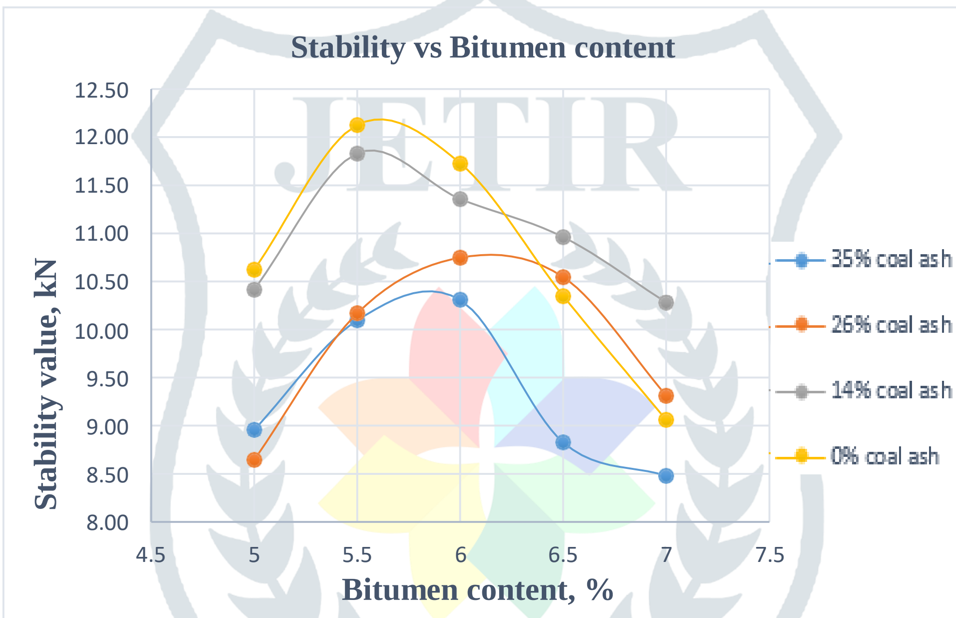



*Figure 5.1 Variation of Stability Value with Bitumen Content at Different Coal Ash Content*

*Table 5.1 Marshall Properties Analysis*

| Fiber Content,% | Fiber Length, mm | OBC, % | Optimum Stability, kN | Flow Value, mm | VA, % | VMA, % | VFB, % | Gmb |
|---|---|---|---|---|---|---|---|---|
| 0.25 | 0 | 5.60 | 11.40 | 3.15 | 2.40 | 15.30 | 84.00 | 2.33 |
| | 5 | 5.70 | 14.20 | 4.00 | 3.60 | 16.70 | 79.00 | 2.28 |
| | 10 | 5.78 | 13.20 | 3.50 | 3.60 | 17.00 | 76.00 | 2.28 |
| | 15 | 5.87 | 12.80 | 3.80 | 3.10 | 16.60 | 80.00 | 2.27 |
| | 20 | 5.73 | 11.90 | 3.80 | 4.00 | 17.00 | 77.00 | 2.27 |
| Fiber Content, % | Fiber Length, mm | OBC, % | Optimum Stability, kN | Flow Value, mm | VA, % | VMA, % | VFB, % | Gmb |
| 0.5 | 0 | 5.60 | 11.40 | 3.15 | 2.40 | 15.30 | 84.00 | 2.33 |
| | 5 | 5.57 | 13.80 | 3.85 | 2.90 | 17.10 | 75.00 | 2.26 |
| | 10 | 5.60 | 15.00 | 3.50 | 2.80 | 15.80 | 82.00 | 2.30 |
| | 15 | 5.80 | 11.50 | 3.60 | 4.30 | 17.60 | 76.00 | 2.25 |

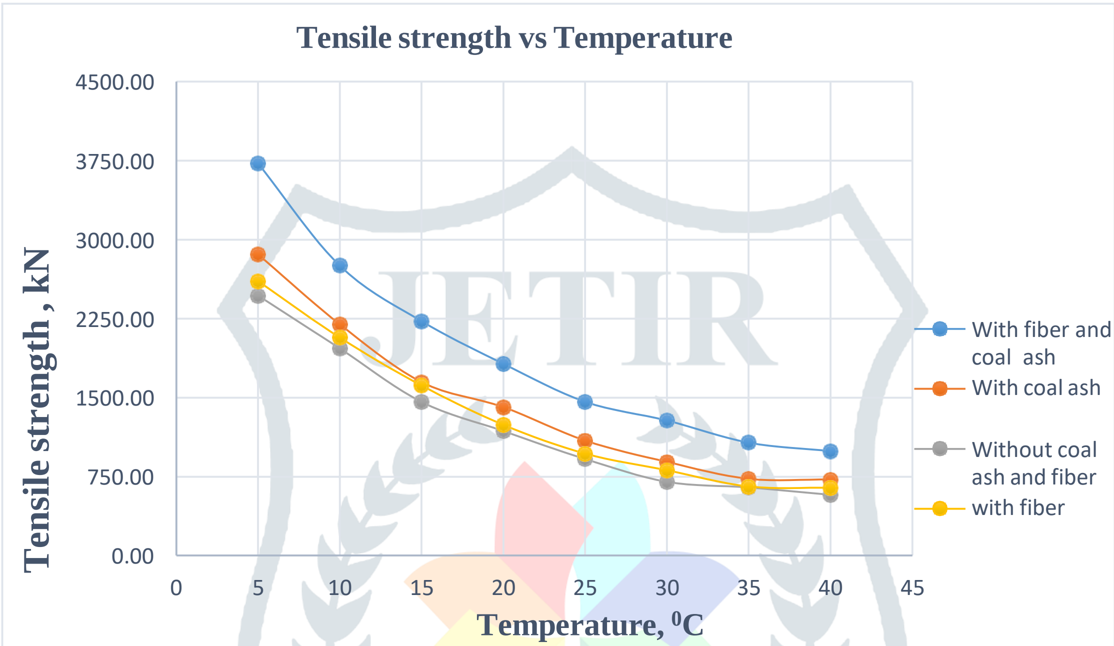
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20 | 6.13 | 12.00 | 4.90 | 4.00 | 17.90 | 78.00 | 2.24 |
| **Fiber Content, %** | **Fiber Length, mm** | **OBC, %** | **Optimum Stability, kN** | **Flow Value, mm** | **VA, %** | **VMA, %** | **VFB, %** | **Gmb** |
| 0.75 | 0 | 5.60 | 11.40 | 3.15 | 2.40 | 15.30 | 84.00 | 2.33 |
| | 5 | 5.90 | 12.20 | 3.70 | 3.60 | 17.30 | 80.00 | 2.26 |
| | 10 | 5.77 | 13.30 | 3.10 | 2.20 | 15.90 | 86.00 | 2.30 |
| | 15 | 6.00 | 12.50 | 3.40 | 4.00 | 17.90 | 78.00 | 2.25 |
| | 20 | 6.13 | 12.30 | 3.50 | 4.30 | 18.35 | 77.00 | 2.24 |
| **Fiber Content, %** | **Fiber Length, mm** | **OBC, %** | **Optimum Stability, kN** | **Flow Value, mm** | **VA, %** | **VMA, %** | **VFB, %** | **Gmb** |
| 1 | 0 | 5.60 | 11.40 | 3.15 | 2.40 | 15.30 | 84.00 | 2.33 |
| | 5 | 5.93 | 12.30 | 4.20 | 3.70 | 17.60 | 80.00 | 2.24 |
| | 10 | 5.77 | 12.50 | 3.40 | 4.40 | 17.65 | 76.00 | 2.24 |
| | 15 | 5.55 | 13.40 | 3.20 | 2.90 | 16.10 | 82.00 | 2.28 |
| | 20 | 5.63 | 12.65 | 3.8 | 2.40 | 16.20 | 83.00 | 2.28 |

**5.5 Static Indirect Tensile Test**

The static indirect tensile test was carried out on four types of samples given below.

- Sample with fiber and coal ash
- Sample with coal ash
- Sample without fiber and coal ash
- Sample with fiber

As seen from the graph given in Figure 5.32, as usual with increase in temperature, the indirect tensile strength of any bituminous mix decreases. But with addition of coal ash along with emulsion coated fiber the indirect tensile strength of DBM sample is increased as compared to unmodified conventional 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 as shown in figure 5.31. It isalso observed that the coal ash also contributes to a marginal increase in tensile strength comparedto unmodified conventional mix, which is an advantage.



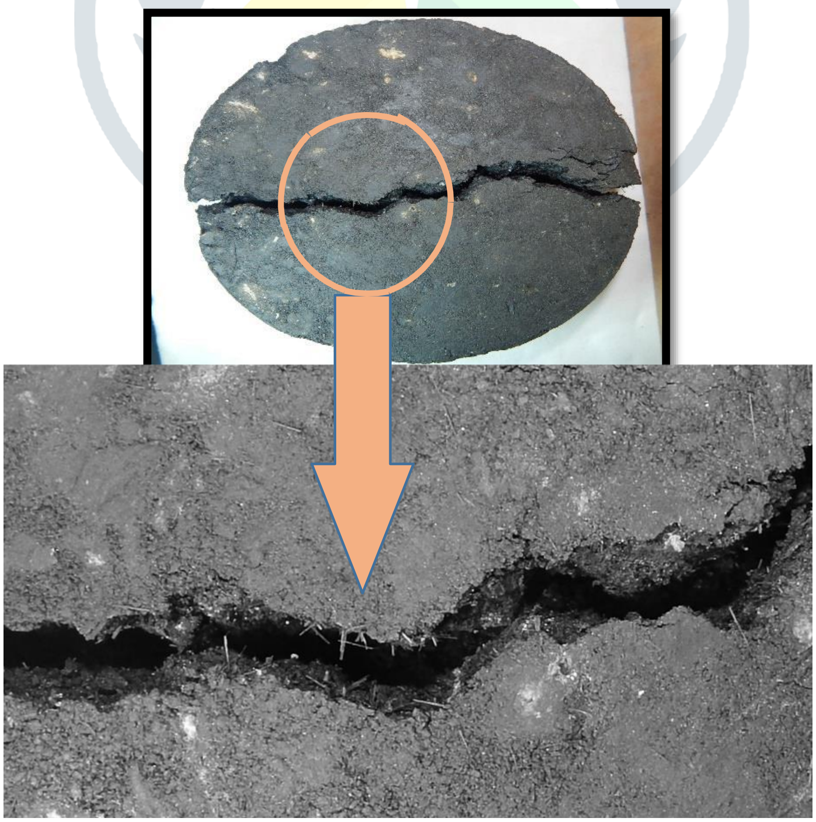



*Figure 5.31 Criss-Cross Pattern of Sisal Fiber at TensileFailure Crack*

### 5.6 Resistance to Moisture Damage (Tensile Strength Ratio (TSR)

The results of tensile strength ratio (TSR) in respect of two different types mixes, one modified and other unmodified are presented in Table 5.2. It was observed that with addition of both fiber and coal ash together, resistance to moisture induced damage was increased as compared to the conventional DBM mixture. This may due to the lesser amount of air voids in modified DBM mixture than unmodified mixture, when prepared with emulsion coated sisal fiber. Similarly fromthe table 5.1, it is observed that a minimal value of resistance to moisture damage is achieved whenthe mix was prepared with either fiber or coal ash.

***Table 5.2 TSR of DBM Mixes With And Without Fiber And Coal Ash.***

| **Tensile Strength Ratio** | | | **Design Requirement** |
|---|---|---|---|
| **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% | |


*Figure 5.33 Variation of Deformation Value at 40$^0$C for DBM Sample With Respect ToTime*

## 6. Concluding Remarks and Future Scope

### 6.1 Summary

Based on experimental study the following conclusions were drawn,

1. From the results of the Marshall tests it was observed that the DBM mixes prepared with bottomash and fly ash used respectively in 300-75 micron sizes and passing 75 micron resulted best mixessatisfying the Marshall criteria when bitumen content, fiber content and fiber length were 5.6%, 0.5% and 10mm respectively.
2. It is also observed that Marshall stability and flow values are quite acceptable when the coal ash content is within 15%.
3. It is also observed that with increase in fiber content and fiber length, air-void and flow decreases and Marshall Quotient increases which in turn is due to higher stability value.
4. An increase in fiber content and fiber length resulted in higher requirement of optimum bitumen content and emulsion for coating of the fibers.
5. From the indirect tensile strength test it is perceived that the indirect tensile strength of sample increased due to the addition of emulsion coated fiber and coal ash, which gives an excellent engineering property for DBM sample to endure thermal cracking.
6. It is also observed the use of emulsion coated fiber, coal ash or both in DBM mix increases the resistance to moisture induced damages determined in terms of tensile strength ratio and retained stability values.

### 6.2 Future Scope

1. As a natural fiber, sisal fiber has shown satisfactory results when used in bituminous mixes. Therefore to utilize the full extent of fibers, other natural fibers such as jute, coconut fiber *etc*. arealso taken in to consideration and their effects on DBM bituminous mix should be tested and studied.

2. In this study only SS-1 emulsion was considered as a coating medium for sisal fiber, therefore the effect of other types of emulsion such as rapid setting emulsion (RS) and medium setting (MS) emulsion are taken in to account and subsequent tests should be performed for future study.

3. Furthermore the effect of different mineral fillers such as cement and lime cannot be overlooked. Lime as an anti-stripping agent and cement as a stabilizing agent can be used as potential mineral filler for DBM mix, and subsequent tests may be performed as a part of future scope.

# References


1. AASHTO T 283, "Standard method of test for resistance of compacted asphalt mixtures to moisture-induced damage", American association of state highway and transportation officials.
2. Ali, N., Chan, J. S., Simms, S., Bushman, R., & Bergan, A. T.; "Mechanistic evaluation of fly ash asphalt concrete mixtures". Journal of Materials in Civil Engineering, (1996), 8(1), 19-25.
3. Al-Suhaibani, A. S., & Tons, E. T.; "Properties of fly ash-extended-asphalt concrete mixes." Transportation Research, (1991).
4. ASTM D 1559, "Test method for resistance of plastic flow of bituminous mixtures using Marshall Apparatus", American society for testing and materials.
5. ASTM D 6931, "Indirect Tensile (IDT) Strength for bituminous mixtures", American society for testing and materials, (2007).
6. ASTM D 792, "Standard test methods for density and specific gravity of plastic by displacement", American society for testing and materials, (2008).
7. Boyes, A. J.; "Reducing moisture damage in asphalt mixes using recycled waste additives" Diss. California Polytechnic State University, San Luis Obispo, (2011).
8. Chakroborty, P., & Das, A. "Principles of Transportation Engineering", Prentice Hall of India, New Delhi, (2010), pp 294-299.
9. Colonna, P.; Berloco, N., Ranieri, V., & Shuler, S. T. (2012), "Application of bottom ash for pavement binder course.", Procedia-Social and Behavioral Sciences 53 (2012): 961-971.
10. Gunalaan, V.; "Performance On Coal Bottom Ash In Hot Mix Asphalt" International Journal of Research in Engineering and Technology, (Aug 2013) eISSN: 2319-1163 | pISSN:2321-7308.
11. Hadiwardoyo, S. P.; "Evaluation of the addition of short coconut fibers on the characteristics of asphalt mixtures." Civil and Environmental Research 3.4 (2013): 63-73.
12. http://www.themartincompanies.com/sites/themartincompanies.com/files/asphalt/pds/SS1.pdf.)
13. http://textilelearner.blogspot.in/2013/01/sisal-fiber-properties-of-sisal-fiber.html
14. http://www.civil.iitb.ac.in/~vmtom/1100_LnTse/407_lnTse/plain/img13.png
15. http://www.google.co.in/imgres?imgurl=http://www.mellausisal.co.uk/img/environmentl/agave.jpg&imgrefurl=http://www.mellausisal.co.uk/about/environmental_statement&h=26&w=400&tbnid=YCOsLX5KgxSLM:&zoom=1&docid=gkrbNH2Xf9aBM&ei=fFRpVYXXNom3uATy7IDwDA&tbm=isch&ved=0CCEQMygFMAU
16. Hunsucker, D. Q.; "Design and Performance of a Bituminous Surface Mixture Containing Bottom Ash Aggregate." (1992).
17. IS: 2386, "Methods of test for aggregates for concrete (P - I): Particle size and shape", Bureau of Indian Standards, New Delhi, (1963).
18. IS: 2386, "Methods of test for aggregates for concrete (P-III): Specific Gravity, Density, Voids, Absorption,

Bulking", Bureau of Indian Standards, New Delhi, (1963).

19. IS: 2386, "Methods of test for aggregates for concrete (P-IV): Mechanical Properties", Bureau of Indian Standards, New Delhi, (1963).
20. IS: 1203, "Methods for testing tar and bituminous materials: determination of penetration", Bureau of Indian Standards, New Delhi, (1978).
21. IS: 1205, "Methods for testing tar and bituminous materials: determination of softening point", Bureau of Indian Standards, New Delhi, (1978).
22. IS: 8887, "Bitumen Emulsion for Roads (Cationic Type)[PCD 6: Bitumen Tar and their Products] Bureau of Indian Standards, New Delhi, (2004).
23. Kar, D.; "A laboratory study of bituminous mixes using a natural fibre." Diss. 2012.
24. Khanna, S. K., & Justo, C. E. G. (1991); "Highway engineering". Nem Chand & Bros, (1991).
25. Ksaibati, K., & Stephen, J.; "Utilization of bottom ash in asphalt mixes". No. MCP Report No. 99-104A. Department of Civil and Architectural Engineering, University of Wyoming, (1999).
26. Ksaibati, K., & Sayiri, S. R. K.; "Utilization of Wyoming bottom ash in asphalt mixes". No. MPC Report No. 06-179. Mountain Plains Consortium, (2006).
27. Kumar, P., Chandra, S., & Bose, S.; "Laboratory investigations on SMA mixes with different additives.", International Journal of Pavement Engineering 8.1 (2007): 11-18.
28. Lei, X., He, X., Guan, P., & Deng, P.; "Effect of Sisal Fiber on Anti-Slide Performance for Asphalt Pavement Surface.", Seventh International Conference on Traffic and Transportation Studies. 2010.
29. Long, R. E., & Floyd, R. W. (1982). "Field Evaluation of Bottom Ash in Hot Mix Asphaltic Concrete". No. FHWA/TX-82/11+ 628-1 Final Rpt, (1982).
30. MORTH, Ministry of Road Transport and Highways, Specification for Road and Bridge Works, 5th Edition, (2013).