T SUBRAMANI / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 3, May-Jun 2012, pp.1794-1804

EXPERIMENTAL INVESTIGATIONS ON COIR FIBRE REINFORCED BITUMINOUS MIXES

T SUBRAMANI
Professor & Dean, Department of Civil Engineering, VMKV Engg College, Vinayaka Missions University, Salem, India.

ABSTRACT

The development of transportation plays an important role in the development of nation. With flexible pavements being widely used in India, steps must be taken to increase the life of the bituminous pavements. Flexible pavements are often plagued with problems of cracking and rutting due to repeated traffic loads. Hence one needs to address these problems in order to improve the performance of flexible pavements. The project studies the suitability of coir as a reinforcing material in bituminous mixes. Marshall method of mix design was adopted for the mixes and the optimum bitumen content, fibre content and fibre length are determined for coir fibre reinforced bituminous mixes and their performance is analysed. An optimum bitumen content of 5%, optimum fibre content of 0.46% and fibre length of 17.25 mm was obtained after analysis. On studying the Marshall parameters, it is found that the addition of coir fibre to semi dense bituminous concrete mix contributes significantly in improving the performance of the mix.

KEYWORDS: Bitumen, coir fibre, Marshall mix design, semi-dense bituminous concrete, stability and flow.

1 INTRODUCTION

1.1 GENERAL

A pavement structure can be designed either as a flexible pavement or a rigid pavement based on its structural behaviour, with flexible pavements being widely preferred in India due to its advantages over rigid pavements and economy. Flexible pavements have low or negligible flexural strength and are rather flexible in their structural action under the loads. These pavements are layered structures with the following component layers.

1. Soil sub-grade
2. Sub-base course
3. Base course
4. Surface course

The layered pavement structure transmits vertical or compressive stresses to the lower layers by grain to grain transfer through the points of contact in the granular structure with strong graded aggregates and should transfer the compressive stresses to a wider area. In light of the above factors, it can be learnt that bituminous mix is one of the best flexible pavement layer materials. Bituminous mix is generally used as a surface course and wearing course in flexible pavements since it is necessary that the wearing course must provide a smooth riding surface that is dense and at the same time take up wear and tear due to traffic.

1.2 DISADVANTAGES OF BITUMINOUS MIXES

The general problems while using bitumen in paving mixes are as follows.

1. Difficulty in mixing
2. Ensuring attainment of desired stability of mix
3. Cracking of bituminous surface
4. Ensuring sufficient adhesion with the aggregates in the mix

Variations in temperature and fatigue induce the formation of cracks in the bituminous surface. The pavement deformations (plastic and elastic deformations) due to repetition of loads may lead to permanent deformations and even permanent failure. Cracking and plastic failure (rutting) in bituminous surface course are caused due to excessive strain in the pavement layers. The undulations and unevenness of the surface due to plastic deformations of the pavement causes vertical oscillations, consumes more fuel, causes wear of the vehicle components and increases vehicle operation cost. As a result, this causes discomfort and fatigue to the passengers. Hence it is necessary to address the problems of rutting and cracking in flexible pavements to overcome the difficulties in use and maintenance of flexible pavements. It is also required to take the necessary steps to keep elastic deformations within the permissible limits since the stresses under the wheel loads cause deformations due to repeated load applications.

1.3 OBJECTIVE

This study aims to investigate the properties of coir fibre reinforced bituminous mixes and to study its advantages over the conventional bituminous mixes.

2. EXPERIMENTAL WORK

2.1 GENERAL

This chapter gives a detailed account of the work methodology adopted, material characterization, mix proportioning and the experimental investigations on coir fibre reinforced bituminous mix.

2.2 MATERIAL CHARACTERISATION

2.2.1 Tests on Aggregates

The coarse aggregate used was a normal weight aggregate with a maximum size of 13 mm. Stone dust was used as the fine aggregate. Salient properties of the aggregates as determined by standard tests are given in Table 1.

TABLE.1 MATERIAL CHARACTERISATION OF AGGREGATES

Property		Value
Specific gravity	13.2 mm aggregate	2.78
	4.75 mm aggregate	2.67
	Stone dust	2.53
Apparent specific gravity	13.2 mm aggregate	2.86
	4.75 mm aggregate	2.70
	Stone dust	2.56
Water absorption (%)	13.2 mm aggregate	1
	4.75 mm aggregate	0.5
	Stone dust	0.5
Impact (%)		23.78

Sieve analysis of the aggregates was done and the results are given in Table 2 with their corresponding gradation curves represented in Fig.1.

TABLE.2 SIEVE ANALYSIS OF AGGREGATES

IS Sieve Size in mm	Percentage Passing		
	13.2 mm Aggregate	4.75 mm Aggregates	Dust
13.2	100	100	100
9.5	73.3	100	100
4.75	1.2	100	100
2.36	0.5	16	100
1.18	0.5	1.7	75.2
0.3	0.5	1.3	49.6
0.075	0.5	0.8	15.6

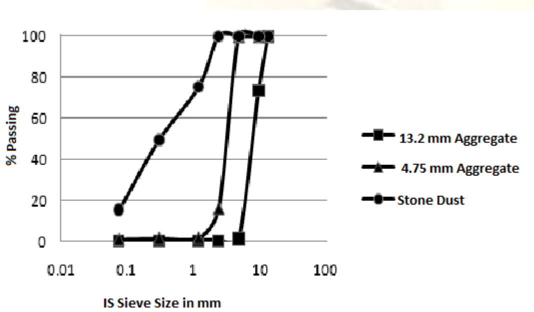

FIG.1. GRADATION CURVE OF AGGREGATES

2.2.2 Tests on Bitumen

60/70 grade of bitumen is used as the binder and its properties as determined by standard test procedures are tabulated in Table .3.

TABLE.3 MATERIAL CHARACTERISATION OF BITUMEN

Property	Value
Penetration (mm)	71.4
Specific Gravity	1.02
Softening Point (°C)	50.5
Ductility (mm)	>100
Static Immersion Test	No Visible Stripping

2.2.3 Tests on Coir Fibre

For the investigations on coir reinforced bituminous mixes, we used unretted brown coir as it is easily available and it does not vary much in properties when compared to retted fibre. The coir was obtained in bundles as shown in Fig.2 and then cut to the required lengths of 10 mm, 15 mm and 20 mm.

FIG.2 UNRETTED BROWN COIR FIBRE BUNDLE

The properties of coir fibre as obtained from various literatures are shown in Table .4.

TABLE.4 PROPERTIES OF COIR FIBRE AS OBTAINED FROM LITERATURES

Property	Value
Diameter (mm)	0.1-0.4
Density (g/cm^3)	0.67-10.0
Natural moisture content (%)	11.44-15.85
Water absorption (%)	85-135
Tensile strength (MPa)	108.26-251.90
Modulus of elasticity (GPa)	2.5-4.5
Strain at failure (%)	13.7-41.0

Table.5 lists some of the properties of coir fibre ascertained in the laboratory following standard test procedures.

TABLE.5 MATERIAL CHARACTERISATION OF COIR FIBRE

Property	Value
Specific Gravity	0.98
Water Absorption (%)	73.47
Bitumen Adsorption (%)	107.14

2.3 PROPORTIONING OF AGGREGATES

2.3.1 Semi Dense Bituminous Concrete

To study the properties of coir fibre reinforced concrete, semi dense bituminous concrete mix grade 1 as prescribed by Ministry of Road Transport and Highways (MoRTH) in Specifications for Road and Bridge Works (up-gradation of third revision) was chosen as the bituminous mix. Semi dense bituminous concrete (SDBC) is used in wearing/binder and profile corrective courses.

TABLE.6 PHYSICAL REQUIREMENTS FOR COARSE AGGREGATE IN SDBC GRADE 1

Property	Test	Value (%)
Cleanliness	Grain Size Analysis	5 Max. passing 0.075 mm sieve
Strength	Aggregate Impact Value	27 Max.
Water absorption	Water Absorption	2 Max.
Stripping	Static Immersion Test	95 Min. retained coating

TABLE.7 MORTH SPECIFIED GRADATION FOR AGGREGATES IN SDBC

IS Sieve in mm	Required %Passing	Upper Limit	Lower Limit	Average Value
13.2	90-100	100	90	95
9.5	70-90	90	70	80
4.75	35-51	51	35	43
2.36	24-39	39	24	31.5
1.18	15-30	30	15	22.5
0.3	9-19	19	9	14
0.075	3-8	8	3	5.5

This usually consists of construction in a single or multiple layers of semi dense bituminous concrete on a previously prepared bituminous bound surface. A single layer is 25mm to 100mm in thickness. Table.6 gives some of the requirements for the physical properties of the aggregates used in SDBC grade 1. The required gradation of the aggregates for semi dense bituminous concrete grade 1 as prescribed in the MoRTH specifications is given in Table.7 with its corresponding gradation curve shown in Fig .3.

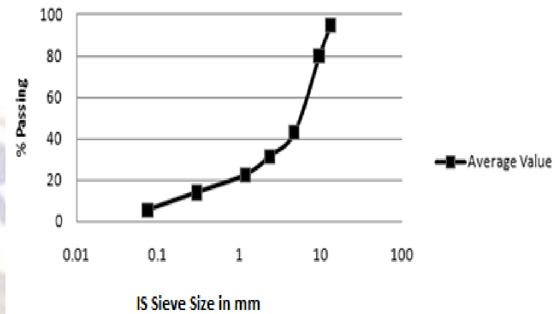

FIG.3 REQUIRED GRADATION CURVE FOR SDBC

2.3.2 Proportioning for SDBC Grade 1

On proportioning the aggregates for semi dense bituminous concrete mix as per MoRTH specifications, the following mix proportion was obtained.
13.2 mm aggregate: 40%
4.75 mm aggregate: 35%

Stone dust: 25%

The gradation of the above mix proportion is given in Table 2.8 and its corresponding gradation curve is shown in Fig..4.

TABLE.8 GRADATION OF PROPORTIONED BITUMINOUS MIX

IS Sieve in mm	Percentage Passing					
	13.2 mm	4.75 mm	Dust	Proportioned Value	Required Value	Acceptable Range
13.2	100	100	100	100	95	90-100
9.5	73.3	100	100	89.32	80	70-90
4.75	1.2	100	100	60.48	43	35-51
2.36	0.5	16	100	30.8	31.5	24-39
1.18	0.5	1.7	75.2	19.60	22.5	15-30
0.3	0.5	1.3	49.6	13.06	14	9-19
0.075	0.5	0.8	15.6	4.38	5.5	3-8
Proportion (%)	40	35	25			

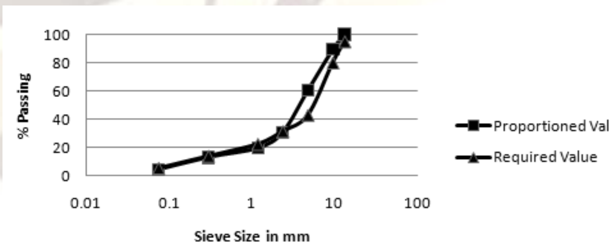

FIG.4 GRADATION CURVE FOR PROPORTIONED MIX

2.4 MARSHALL METHOD OF MIX DESIGN

Marshall Test is used for the bituminous mix design as per Indian (MoRTH) recommendation.

2.4.1 Principle of Marshall Method

Marshall Test is basically an unconfined compression test where load is applied to a cylindrical specimen of bituminous mix and the sample is monitored till its failure. The resistance to plastic deformation of the cylindrical specimen of bituminous mixture is measured when loaded at the periphery at 5 cm per minute. Stability and flow, together with density, voids and percentage of voids filled with binder are determined at varying binder contents to obtain an 'optimum' bitumen content for stability, durability, flexibility, fatigue resistance, etc.

The Marshall method of mix design essentially consists of the following three stages.

1. Bulk Density determination
2. Stability and Flow test
3. Density and Voids analysis

2.4.2. Marshall Apparatus

The Marshall test apparatus essentially consists of the following equipment as detailed in ASTM D 1559.

(a) Mould Assembly
(b) Compaction Pedestal and Hammer
(c) Breaking Head
(d) Loading Machine
(e) Flow meter

The whole setup including the breaking/test head is shown in Fig..5.

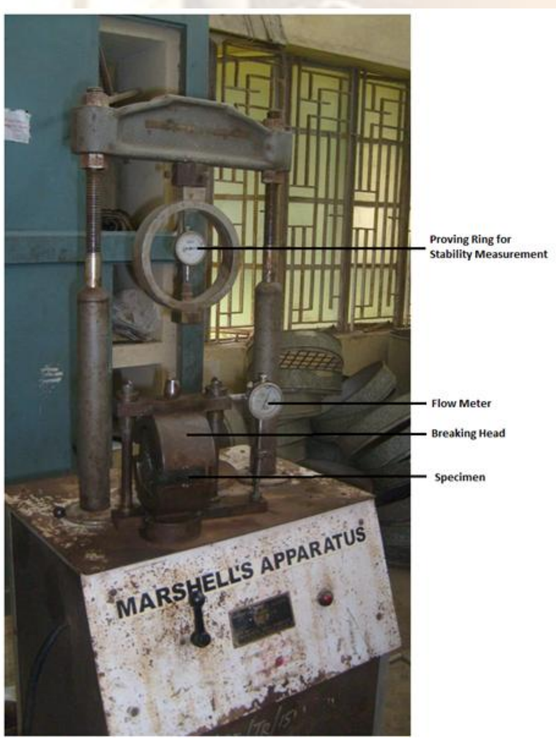

FIG.5 MARSHALL APPARATUS WITH BREAKING HEAD

2.4.3 Preparation of Marshall Compaction Specimens

The procedure for preparation of specimens for the Marshall test is detailed in this section and shown in Figure.6. A total of 81 specimens were prepared and tested in addition to the reference mix as detailed in Table.9.

(a) Weighing of materials: The materials for the sample viz. aggregates of three different sizes, 13.2 mm, 4.75 mm and stone dust, 60/70 grade bitumen and coir fibre of required length were weighed according to the proportioned values for the various mixes. 1350 grams of materials per mix was taken to obtain a theoretical density of 2.4-2.5 g/cc for the cylindrical samples.

TABLE .9 DETAILS OF MARSHALL COMPACTION SPECIMENS

% by Weight of Coir Fibre in Bituminous Mix	Length of Coir Fibre	Bitumen Content	Number Of Specimens
0.3%	10 mm	4%	3
		5%	3
		6%	3
	15 mm	4%	3
		5%	3
		6%	3
	20 mm	4%	3
		5%	3
		6%	3
0.5%	10 mm	4%	3
		5%	3
		6%	3
	15 mm	4%	3
		5%	3
		6%	3
	20 mm	4%	3
		5%	3
		6%	3
0.7%	10 mm	4%	3
		5%	3
		6%	3
	15 mm	4%	3
		5%	3
		6%	3
	20 mm	4%	3
		5%	3
		6%	3

(b) Weighing of materials: The materials for the sample viz. aggregates of three different sizes, 13.2 mm, 4.75 mm and stone dust, 60/70 grade bitumen and coir fibre of required length were weighed according to the proportioned values for the various mixes as given in Table 3.10. 1350 grams of materials per mix was taken to obtain a theoretical density of 2.4-2.5 g/cc for the cylindrical samples.

(c) Heating of aggregates: The aggregates of the required gradation were mixed in a pan. The coir fibre was also added to the aggregates and mixed well to ensure uniform distribution of fibre. The entire mixture was heated to a temperature of 150-160°C.

(d) Addition of bitumen: The weighed bitumen for a sample was added to the heated aggregate mix. The bitumen was heated to a liquid state and mixed well with the aggregates to get a homogenous mixture at 160-170°C.

(e) Pouring into mould: The homogenous bituminous mix was poured into the mould for compaction at 160-170°C to ensure compaction was done at 150°C. The cylindrical moulds with an inside diameter of 101.7 mm and a height of 76.2 mm, base plates, and extension collars shall conform to ASTM D1559 -Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus.

(f) Compaction of specimen: The specimen was compacted with 75 blows to each side of the cylindrical sample mounted on a standard mould assembly with a standard Marshall hammer that has a circular tamping face and a sliding weight of 4.536 kg with a free fall of 45.7 cm to get the Marshall Compaction Specimen. The compacted specimen was allowed to cool down to room temperature before extraction of the sample.

(g) Extraction of specimen: A steel disc with a diameter not less than 100 mm and a minimum thickness of 13 mm was used for extracting the compacted specimen from the mould by applying a slow gradual force using a hydraulic jack to the face of the specimen.

(a) (b)

(b) (d) (e)

FIG.6 PREPARATION OF MARSHALL COMPACTION SPECIMEN

(a) Mixing and Heating of Aggregates and Coir Fibre
(b) Addition of Bitumen and Heating
(c) Pouring of Sample into Mould
(d) Marshall Hammer Compaction Setup
(e) Compacted Specimen

2.4.4. Bulk Density Determination

It is necessary to determine the various density parameters for the sample like theoretical density, bulk density and specific gravity before testing for stability and flow. For this purpose the weight of the extracted sample was measured in air and in water.(Figure.7). The bituminous sample being porous may absorb water into its voids and hence it becomes necessary to coat the samples with wax to prevent the entry of water(Figure.8).. Before coating the samples with wax, the dimensions of the extracted sample were noted down at room temperature.

(a) (b)

FIG.7 EXTRACTION OF COOLED SAMPLE

(a) (b)

FIG.8 WAX COATING OF SAMPLES

2.4.5 Stability and Flow Value Test

ASTM D 1559 standards prescribe that the bituminous mix specimens must be tested at 60±1°C. To facilitate this, the wax coated samples after bulk density determination were kept in a water bath maintained at 60°C for 30-40 minutes as shown in Fig.9. The guide rods and the entire breaking head setup were cleaned and lubricated. The specimen was removed from the water bath and was placed with its axis horizontal to the test heads. The complete assembly was quickly placed on the base plate of the Marshall compression machine. The flow dial gauge was placed over the guide rod and the dial gauges of proving ring and flow meter were adjusted to read zero. The machine was set to operation for applying load until the maximum value was reached. The values of maximum load and the flow dial gauges were recorded and the machine was reversed and the failed specimen removed from the test head as shown in Fig.9

(a) (b)

FIG.9 STABILITY AND FLOW VALUE TEST

(a) Wax Coated Samples in Water Bath at 60°C
(b) Removal of Failed Specimen after Testing

3. RESULTS AND DISCUSSION

3.1 GENERAL

In this chapter, the various density and void parameters for the different bituminous mixes are calculated, analysed and presented. The results of the Marshall test on samples of coir fibre reinforced bituminous mixes are analysed and the Optimum Bitumen Content (OBC) for the various mixes are obtained. In a similar manner the Optimum Fibre Content (OFC) and Optimum Fibre Length (OFL) are also determined using the Marshall procedure. The values obtained for the coir reinforced mixes are compared with those obtained for conventional reference mix and the comparative performance of coir fibre reinforced bituminous mixes is discussed.

3.2 DENSITY AND VOID PARAMETERS

The Marshall method of mix design not only considers stability and flow of the bituminous mix but also takes into consideration the density, voids and percentage of voids filled with binder to determine the optimum bitumen content. This ensures that the OBC obtained gives an economical blend with sufficient workability and at the same time complying with the required standards. The density and void parameters are calculated using the guidelines of Manual Series MS-2 of Asphalt Institute. Detailed expressions for various parameters are presented in Appendix –A.

3.3 MARSHALL TEST RESULTS

The results of the Marshall Test i.e. Marshall stability and flow values, density and void parameters for the bituminous mixes are given in Table .10.

TABLE. 10. MARSHALL TEST RESULTS

Mix No.	% Bitumen	Coir Length mm	% Fibre	No. of Samples	Stability kN	Flow mm	Bulk Density g/cc	Theoretical Density g/cc	Bulk Specific Gravity	Volume of Voids	VMA	VFB
1	6	-	-	3	15.62	2.98	2.32	2.44	2.28	4.71	19.37	75.18
2	5	-	-	3	14.45	3.00	2.32	2.47	2.24	6.30	17.66	64.68
3	4	-	-	3	12.74	3.57	2.33	2.51	2.25	7.09	16.24	56.58
4	6	10	0.3	3	15.84	7.10	2.26	2.43	2.27	6.72	20.03	66.93
5	6	10	0.5	3	16.18	7.56	2.22	2.42	2.23	8.42	21.46	60.98
6	6	10	0.7	3	14.26	7.98	2.24	2.41	2.16	7.37	20.52	64.21
7	6	15	0.3	3	17.04	8.00	2.33	2.43	2.27	4.19	17.87	76.77
8	6	15	0.5	3	17.11	7.03	2.28	2.42	2.27	5.60	19.04	70.86
9	6	15	0.7	3	16.06	7.27	2.31	2.41	2.23	4.17	17.77	76.79
10	6	20	0.3	3	16.56	5.62	2.33	2.42	2.22	4.69	18.82	76.04
11	6	20	0.5	3	17.16	8.18	2.31	2.42	2.20	4.69	18.25	74.58
12	6	20	0.7	3	16.51	7.62	2.34	2.41	2.19	3.20	16.94	81.59
13	5	10	0.3	3	15.19	6.77	2.31	2.46	2.29	6.30	17.62	64.24
14	5	10	0.5	3	17.38	6.85	2.29	2.46	2.29	6.86	18.07	62.13
15	5	10	0.7	3	20.28	6.21	2.31	2.45	2.27	5.70	17.02	66.79
16	5	15.00	0.30	3	19.08	7.63	2.30	2.46	2.29	6.54	17.82	63.35
17	5	15.00	0.50	3	13.75	5.45	2.38	2.46	2.27	3.27	14.92	78.28
18	5	15.00	0.70	3	18.02	5.93	2.36	2.45	2.24	3.55	15.13	76.79
19	5	20.00	0.30	3	25.99	5.84	2.33	2.46	2.36	5.29	16.73	68.76
20	5	20.00	0.50	3	24.62	6.60	2.32	2.46	2.30	5.60	16.96	67.36
21	5	20.00	0.70	3	18.43	7.80	2.29	2.45	2.24	6.64	17.84	62.82
22	4	10.00	0.30	3	10.15	4.83	2.20	2.50	2.28	11.96	20.59	42.13
23	4	10.00	0.50	3	8.21	4.93	2.25	2.49	2.16	9.83	18.65	47.34
24	4	10.00	0.70	3	6.07	6.17	2.27	2.49	2.11	8.82	17.71	50.55
25	4	15.00	0.30	3	9.55	4.54	2.19	2.50	2.18	12.55	21.12	40.80
26	4	15.00	0.50	3	6.96	6.39	2.12	2.49	2.18	14.83	23.15	36.01
27	4	15.00	0.70	3	11.40	4.38	2.12	2.49	2.17	14.66	22.98	36.67
28	4	20.00	0.30	3	9.79	5.76	2.27	2.50	2.21	9.38	18.27	48.72
29	4	20.00	0.50	3	10.46	5.86	2.26	2.49	2.20	9.32	18.19	48.79
30	4	20.00	0.70	3	13.54	4.62	2.22	2.49	2.19	10.85	19.54	44.59

3.4 DETERMINATION OF OPTIMUM BITUMEN CONTENT (OBC)

The OBC for a mix having a particular fibre content and fibre length is determined by taking the average of the bitumen contents corresponding to the maximum Marshall stability, minimum flow, mean VV and mean VFB.

3.4.1 OBC for reference mix

Table.11gives the various parameters for the reference mix which is the conventional SDBC grade 1 bituminous mix without any addition of coir fibre. These values are plotted against the binder content as shown in Fig.10 and the binder content corresponding to the maximum stability, minimum flow, mean VV and mean VFB are taken and averaged. This gives the optimum binder content for the reference mix by the Marshall method. Table.12 gives the bitumen content corresponding to the optimum values.

TABLE.11 PARAMETERS OF REFERENCE MIX

Bitumen Content (%)	Stability in kN	Flow in mm	VV	VFB
6	15.62	2.98	4.71	75.18
5	14.45	3.00	6.30	64.68
4	12.74	3.57	7.09	56.58

TABLE.12 OPTIMUM BITUMEN CONTENT FOR REFERENCE MIX

Parameter	Value	Corresponding Bitumen Content (%)
Maximum Stability in kN	15.62	6.0
Minimum Flow in mm	2.98	6.0
Mean VV	6.03	5.2
Mean VFB	65.48	5.1
OBC		5.6

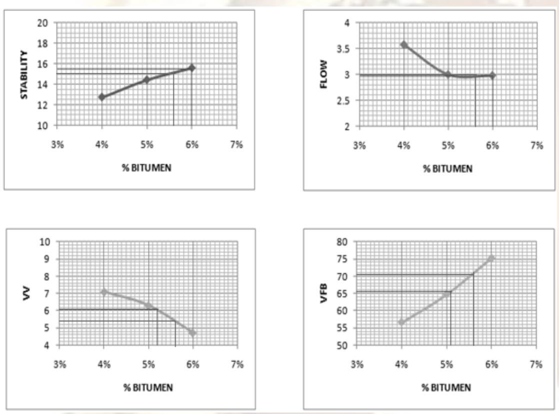

FIG.10 OPTIMUM BITUMEN CONTENT FOR REFERENCE MIX

After determining the OBC for the bituminous mix, the values of stability, flow, VV and VFB corresponding to this OBC are obtained from the graphs. These values for the reference mix are as shown in Table.13.

TABLE.13 PARAMETERS CORRESPONDING TO OBC OF REFERENCE MIX

OBC (%)	Stability in kN	Flow in mm	VV	VFB
5.6	15.50	3.00	5.40	65.00

3.4.2 OBC for Fibre Reinforced Bituminous Mixes

As detailed above, the optimum bitumen content by Marshall method of mix design and the corresponding parameters are obtained for the different mixes reinforced with coir fibre and presented in Table.14.

TABLE.14 OPTIMUM BITUMEN CONTENT FOR FIBRE REINFORCED BITUMINOUS MIXES

Mix	Fibre Length in mm	Fibre Content (%)	OBC (%)	Stability in kN	Flow in mm	VV	VFB
Reference	-	-	5.6	15.50	3.00	5.40	65.00
1	10	0.3	4.8	14.00	6.40	7.00	61.00
2	10	0.5	4.5	13.00	6.00	8.00	55.00
3	10	0.7	4.5	14.00	6.00	7.00	60.00
4	15	0.3	4.7	17.00	6.80	8.00	57.00
5	15	0.5	5.0	13.75	5.45	3.27	78.28
6	15	0.7	4.6	16.00	5.40	7.47	63.42
7	20	0.3	5.1	26.00	5.30	5.00	70.00
8	20	0.5	4.6	20.50	5.80	6.80	61.00
9	20	0.7	4.7	17.50	7.00	7.80	57.00

3.5 VARIATION OF MARSHALL PARAMETERS WITH RESPECT TO FIBRE CONTENT AND LENGTH

Table.15 and Table.16 details the values of Marshall stability, flow and mix volumetrics for varying fibre content and fibre length respectively.

TABLE.15 VARIATION OF MARSHALL PARAMETERS WITH RESPECT TO FIBRE CONTENT

Fibre Length in mm	Fibre Content (%)	OBC (%)	Stability kN		Flow mm		VV		VFB	
			Value	% Deviation	Value	% Deviation	Value	% Deviation	Value	% Deviation
10	0.30	4.80	14.00	2.44	6.40	4.35	7.00	4.55	61.00	3.98
	0.50	4.50	13.00	4.88	6.00	2.17	8.00	9.09	55.00	6.25
	0.70	4.50	14.00	2.44	6.00	2.17	7.00	4.55	60.00	2.27
15	0.30	4.70	17.00	9.09	6.80	15.58	8.00	28.07	57.00	13.94
	0.50	5.00	13.75	11.76	5.45	7.37	3.27	47.65	78.28	18.19
	0.70	4.60	16.00	2.67	5.40	8.22	7.47	19.58	63.42	4.25
20	0.30	5.10	26.00	21.88	5.30	12.15	5.00	23.47	70.00	11.70
	0.50	4.60	20.50	3.91	5.80	3.87	6.80	4.08	61.00	2.66
	0.70	4.70	17.50	17.97	7.00	16.02	7.80	19.39	57.00	9.04

It can be observed that for 10 mm fibre length, varying the fibre content does not affect the parameters but this is not the case with 15 mm fibre and 20 mm fibre reinforced bituminous mixes. Table 3.7 details the variation of Marshall test results with respect to fibre length. The properties of 10 mm fibre do not change much. It can be observed from the values obtained for 15 mm fibre, that

TABLE.16 VARIATION OF MARSHALL PARAMETERS WITH RESPECT TO FIBRE LENGTH

Fibre Content (%)	Fibre Length in mm	OBC (%)	Stability kN		Flow mm		VV		VFB	
			Value	% Deviation	Value	% Deviation	Value	% Deviation	Value	% Deviation
0.30	10	4.80	14.00	26.32	6.40	3.78	7.00	5.00	61.00	2.66
	15	4.70	17.00	10.53	6.80	10.27	8.00	20.00	57.00	9.04
	20	5.10	26.00	36.84	5.30	14.05	5.00	25.00	70.00	11.70
0.50	10	4.50	13.00	17.46	6.00	4.35	8.00	32.82	55.00	15.07
	15	5.00	13.75	12.70	5.45	5.22	3.27	45.71	78.28	20.88
	20	4.60	20.50	30.16	5.80	0.87	6.80	12.89	61.00	5.81
0.70	10	4.50	14.00	11.58	6.00	2.17	7.00	5.70	60.00	5.62
	15	4.60	16.00	1.05	5.40	11.96	7.47	0.63	53.42	5.96
	20	4.70	17.50	10.53	7.00	14.13	7.80	5.07	57.00	0.34

increase in fibre length marginally increases the stability while other parameters remain unchanged. Further increase in fibre length (20 mm) significantly increases stability of the mix and there is a marginal decrease in air voids.

3.6 DETERMINATION OF OPTIMUM FIBRE CONTENT

The optimum fibre content for a mix having a particular fibre length is determined following the same procedure used for obtaining the optimum binder content. Table.17 gives the various parameters for the bituminous mix with 10 mm coir fibre. The OFC for 10 mm fibre length is computed from the graphs as shown in Fig.11.

TABLE.17 PARAMETERS OF 10 MM COIR REINFORCED BITUMINOUS MIX

% Fibre	OBC (%)	Stability in kN	Flow in mm	VV	VFB
0.3	4.80	14.00	6.40	7.00	61.00
0.5	4.50	13.00	6.00	8.00	55.00
0.7	4.50	14.00	6.00	7.00	60.00

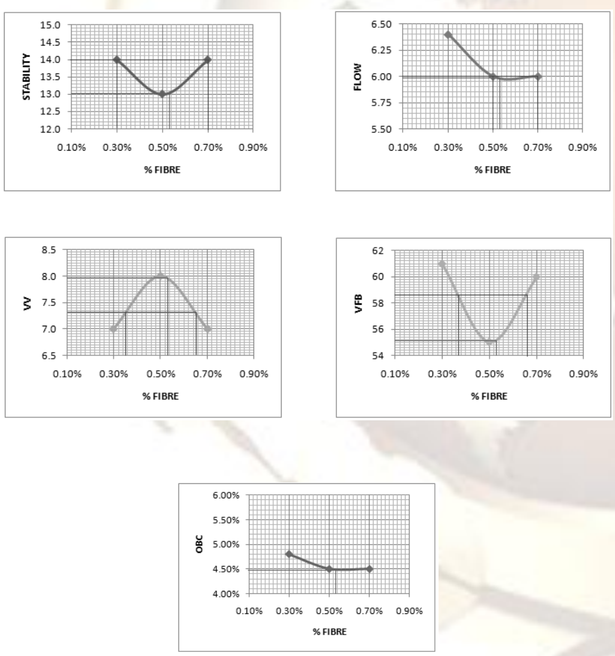

FIG.11 OPTIMUM FIBRE CONTENT FOR 10 MM FIBRE

Table.18 gives the fibre content corresponding to the optimum values of stability, flow, VV and VFB.

TABLE.18 OPTIMUM FIBRE CONTENT FOR 10 MM MIX

Parameter	Value	Corresponding % Fibre Content
Maximum Stability in kN	14.00	0.50
Minimum Flow in mm	6.00	0.60
Mean VV	7.33	0.51
Mean VFB	58.67	0.51
OFC		0.53

On determination of the optimum fibre content for the 10 mm fibre reinforced mixes, the values of stability, flow, VV and VFB corresponding to this OFC are obtained from the graphs. These values are given in Table.19.

TABLE.19 PARAMETERS CORRESPONDING TO OFC

Fibre Length in mm	Ofc	Stability in kN	Flow in mm	VV	VFB	OBC
10	5.30	13.00	6.00	7.95	55.2	4.5

In a similar manner the optimum fibre content for 15 mm fibre and 20 mm fibre reinforced mixes are also obtained and the findings are tabulated in Table.20.

TABLE.20 OPTIMUM FIBRE CONTENT FOR DIFFERENT FIBRE LENGTHS

Mix	Fibre Length in mm	OFC	OBC	Stability in kN	Flow in mm	VV	VFB
1	10	0.53	4.50	13.00	6.00	7.95	55.20
2	15	0.51	5.00	13.70	5.40	3.25	79.00
3	20	0.38	4.90	23.50	5.40	5.80	66.00

3.7 DETERMINATION OF OPTIMUM FIBRE LENGTH

The optimum fibre length following the investigations on fibre reinforced bituminous mixes is obtained by adopting the Marshall procedure of determination of OBC. Table.21 gives the various parameters for the three different lengths of coir fibre. These values are plotted against the fibre length as shown in Fig.12.

TABLE.21 PARAMETERS FOR VARYING LENGTHS

Fibre Length in mm	OFC	OBC	Stability in kN	Flow in mm	VV	VFB
10	0.53	4.50	13.00	6.00	7.95	55.20
15	0.51	5.00	13.70	5.40	3.25	79.00
20	0.38	4.90	23.50	5.40	5.80	66.00

Table.22 gives the value of stability, flow, VV and VFB corresponding to the optimum fibre length thus obtained.

TABLE.22 PARAMETERS CORRESPONDING TO OFL

OFL mm	OFC	OBC	Stability in kN	Flow in mm	VV	VFB
17.25	0.46	5.00	17.50	5.36	4.00	76.00

3.8 PERFORMANCE OF COIR FIBRE REINFORCED MIXES

On detailed analysis of the Marshall test results, the optimum values of bitumen content, fibre content and fibre length for coir fibre reinforced bituminous mix are obtained as follows.

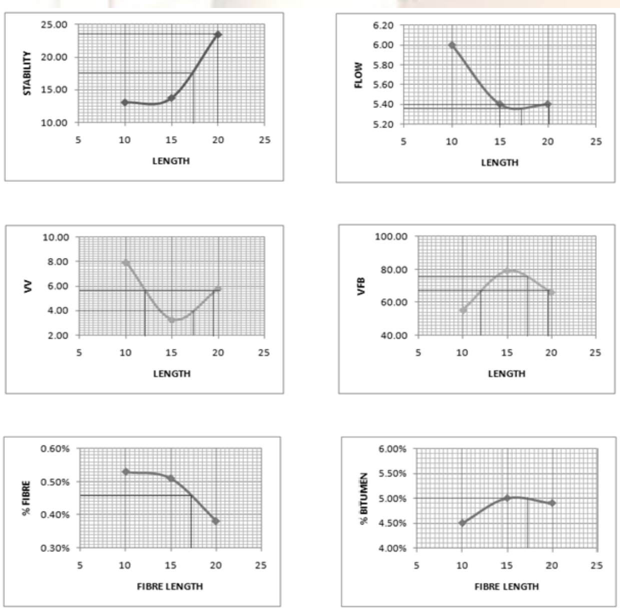

FIG.12 OPTIMUM FIBRE LENGTH FOR COIR FIBRE REINFORCED BITUMINOUS MIXES

Optimum Bitumen Content : 5.00%
Optimum Fibre Content : 0.46%
Optimum Fibre Length : 17.25 mm

The parameters like stability, flow, VV and VFB corresponding to the above optimum values are also obtained. This performance of coir fibre reinforced bituminous mixes is compared with that of unreinforced reference mix in this section. The performance of the reference mix and the final optimum coir fibre reinforced mix is also compared with the MoRTH specifications for semi dense bituminous concrete grade 1 and checked whether all the parameters are within specified limits. Table. 23 gives the values of various parameters of the bituminous mixes.

TABLE. 23 COMPARATIVE PERFORMANCE OF FIBRE REINFORCED BITUMINOUS MIX

Parameter	SDBC Requirements (MoRTH)	Reference Mix	Coir Fibre Reinforced Mix	% Increase/ Decrease
Bitumen Content (%)	4.5 Min.	5.6	5.0	-10.7
Marshall Stability at 60°C in kN	8.2	15.50	17.50	+12.9
Flow in mm	2-4	3.00	5.36	+78.7
Volume of Voids	3-5	5.40	4.00	-25.9
Voids Filled with Bitumen	65-78	65.00	76.00	+16.9

3.8.1 Comparative Performance of Coir Fibre Reinforced Bituminous Mix

On observing the values presented in Table.23, a comparison can be drawn between conventional unreinforced bituminous mix and coir reinforced bituminous mix.The optimum bitumen content for semi dense bituminous concrete should be more than 4.5% and this is true for both the reference mix and the coir fibre reinforced mix. But the OBC content decreases by 10.7% when coir fibre is added to the SDBC mix. This indicates that fibre reinforcement in bituminous mixes will lead to an economic mix with lower binder content.

There is a significant increase in the Marshall stability value on addition of coir fibre. This increase in stability by nearly 13% will help achieve stronger pavement sections. Such an increase may be attributed to the improved load transfer mechanism on addition of coir fibre to the bituminous mix.

The flow value is nearly doubled in magnitude on addition of coir fibre reinforcement to the bituminous mix. From Table.17, it can be inferred that the flow value decreases with increasing fibre length. This decrease in flow value due to increase in the length of the fibre reinforcement is due to the fact that increase in length of fibre provides improved interlock of fibres and hence minimises the vertical deformation on application of compressive load. But practically, on increasing the fibre length, it becomes difficult to obtain a homogeneous bituminous mix since balling of fibre occurs. Also from the literature studies it is observed that beyond a critical fibre length the stability remains constant and hence increase in fibre length beyond a certain value is not preferable.

The volume of voids 4% observed in coir fibre reinforced bituminous mix lies within the specified limits of 2-4% prescribed for SDBC. This value is a 26% decrease when compared to the percentage voids 5.4% obtained for the reference mix. This decrease in the percentage voids in the mix shows that the mix is well reinforced by the coir fibre and more homogeneous than the reference mix. Also the percentage voids filled with binder increases by 17% on addition of coir fibre thus improving the performance of the bituminous mix.

TABLE.24 COMPARATIVE PERFORMANCE OF DIFFERENT FIBRES

Fibre Type		OBC %	OFC %	OFL mm
Coir Fibre	**Natural**	**5.00**	**0.46**	**17.25**
Cellulose	Natural	6.95	0.35	5.00
Glass Fibre	Artificial	5.80	0.25	15.00
Jute Fibre	Natural	6.10	0.10	6.00
Polyester	Artificial	4.62	0.25	8.00
Polypropylene	Artificial	5.50	0.30	10.00

Table.24 gives the comparative performance of different fibres as obtained from the literature studies. It can be observed that among the natural fibres, coir fibre requires the least amount of binder and hence it can be said to be the one giving the most economical mix. The percentage fibre content is seen to decrease with decreasing fibre length and hence we get a comparatively higher fibre content of 0.46% for the coir fibre with 17.6 mm length.

4 CONCLUSION

4.1 GENERAL

In this chapter, the salient features of this project work on coir reinforced bituminous mixes are examined and conclusions are drawn after a detailed analysis of the results obtained. The scope for future investigations in the same area of study is also discussed.

4.2 SUMMARY OF EXPERIMENTAL RESULTS

A total of ninety samples of semi dense bituminous concrete including the reference mix were tested. The mix variables were as follows.

Fibre type Coir fibre
Fibre content 0.3%; 0.5%; 0.7%
(By weight of the mix)
Fibre length 10mm; 15mm; 20mm
Bituminous mix Semi Dense Bituminous Concrete Grade 1
Bitumen content 4%; 5%; 6%

Adopting the Marshall method of mix design the mix volumetrics were computed along with tests for Marshall stability and flow. The optimum bitumen content and its corresponding parameters were determined for the reference mix. The optimum bitumen content, optimum fibre content and the optimum fibre length were computed for the coir fibre reinforced bituminous mix and the following result was obtained.

Optimum Bitumen Content : 5.00%
Optimum Fibre Content : 0.46%
Optimum Fibre Length : 17.25 mm

The values of stability, flow, density and void parameters corresponding to the above optimum conditions were determined and compared with the values obtained for the reference mix (Table.23) to understand the comparative performance of coir fibre reinforced bituminous mix.

4.3 CONCLUSIONS

Addition of coir fibre to semi dense bituminous concrete mix contributes significantly in improving the performance of the mix. Stability value increases by 1.3 times when compared to the reference mix making the mix more stable for the traffic load. However, flow value showed an increment of about 1.8 times on comparison with the reference mix.

The strength and void parameters of the coir fibre reinforced bituminous mix also satisfy the requirements of Specifications for Road and Bridge Works (up-gradation of third revision), MoRTH.

No significant variation in the optimum bitumen content was observed even with addition of coir fibre. The OBC for coir fibre reinforced bituminous mix reduced by 8.9% when compared to the reference mix. With this, it can be concluded that additional bitumen is not required to prepare fibre reinforced SDBC mix.

From the test results obtained, the optimum fibre content computed was 0.46% by weight of the total mix. The Marshall parameters corresponding to this fibre content satisfies the requirements of MoRTH. The optimum fibre length determined from the results was 17.25 mm whose results also satisfy MoRTH specifications for SDBC. The values of OFC and OFL obtained are in agreement with already published literature on coir fibre (OFC – 0.5-0.7%; OFL – 10-20 mm) reinforced bituminous mixes.

4.4 SCOPE FOR FUTURE WORK

A systematic study is required to understand the elastic behaviour of coir fibre reinforced semi dense bituminous concrete as the coir is likely to impart more expandability to the bituminous mix.

Experimental investigations on the rutting behaviour of coir fibre reinforced bituminous mixes will help understand the performance of the mix under loading.

- Case study on the abrasive resistance of coir fibre reinforced semi dense bituminous concrete may also be attempted.

5. REFERENCES

[1]. Abtahi, et al (2009) Fibre Reinforced Asphalt Concrete – A Review. *Construction Building Materials* and Building Materials, Iran.

[2]. Chen and Wu (2009) Experimental Study of Fibres in Stabilizing and Reinforcing Asphalt Binder. *Fuel*, China.
[3]. IS 73-2006, Paving Bitumen – Specifications, Third Revision, *Bureau of Indian Standards.*
[4]. MoRTH, Specifications for Road and Bridge Works, Upgradation of Third Revision, *Ministry of Road Transport and Highways.*
[5]. Panda, N. (2010) Laboratory Investigation on Stone Matrix Asphalt using Sisal Fibre for Indian Roads. *B.Tech. Project*, India.
[6]. Tapkin, S., et al (2009) Repeated Creep Behaviour of Polypropylene Fibre Reinforced Bituminous Mixtures. *Journal of Transportation Engineering*, Turkey.
[7]. Wu, et al (2009) Investigation of the Dynamic and Fatique Properties of Fibre Modified Asphalt Mixtures. *International Journal of Fatuque* (31), China, 1598-1602
[8]. Yamuna,Studies on Suitability of Coir Fibre Reinforced Cement Composite as a Pavement Quality Material, M.Tech. *Thesis*, Pondicherry University, 2008.