Comprehensive Experimental Investigation on the Influence of Coal Ash and Natural Fiber Additives on the Engineering Performance, Durability, and Structural Behavior of Dense Graded Bituminous Mixes

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Abstract**-- Coal-based thermal power plants have been a key 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 deliver the optimum use of ash, namely bottom ash as fine aggregate and fly ash as mineral filler with natural fiber (such as sisal fiber) used to improvise the engineering properties of bituminous paving mixes. For national interest these waste products, which are available easily and abundantly cane be used economically for bituminous paving purpose, which ultimately helps in saving the natural aggregate resources of the nation.**

Index Terms**— Dense Graded Bituminous Mixes (DGBM), Coal Ash, Natural Fibers, Bitumen Modification, Pavement Performance, Marshall Stability, Indirect Tensile Strength (ITS), Moisture Susceptibility, Fiber Reinforcement, Sustainable Road Construction, Waste Material Utilization, Rutting Resistance, Fatigue Life, Asphalt Mixture Design, Eco-friendly Pavement Materials**

I. INTRODUCTION

1.1. Background of the study

Pavements or highways or roads are regarded backbone, upon as country's which its upswing and progress depend upon . All countries normally have a series of programs for building a replacement road infrastructures or emerging the prevailing one. Construction of both flexible & rigid pavement include a gross amount of investment to succeed in better performance oriented & smooth quality of pavement which will endure for while . In India, where highways are considered because the primary function of transportation, Government of India are investing an enormous amount of cash for developing the pavement construction & maintenance. an in depth engineering study may retain significant amount of investment & pavement materials, which successively achieve a reliable performance of the in-service highway. Regarding flexible pavement, two major facts are taken into considerations i.e. pavement design & mix design. this research study is concentrated 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‟s known that the bituminous paving technique was firstly introduced on rural roads . The formal mix design method was first made possible by Habbard field method, which was originally developed for the s&-bituminous mixture. But one of the focal limitation of this technique was its incompatible of h&ling 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 early stage, 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

1.2.2. Bituminous mix design

Bituminous pavement comprises of a mix of stone chips, graded from nominal maximum aggregates size (NMAS), through the fine fraction smaller than 0.075 mm mixed with appropriate amount of bitumen which will be compacted adequately with smaller air voids & will have adequate dissipative & elastic properties. The aim of bituminous mix design is to work out the fair proportion of bitumen & aggregates fraction to yield a mix that‟s effective, durable, reliable & economical.

1.2.3. Types of bituminous mixes

Bituminous mixes are combination of mineral aggregate & binder that are mixed with their optimum value to get down & compacted in layers for building smooth road. Mixing of bitumen & mineral aggregates are wiped out several ways, which are listed below.

II. LITERATURE REVIEW

2.1 General reviews about bottom ash, fly ash & sisal fiber in different bituminous mixes

R. E. Long & R.W. Floyd (1982) studied that aggregate shortages & increased transportation costs have greatly increased prices of related construction items in areas of Texas which is not blessed with natural aggregates. Some natural aggregates are not performing up to expectations as documented by stripping, rutting & other visual signs of pavement distress noted throughout the Department. Because of these spiralling construction costs & need to field evaluate bottom ash, District 1, supported by the Materials & Tests Division, decided to construct three field test pavements substituting bottom ash for part of the natural aggregates in hot mix asphaltic concrete (HMAC).

III. 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 & compacted to achieve an elastic body which is seamlessly impervious & hard. The study of mix design is to attain the suitable proportion of aggregate, bitumen & 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 & quality of the aggregates are considerably important to pavement. There are three types of mineral aggregates used in bituminous mixes, which are given below.

Figure 3.1 Fly ash

Figure 3.2 Bottom ash

Figure 3.3 Stone chips

Table 3.1 Physical property of coarse aggregate & fine

Property	Code specification	Test Result	
		Natural Aggregate	Bottom ash
Aggregate impact value, %	IS:2386 part-IV	14	-
Aggregate crushing value, %	IS:2386 part-IV	13.5	-
Los Angles Abrasion test, %	IS:2386 part-IV	18	-
Soundness test (five cycle in sodium sulphate), %	IS:2386 part-V	3	8.2
Flakiness index, %	IS:2386 part-I	11.9	-
Elongation index, %	IS:2386 part-I	12.5	-
Water absorption, %	IS:2386 part-III	0.14	10.75
Specific gravity	IS:2386 part-III	2.7	2

3.2.2 Bitumen

The paving bitumen grade VG-30 (VG-viscosity grade) was used in this experimental study. Initially, two bitumen grades such as VG-30 & VG-10 were used to study the Marshall characteristics of mixes with the materials considered. These initial trials resulted better Marshall characteristics, especially the Marshall stability in respect of mixes made up of bottom ash, fly ash & emulsion coated fiber with VG-30 bitumen as binder. The physical characteristics of VG-30 bitumen tested as per IS standards are given in Table-3.2.

Table 3.2 Physical property of binder.

Physical Properties	IS Code	Test Result
Penetration at 25°C/100gm/5s, 0.01mm	IS:1203-1978	46
Softening Point, °C	IS:1205-1978	46.5
Specific gravity, at 27°C	IS:1203-1978	1.01
Absolute viscosity, Brookfield at 160°C, Centi Poise	ASTM D 4402	200

3.2.3 Additives (Sisal Fiber)

The sisal fiber has been used as a modifier for improving the engineering properties of conventional

DBM mixtures. In this experimental work sisal fibers were coated with slow setting emulsion (SS-1) & stored at 110oC in hot air oven for 24hrs. Emulsion coating was considered 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.3.4 (a). It is durable, anti static & recyclable [13]. The physical & chemical property of sisal fiber are given in Table - 3.3.

Figure 3.4 (a) Sisal fiber used.

Figure 3.4 (b) Sisal fiber plant

IV. EXPERIMENTAL WORK

4.1 Experimental Design

The adopted gradation for DBM sample has been considered as specified in MORTH (2013) & is given in Table-4.1. Throughout the experimental study the aggregate gradation given in Table4 was followed, & the following tests were performed. The aggregate gradation curve is shown in figure.4.1.

Table 4.1 Gradation of aggregate.

Sieve size (mm)	Adopted gradation (% Passing)	Specified limit (as per MORTH, 2013) (% Passing)	
37.5	100	100	Natural aggregate
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	Bottom ash
0.075	5	2-8	Fly ash

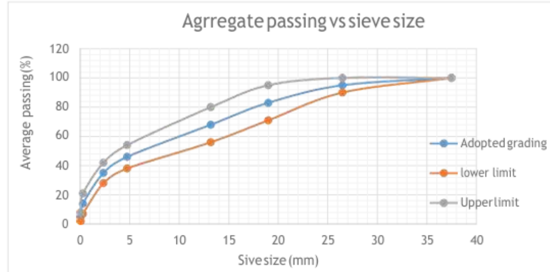

Figure 4.1 Aggregate gradation curve.

4.2. Design mix

The DBM mixtures were prepared in accordance with the Marshall procedure specified in ASTM D6927-2015. All ingredients of mixture, such as coarse aggregates, fine aggregates, filler, fiber & VG-30 bitumen were mixed in a specified procedure. Before preparing the samples, fibers were coated with SS-1 emulsion & stored in a hot air oven at 1100C as shown in Figure 4.3. Coated fiber are stored for 24 hours to ensure proper coating around each fiber & to drain down extra bitumen that may adhere to fiber, as shown in Figure 4.3 [26 & 27]. Then the fibers were cut into specified lengths of about 5mm, 10mm, 15mm & 20mm as given in figure 4.4. The aggregates & bitumen were heated separately to the mixing temperature of 1550C to 1600C. The temperature of the aggregates was maintained 100C higher than that of the binder.

Figure 4.2 Coating of emulsion on fiber.

Figure 4.3 Oven dry coated fiber.

(a) (b) (c)

Figure 4.8
(a) Sample Prepared in gyratory compactor, (b) Moisture susceptibility test in progress, (c) Failure cracks in DBM sample

V. ANALYSIS OF RESULTS & DISCUSSION

5.1 Introductions

This chapter deals with results analysis & 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 & the equation used for Marshall Properties analysis are given below. Second section deals with calculation & comparison of optimum binder content, optimum fiber content & optimum fiber length of DBM mixes with & without coal ash used as fine aggregate & filler. Third section deals with analysis made from the experiment such done in previous chapter static indirect tensile, static creep test at 400C, moisture susceptibility test (Tensile strength ratio), & retained stability test.

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

- Sample with fiber & coal ash
- Sample with coal ash
- Sample without fiber & 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 is also observed that the coal ash also contributes to a marginal increase in tensile strength compared to unmodified conventional mix, which is an advantage.

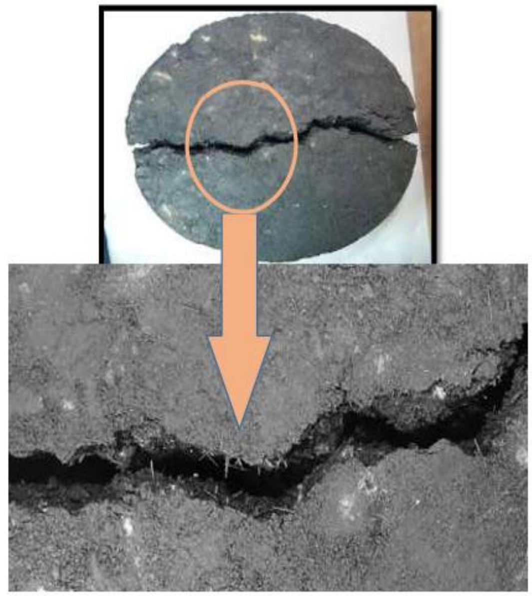

Figure 5.31 Criss-cross pattern of sisal fiber at tensile failure crack

VI. CONCLUDING REMARKS & 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 bottom ash & fly ash used respectively in 300-75 micron sizes & passing 75 micron resulted best mixes satisfying the Marshall criteria when bitumen content, fiber content & fiber length were 5.6%, 0.5% & 10mm respectively.
2. It is also observed that Marshall stability & flow values are quite acceptable when the coal ash content is within 15%.
3. It is also observed that with increase in fiber content & fiber length, air-void & flow decreases & Marshall Quotient increases which in turn is due to higher stability value.
4. An increase in fiber content & fiber length resulted in higher requirement of optimum bitumen content & 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 & 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 & retained stability values.

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