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A Study On Use Of Natural Fiber By Dense Grade Bituminous Mixes With Coal Ash

Yendurthy Santhosh[1], B Khadar Mohammed[2]
[1](M.Tech, Transportation engineering, MVR College of Engineering and Technology)
[2](Assistant Professor, MVR College of Engineering and Technology)

Abstract

Coal-based thermal power plants have been a key source of power generation in India. The prime waste product of a coal thermal power plant is 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 can be used economically for bituminous paving purpose, which ultimately helps in saving the natural aggregate resources of the nation.

In the present study, dense graded bituminous mix specimens are prepared using natural aggregate as coarse aggregates, bottom ash as fine aggregates, fly ash as filler and sisal fiber as additive. Proportion of aggregate for dense graded bituminous macadam (DBM) grading has been considered as per MORTH (2013) having nominal maximum aggregates size (NMAS) 26.5 mm. To strengthen the mix, slow setting emulsion (SS1) coated sisal fiber is added in varying percentage of 0, 0.25%, 0.5%, 0.75%, and 1% by weight of the mix, with different length variations such as 5mm, 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. VG30 and VG10, out of which the initial trials resulted better Marshall Characteristics with VG30 bitumen and hence were considered for subsequent study. Detailed study with Marshall Test results were used to determine the marshal characteristics, optimum binder content and also optimum fiber content including the optimum length of fiber. Marshall stability as high as 15kN was obtained with optimum bitumen content of 5.57%, with optimum fiber content of 0.5% with optimum fiber length of 10 mm. Further, for delivering the performances of the pavement, various performance tests were also conducted such as moisture susceptibility test, indirect tensile strength (ITS), creep test and tensile strength ratio of bitumen mixes. It is finally observed that not only satisfactory, but also much improved engineering properties result with coal ash as fine aggregate and filler, stabilized with natural sisal fiber duly coated with SS-1 emulsion in advance.

Utilization of non-conventional aggregate like coal ash and natural fiber 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.

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

INTRODUCTION

Background of the study

Pavements or highways or roads are regarded as country's backbone, upon which its upswing and 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 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 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 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.

Bituminous mix design

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 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 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 adapted in 1940's and 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 and will have adequate dissipative and elastic properties. The aim of bituminous mix design is to determine the fair proportion of bitumen and aggregates fraction to yield a mixture that is effective, durable, reliable and economical.

Types of bituminous mixes

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

Hot mix asphalt

Commonly known as HMA, is prepared by heating bitumen binder and moisture dry aggregate to a mixing temperature of 150 0C to 160 0C (300 0F to 330 0F) 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, and racetracks.

Warm mix asphalt

Frequently known as WMA, is prepared by mixing aggregate and binder at a moderate temperature of 100 0C to 135 0C. 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 sand emission of harm gasses are comparatively lower than hot mix. Not only had 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 and bitumen in a proper ratio) to a mixture that is easy to work and 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 and evaporate after compaction is done. Cutback bitumen has been widely used in contradiction due to its nonpolluting characteristic and 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 and once the mixer is ready, it is transported to the site where it generally laid in different thickness for footpath, road and for flooring or roof applications.

HOT MIX ASPHALT

Hot Mix Asphalt (HMA) is mixture of aggregate and bitumen that are mixed, placed and compacted at higher temperature. The three types of HMA are Dense Graded Bituminous Macadam (DBM), Stone Matrix Asphalt (SMA) and Open graded mix.

Dense Graded Bituminous Macadam (DBM)

This type of bituminous mix is a well-graded HMA with proper proportion of all aggregate fractions. It is hard and relatively impermeable. Dense-graded mixes are classified as fine-graded and coarse graded.

Stone Matrix Asphalt (SMA)

Stone matrix asphalt (SMA), which is occasionally called as Stone Mastic Asphalt, is a gap-graded mix, eventually developed to maximize the rutting resistance caused by heavy traffic. SMA has high coarse aggregate fractions that interlock to each other, to form a stone skeleton that resists permanent deformation. SMA is preferably used for surface courses on high volume roads. Mineral filler sand additives are used to check the drain-down of bitumen binder during construction.

Open-Graded Mixes

Unlike DBM and SMA, an open-graded mix is made-up of only stone chip sand bituminous binder. Due to absence of Fine aggregate and filler it became porous and offers surface water to drain down quickly. It is used as a drainage layer under dense-graded HMA, SMA or PCC. It has enough friction with relatively little strength than other. It is purposefully constructed with high air void that reduce road tire noise by up to 50%.

RAW MATERIALS

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 to attain the suitable proportion of aggregate, bitumen and other additives if added.

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 quality coarse 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 sieve is 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.

Bitumen

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

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.

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 start binding the aggregate. The first sign of break down occur when the color of bitumen emulsion film change from chocolate brown to black. Bituminous emulsion is 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)

Physical property of coarse aggregate and 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

Physical property of binder.

Physical Properties	IS Code	Test Result
Penetration at 25^{o}C/100gm/5s, 0.01mm	IS:1203-1978	46

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Volume 06 Issue 08
July 2019

Softening Point, ^{O}C	IS:1205-1978	46.5
Specific gravity, at $27^{O}C$	IS:1203-1978	1.01
Absolute viscosity, Brookfield at $160^{O}C$, Centi Poise	ASTM D 4402	200

Additives (Sisal Fiber)

The sisal fiber, a naturally and locally available product 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) and stored at $110^{O}C$ 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 and recyclable [13]. The physical and chemical property of sisal fiber is given in Table -3.3.

Figure 3.4 (a) Sisal fiber used.

Figure 3.4 (b) Sisal fiber plant [15]

Table 3.3 Physical and chemical property of sisal fiber[13].

Chemical composition	
Composition	Test result
Cellulose, %	65
Hemicellulose, %	12
Lignin, %	9.9
Waxes, %	2
Physical property	
Property	Test result
Density, gm/cc	1.51
Tensile strength, MPa	510-640
Young's modulus, MPa	9.5-2.0
Elongation at break, %	2.0-2.5

Experimental Design

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 Table4 was followed, and the following tests were performed. The aggregate gradation curve is shown in figure.4.1.

Table: Gradation of aggregate

Table 4.1 Gradation of aggregate.

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	Natural aggregate
4.75	46	38-54	
2.36	35	28-42	
0.3	14	7-21	Bottom ash
0.075	5	2-8	Fly ash

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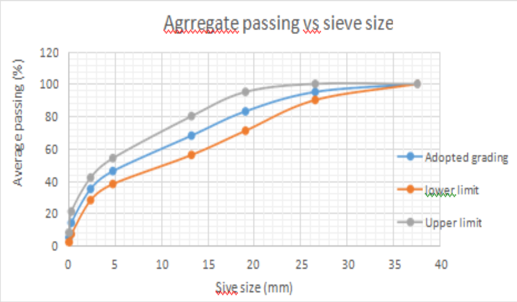

Figure 4.1 Aggregate gradation curve.

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*

ANALYSIS OF RESULTS AND DISCUSSION

Introduction

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 properties analysis are given below. Second section deals with calculation and comparison of optimum binder content, optimum fiber content and optimum fiber length 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 ^{o}C, moisture susceptibility test (Tensile strength ratio), and retained stability test.

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, from which the percentage of fly ash as mineral filler is fixed, *i.e.* 5% of weight of the mix. The bottom ash content is varied according to the DBM gradation specified in MORTH (2013), which is given in chapter 4.

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.

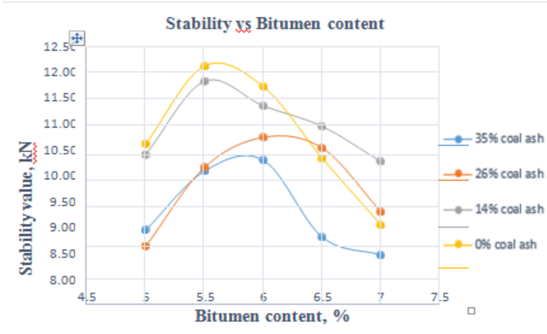

Figure 5.1 Variation of Stability value with bitumen content at different coal ash content

Marshall Flow value

It was seen from the flow value vs bitumen content graph shown in figure 5.2 that with increase in bitumen content and Coal ash content the flow value increase. But with 14% coal ash content by weight of mix the flow value decrease as compare to the conventional mix.

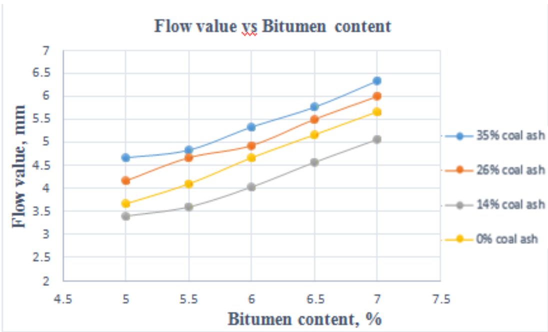

Figure 5.2 Variation of Flow value with bitumen content at different coal ash content

Air void

It is observed from the graph shown in figure 5.3 that with increase in coal ash the air void increases. By taking 14% coal ash by weight of the mix, the air void is fairly near to the conventional mix, which means coal ash can be used with some modification to achieve optimum properties than conventional mix.

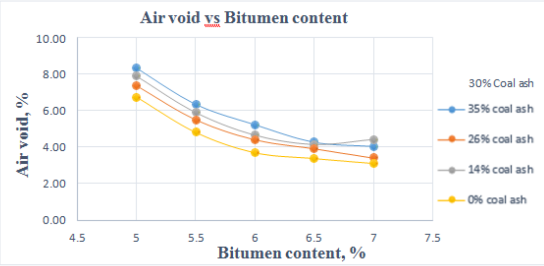

Figure 5.3 Variation of Air void value with bitumen content at different coal ash content

Unit weight

From the Unit weight and bitumen content graph shown in figure 5.4 it is observed that with increase in coal ash content the unit weight of DBM samples decreases. Coal ash been a lighter material cause the decrease of unit weight.

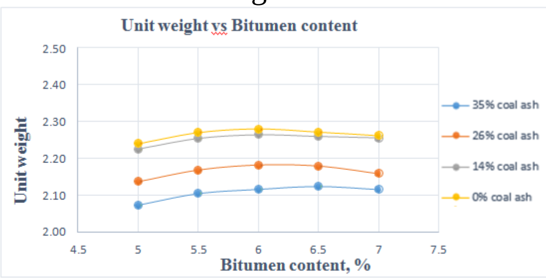

Figure 5.4 Variation of unit weight value with bitumen content at different coal ash content

Voids in Mineral Aggregate (VMA)

From the observation of VMA vs bitumen content graph in Figure 5.5, it is clear that with increase in bitumen content voids in mineral aggregate decrease rapidly first and then increases steadily.

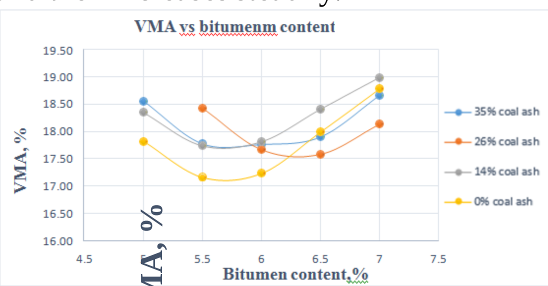

Figure 5.5 Variation of VMA value with bitumen content at different coal ash content

Voids Filled with Bitumen (VFB)

It is observe from the VFB and bitumen content graph shown in Figure 5.6 that VFB increase rapidly with increase in bitumen and coal ash content.

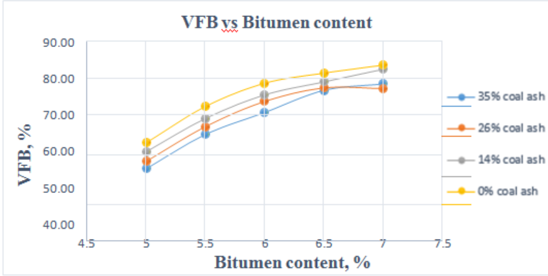

Figure 5.6 Variation of VFB value with bitumen content at different coal ash content

Table 5.1 Marshall Property's 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

Static indirect tensile test

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

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Volume 06 Issue 08
July 2019

- *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 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.

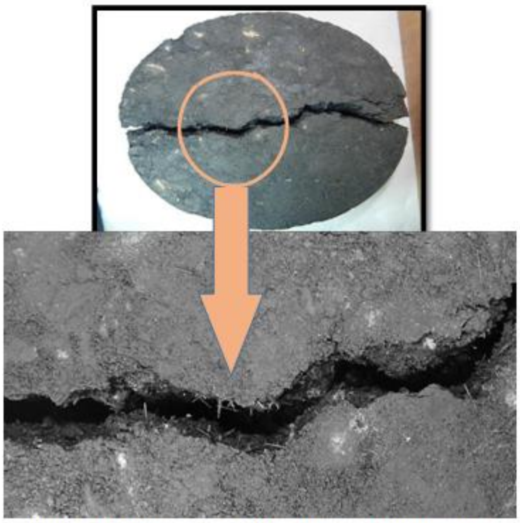

Figure 5.31 Criss-cross pattern of sisal fiber at tensile failure crack

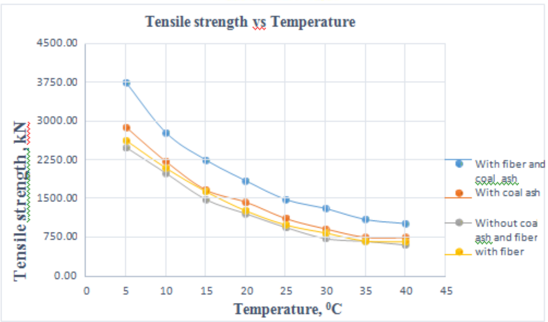

Figure 5.32 Graph between Tensile strength vs Temperature

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

The results of tensile strength ratio (TSR) in respect of two different types mixes, one modified 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 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 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%	

Retained stability test

Retained stability was evaluated for DBM sample which were prepared with fiber, coal ash and conventional aggregate and given in table 5.3. It was observed that the sample containing both emulsion coated fiber and 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 and hence given reduced stability than design requirement.

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

Retained stability	Design requirement

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e-ISSN: 2348-6848
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Volume 06 Issue 08
July 2019

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 (%)	
DBM with fiber and Coal ash	14.78	13.21	89.37	Minimum 75% (as per MORTH specification)
DBM with Coal ash	13.88	10.17	73.21	
DBM with fiber	12.63	10.10	79.94	
DBM without fiber and 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 shown in figure 5.33 that the deformation value for DBM sample that is prepared with 0.5% fiber content, 10mm fiber length, 14% coal ash (9% bottom ash and 5% fly ash) by weight of the mix and 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.

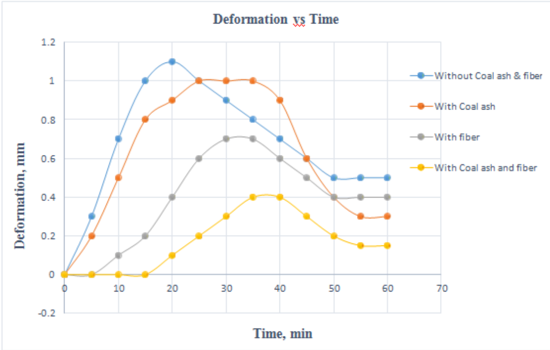

Figure 5.33 Variation of Deformation value at 40°C for DBM sample with respect to time

CONCLUSION

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 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.
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.

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