A STUDY ON DEVELOPMENT IN ENGINEERING PROPERTIES OF DENSE GRADE BITUMINOUS MIXES WITH COAL ASH BY USING NATURAL FIBER

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ABSTRACT

The 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, & creep value. Again the possible effects of fiber on bitumen mixes are also taken into consideration, & comprehensive study was done to find the optimum fiber content & fiber length that will increase the engineering property of bituminous mix.

Utilization of non-conventional materials like coal ash & 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 & environmental pollution, can find one way for its reuse in an economical way by substituting natural resources of stone dust.

1. INTRODUCTION

Pavements or highways or roads are regarded as country's backbone, upon which its upswing & progress 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 & rigid pavement include a gross amount of investment to reach better performance oriented & 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 have been investing a huge amount of money for developing the pavement construction and maintenance. A detailed engineering study may retain significant amount of investment & 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.

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 limitation 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 Hveemstabilometer 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 mix design, to assess the quantity of bitumen vital for the mixture. On the other h&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 & successively adapted in 1940's & 50's.

Bituminous mix design

Bituminous pavement comprises of a mixture 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 that can be compacted adequately with smaller air voids & will have adequate dissipative & elastic properties. The aim of bituminous mix design is to determine the fair proportion of bitumen & aggregates fraction to yield a mixture that is effective, durable, reliable & economical.

Types of bituminous mixes

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

Hot mix asphalt

Commonly known as HMA, is prepared by heating bitumen binder & moisture dry aggregate to a mixing temperature of 150 ^{0}C to 160 ^{0}C (300 ^{0}F to 330 ^{0}F) which will provide a consistent mixture to work with. Due to high temperature of the mixture it is possible to compact the mixture to its optimum air content to give better stability than others. There as on being which HMA is widely used on highly trafficked roadways such as highways, airfields, & racetracks.

Warm mix asphalt

Frequently known as WMA, is prepared by mixing aggregate & binder at a moderate temperature of 100 ^{0}C to 135 ^{0}C. The virgin binder is modified with foreign additives prior to mix, which will help bitumen binder to mix properly with mineral aggregate. Due to low temperature of mixing, consumption of fuel s& emission of harm gasses are comparatively lower than hot mix. Not onlyhad it improved workability, but also the low-temperature laying helps in accessing road surface much quickly.

Cold mix asphalt

This technique is practiced where high mixing temperature is a problem. The aggregate is blended with emulsified bitumen (a combination of water & bitumen in a proper ratio) to a mixture that is easy to work & compact. When water evaporates from emulsion leaving back bitumen, the cold mix will, ideally, take on the properties of cold HMAC. Cold mix is frequently used as a patch material on a lesser trafficked roads.

Cut-back asphalt

A lighter fraction of petroleum is dissolved with bitumen binder to produce a less viscous liquid that will dissolve with the aggregate & evaporate after compaction is done. Cutback bitumen has been widely used in contradiction due to its nonpolluting characteristic & easy to work with.

Mastic asphalt or sheet asphalt

Mastic asphalt is made by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has turns to a viscous liquid before it is added to aggregates. The mixture is cooked for 6-8 hours to mature & once the mixer is ready, it is transported to the site where it generally laid in different thickness for footpath, road & for flooring or roof applications.

2. LITERATURE SURVEY

Sinha, A. K., et al. (2009) conducted test on sub-soil for a proposed road construction of a 4 kmwith pond ash which is running from

Kalindi Colony to KalindiKunj in New Delhi, India. Some field tests were conducted such as Standard Penetration Test (SPT) & Cone Penetration Test (CPT). Based on the laboratory experiments & field results, the design of pond ash embankment with & without berm was also done in two types of conditions *i.e.* steady seepage condition & sudden draw down with seismic factor.It is observed that under the highest flood level with seismic effect, the fly ash embankment is exposed to both sudden draw down & steady seepage conditions.

Partl, Manfred, K. Sokolov, & H. Kim. (2008) conducted Laboratory study on a special typeof carbon fiber grid which was placed at different depth in asphalt pavements. The purpose of the study was to obtain the design information about the position of the grid which will give optimum result. Two different types of asphalt pavements were examined (a) asphalt concrete & (b) mastic asphalt.This study reveals that with addition of carbon grid stiffness, failure strain & stress, & resistance against low temperature cracking increased. However, during rutting tests with Model Mobile traffic Load Simulator (MMLS) it was found that the grid was not able to improve resistance against flow value in the mastic asphalt layer.

Kumar, Pawan, SatishCh&ra, & Sunil Bose (2007) studied the performances of the SMAmixture modified with crumb rubber modified binder (CRMB) & low viscosity binder coated jute fibers. The performance of SMA mixture were assessed by conducting two different methods of drain-down, durability test, moisture susceptibility test, fatigue life tests & rutting test. He also compared the characteristic of modified SMA prepared with coated jute fiber & with other patented fibers. From the test observation he conclude that fiber content of 0.3% by weight of the mix improve the Drain-down property of the mix. Also in moisture susceptibility test the mixture shows satisfactory result. The observation from Hamburg wheel tracking tests, aging tests & flexural fatigue tests carried out on three mixes of SMA indicate better result than conventional mix.

Kar, Debashish(2007)studied the effect of indigenously available sisal fiber on SMA & BCmixture. He considered sisal fiber as an additive for BC mix & stabilizing agent for SMA mix. Fiber content varied from 0% to 0.5% by weight of total mix whereas binder content was varied from 4% to 7%. For mineral filler he used fly ash, as it has shown satisfactory result at the initial stage of experiment. For the performance test the BC & SMA mixes were subjected to various test such as Drain down test, Static Creep test & Static Indirect Tensile Strength Test. B From the Marshall properties test it was observe, addition of fiber helps to improve the Marshall Stability & indirect tensile strength, it also reduces the Drain down. He again observed that the indirect tensile strength of SMA mixture is better than BC mixture. From Marshall test he found that the optimum binder content for BC & SMA were 5% & 5.2% respectively whereas optimum fiber content were 0.3%.

3. PROPOSED METHOD

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)

Mix Design

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 110^{0}C. Coated fiber are stored for 24 hours to ensure proper coating around each fiber and to drain down extra bitumen that may adhere to fiber. Then the fibers were cut into specified lengths of about 5mm, 10mm, 15mm & 20mm. The aggregates and bitumen were heated separately to the mixing temperature of

155^0C to 160^0C. The temperature of the aggregates was maintained 10^0C higher than that of the binder. Required quantities of bitumen VG-30 & coated emulsion fiber pieces were added to the pre-heated aggregates & thoroughly mixed.

The quantity of binder to be added was calculated from subtracting the weight of emulsion coated fiber from weight of design binder. Proper mixing was done manually till the colour and consistency of the mixture appeared to be uniform. The mixing time & temperature was maintained within 2-5 minutes & 150^0C-160^0C respectively. The mixture was then poured in to a pre-heated Marshall mould &compacted using Humboldt Automatic Marshall Compact with 75 compaction blows on each side. The specimens were kept 24 hours for cooling to a temperature of $25^{\pm}1^0$C.

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.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 were done before the Marshall stability test. In this voids analysis bulk specific gravity (Gmb), air voids (VA), voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and Marshall Quotient were determined, that are discuss in next chapter.

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 on the Indirect Tensile Strength (ITS) of mixes with & 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 & was calculated

$$St = \frac{2000 \times P}{\pi \times D \times T}$$

Where St= Indirect Tensile strength, kPa

P = Maximum Load, kN

T = Specimen height before testing, mm

D = Specimen Diameter, mm

The test temperature was varied from 5^0C to 40^0C at an increment of 5^0C. The average tensile strength of three sample was reported.

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 & 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 $60^{\pm}1.0$°C for 24 hour.

Retained stability test

The loss of stability in bituminous mixes due to penetration of moisture is measure in the form of Retained stability test. This test also shows the sign of percentage striping of bitumen from aggregate. The test was conducted in accordance with the STP 204-22 with standard Marshall Samples, prepared according to the Marshall procedure specified in ASTM D6927-2015. Six specimen were prepared with 4% air void and divided into two subset. Each of the subset were conditioned with water at $60^{\pm}1^{0}$C for half an hour & 24 hours & tested in accordance to Marshall stability test. A minimum of 75% retained stability is required as per MORTH-2013 to claim the mixture can with stand moisture.

4. RESULTS

Static indirect tensile test

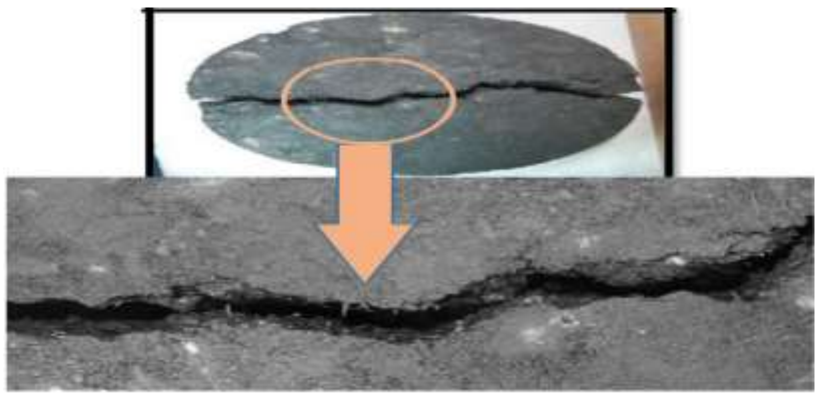

Figure .Criss-cross pattern of sisal fiber at tensilefailure crack

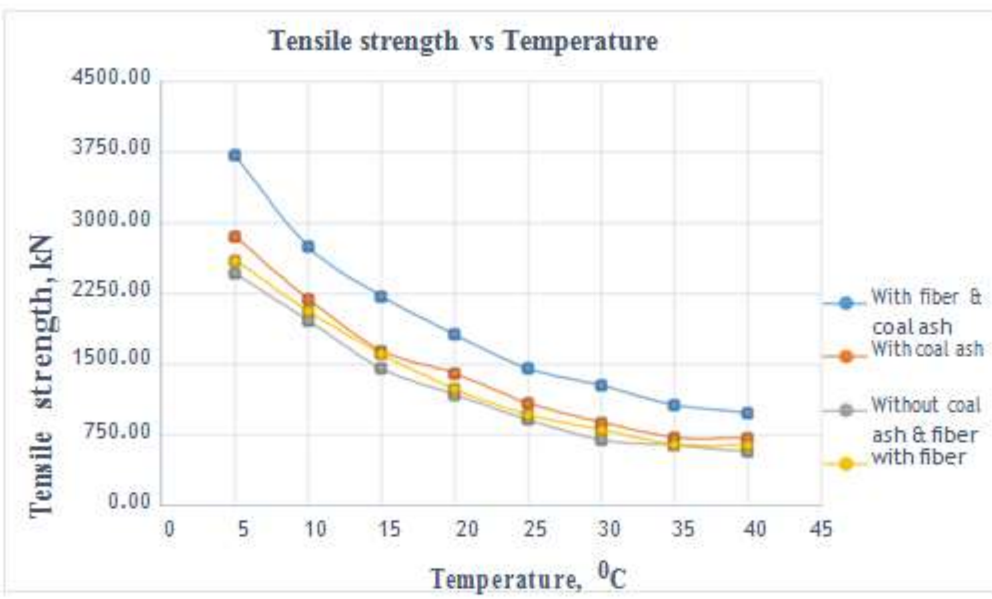

Figure . Graph between Tensile strength vs Temperature.

Resistance to moisture damage (Tensile Strength Ratio (TSR))

The results of tensile strength ratio (TSR) in respect of two different types mixes, one modified & other unmodified are presented in Table 5.2. It was observed that with addition of both fiber & 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 from the table 5.1, it is observed that a minimal value of resistance to moisture damage is achieved when the mix was prepared with either fiber or coal ash.

Table. TSR of DBM mixes with & without fiber & 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%	

Retained stability test

Retained stability was evaluated for DBM sample which were prepared with fiber, coal ash & conventional aggregate and given in table. It was observed that the sample containing both emulsion coated fiber & coal ash has given higher result than conventional DBM sample. But the sample prepared only with coal ash and conventional aggregate has shown less resistance to moisture andhence given reduced stability than design requirement.

Table . Retained stability of DBM mixes with & without fiber & coal ash.

Retained stability				Design requirement
Type of mixture	Avg. stability after half an hour in water at 60 °c (kN)	Avg. stability after 24 hours in water at 60 °c (kN)	Avg. retained stability (%)	Minimum 75% (as per MORTH specification)
DBM with fiber & Coal ash	14.78	13.21	89.37	
DBM with Coal ash	13.88	10.17	73.21	
DBM with fiber	12.63	10.10	79.94	
DBM without fiber & Coal ash	13.56	10.45	77.03	

Static creep test

Static creep test is a measure of permanent deformation due to constant loading for a long period of time. It was observed from the deformation and time graph that the deformation value for DBM sample that is prepared with 0.5% fiber content, 10mm fiber length, 14% coal ash (9% bottom ash & 5% fly ash) by weight of the mix & optimum binder content of 5.6% by weight of the mixture decreased when compared with other modified and unmodified DBM mix. It is also seen that with either addition of coal ash or fiber in the mixture, the deformation value decrease when compared to conventional mixture.

penetration test

Trail no	Initial dail reading	Final dail reading	Penetration 1/10 th mm	Average value
	(1)	(2)	(2)-(1)	
1	196	241	45	48 mm
2	180	230	50	
3	175	223	48	

Softening point of bitumen:
Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. Mean value of softening is 51^0C.

Testing Activity	Sample No1		Sample No 2		Mean value of softening point
	Ball no		Ball no		
	1	2	1	2	
Temp.at which sample touches bottom plate in centigrade	50.4	50.9	50.3	50.9	51^0C

Viscosity test:

SNo	Description	Bulb-B	Bulb-C
1	Specific test temperature in ^{0}C	60^0C	60^0C
2	Flow timein seconds	72	118
3	Calibration factor	42.1245	25.6127
4	Viscosity in poise	3032.9640	3022.2986
5	Average viscosity in poise	3028 poise	

5. CONCLUSION

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. It is also observed that Marshall stability & flow values are quite acceptable when the coal ash content is within 15%. 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. An increase in fiber content & fiber length resulted in higher requirement of optimum bitumen content & emulsion for coating of the fibers. 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.

6. REFERENCES

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