Journal of Civil Engineering (IEB), 44 (2) (2016) 111-120

Coir fiber reinforced bituminous concrete

Faria Haider, Md. Saifur Rahman, Md. Tawfiq Rahman and Md. Shariful Islam

Department of Civil Engineering
Ahsanullah University of Science and Technology, Dhaka 1208, Bangladesh

Received 11 March 2016

Abstract

The objective of the experiment is to introduce fiber into the matrix of bituminous concrete in order to contribute it with additional tensile strength. It is expected to give a more firm mixture with better compressibility, stability and durability. The introduction of fiber is expected to provide more abrasive resistance and increased void tends to decrease bleeding with applied loads and compaction. The proposed work, presents the studies on stability, flow and volumetric properties of the coir fiber reinforced bituminous concrete by varying the binder content (4%, 5% and 6%), fiber content (0.3% ,0.5% and 0.7%) and fiber length (10 mm,15mm and 20mm). Optimum binder content, optimum fiber content and optimum fiber length of the coir fiber reinforced bituminous concrete was obtained and compared with the non-fibered reference mix.

Keywords: Coir, aggregate, control mix, Marshall Method, optimum bitumen content, optimum fiber length, VIM, VFB.

1. Introduction

The stature of a nation or a country is envisaged by its progression in structural and socio-economical standard. The development of a nation is primarily dependent upon contribution of all of its parts to its peak. To ensure such connectivity, alignment and maintenance of its network system plays the major role. The best means of network system is roadways. The alignment and design being a crucial engineering concern, meet its requirement to standard. But the forgotten promises of roadway development are its maintenance. In developing countries like Bangladesh there is a mismatch of budget and concern to roadway maintenance, and regulatory measures for conformity to roadway standards.

It is a usual overlooked crime to overload the streets beyond its design capacity permits, which meets no regulatory measures. This leads to destruction of roadway structures, and concerned bodies rarely make a move to remedy. This leads to mismanagement and economical loss. Two major damages are seen for flexible pavements, rutting and cracking. Rutting can be overcome by the use of modified binders with additives like crumb rubber, natural rubber, polymers, etc. However, the problem of fatigue cracking is still persistent. Fatigue cracking occurs because bituminous layers are weak in tension. Therefore, reinforcement of the bituminous mixes is one approach to improve the tensile strength. Fibers are the most suitable reinforcing material for bituminous mixes.

Natural fibers are good substitute for synthetic fibers due to their lower cost, ecological recycling and low specific gravity. Among natural fibers growing attention is nowadays being paid to coir fiber due to its easy availability, good-wearing resistance and more durable property.

In our experiment the variables are fiber content (0.3%, 0.5%, 0.7%), fiber length (10mm, 15mm, 20mm) and binder content (4%, 5% and 6%). Stability, flow and volumetric properties of the mixes are taken as observed parameters for the present work. Marshall Test method was adopted for the required parameter analysis.

2. Material description

Three materials are used for sample preparation, there description and characteristics are presented below:

2.1 Aggregates

They are major constituent of volume and strength and are selected in combination of three gradation sizes, 13.2mm, 4.75mm & stone dust as filler. They are angular in texture and must meet following criteria.

Table 1
Physical requirements of coarse aggregates

Property	Test	Value, %
Cleanliness	Grain size analysis	5 max passing 0.075mm sieve
Strength	Aggregate impact value	27 max
Water absorption	Water absorption	2 max
Stripping	Static immersion test	95 min retained coating

Table 2
Gradation for semi dense bituminous concrete

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

2.2 Bitumen

It is the binding reagent that supplies cohesion to the bituminous matrix in order to carry out loads superimposed over it. 80/100 grade is mostly used in Bangladesh so is chosen. It should meet the following criteria.

Table 3
Material characteristic of bitumen

Property	Value
Penetration (mm)	80~100
Specific Gravity	1.129
Softening Point (°C)	50~60
Ductility (mm)	>100
Static Immersion Test	No Visible Stripping

2.3 Coir

Coir fibers are found between the hard, internal shell and the outer coat of a coconut. The individual fiber cells are narrow and hollow, with thick walls made of cellulose. They are pale when immature, but later become hardened and yellowed as a layer of lignin is deposited on their walls. The two varieties of coir are brown and white. Brown coir harvested from fully ripened coconuts is thick, strong and has high abrasion resistance & are preferably used in our experiment, meeting the following criteria.

Table 4
Properties of coir fibers as obtained from literature

Property	Value
Diameter (mm)	0.1-0.4
Density (g/cm3)	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

3. Methodology

Marshall Test method adapted to obtain stability and volumetric properties of coir mix and control mix without coir and performance compared. Three bituminous proportions used (4%, 5%, and 6%) along with coir proportions of (0.3%, 0.5%, and 0.7%) of three selected lengths (10mm, 15mm, 20mm). The control mix used to obtain the optimum bitumen content for the reference mix without coir and corresponding stability, flow, void in mixture (VIM) and voids filled with bitumen (VFB) values obtained. The rest 27 coir mixtures used to obtain the optimum coir concentration and length along with the previously mentioned stability and volumetric properties. The combination is presented in the following flow chart.

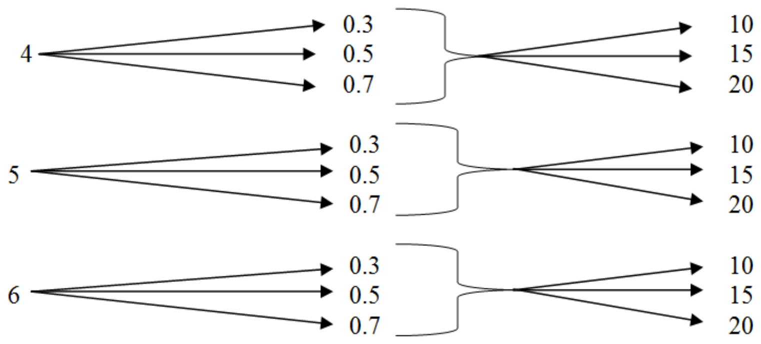


Fig. 1. Bitumen content (%), Coir content (%) and Coir length (mm)

The process to obtain optimum for coir mix is very simple, and uses the Marshall method. Three variables namely binder content, coir content and coir length. Each time two variables kept fixed and one analyzed. First, for a specific binder content and length Marshall Method used to derive optimum bitumen for the mix and the stability, flow and volumetric properties. In the second step for each specific coir length, coir content is taken as variable and graphs plotted against it as per Marshall Method. Optimum coir & bituminous content along with other Marshall parameters are thus obtained corresponding to individual fiber length. In the final step Marshall Parameters are plotted corresponding to variable coir length to obtain optimum fiber length, content and corresponding bituminous content and other Marshall parameters.

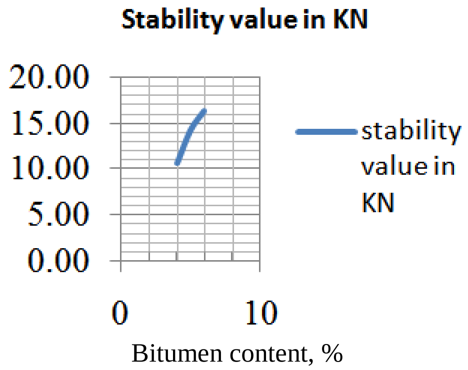
4. Results and discussion

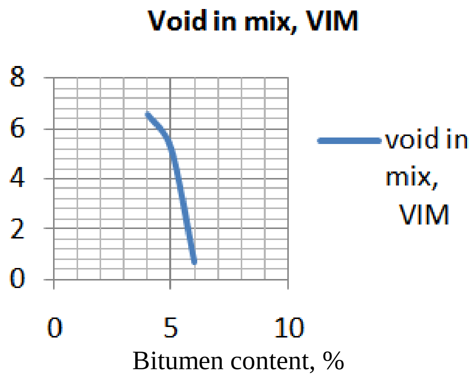
Table 5
Marshall Test parameters of the samples

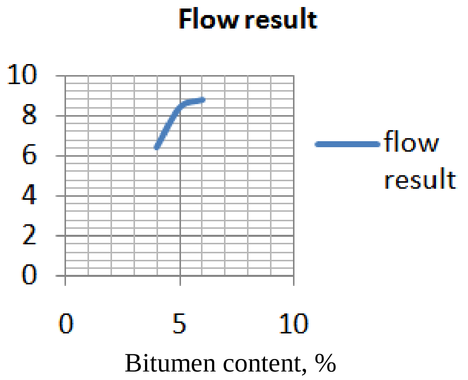
Specimen No.	Bitumen Content, %	Fiber Content, %	Fiber Length, mm	Stability Value (KN)	Flow Result	Void in mix, VIM	Voids filled with bitumen, VFB
1	4	0	0	10.58	6.4	6.59	37.13
2	5	0	0	14.24	8.4	5.23	53.42
3	6	0	0	16.34	8.8	0.69	92.35
4	4	0.3	10	7.02	10	8.25	35.27
5	4	0.5	10	10.33	11.2	5.18	49.64
6	4	0.7	10	8.35	16.4	9.23	36.61
7	5	0.3	10	11.22	11.76	2.82	70.82
8	5	0.5	10	8.66	14.24	2.67	73.28
9	5	0.7	10	6.68	17.6	5.96	55.78
10	6	0.3	10	9.00	17	6.58	54.30
11	6	0.5	10	10.00	18	6.20	57.52
12	6	0.7	10	8.00	18.5	10.37	45.12
13	4	0.3	15	9.26	15.6	6.89	39.84
14	4	0.5	15	7.13	19.6	8.67	36.22
15	4	0.7	15	7.25	24.8	8.27	39.44
16	5	0.3	15	19.00	20	6.91	45.72
17	5	0.5	15	13.00	19	7.72	43.52
18	5	0.7	15	18.00	19.5	8.57	42.85
19	6	0.3	15	13.89	14.04	0.40	95.82
20	6	0.5	15	10.29	13.92	2.85	76.61
21	6	0.7	15	11.41	15.28	3.16	75.49
22	4	0.3	20	10.52	13.2	5.27	46.85
23	4	0.5	20	8.72	16.52	6.38	44.16
24	4	0.7	20	7.30	19.8	7.69	41.35
25	5	0.3	20	22.00	16	4.07	59.61
26	5	0.5	20	20.00	17	6.50	48.11
27	5	0.7	20	17.50	18	8.57	42.85
28	6	0.3	20	12.60	11.88	0.03	99.64
29	6	0.5	20	10.84	15.92	2.01	82.39
30	6	0.7	20	9.73	18.72	4.39	68.70

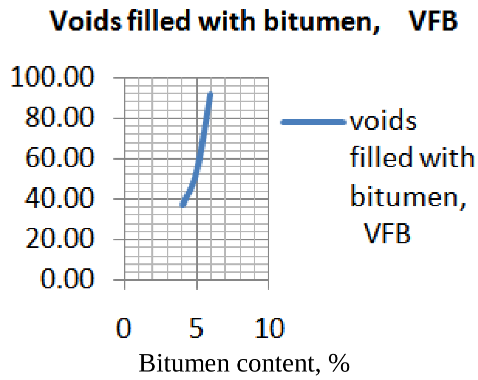
Thirty (30) Marshall Samples made 3 reference samples without coir for comparing the performance of coir mixture and rest 27 coir samples of different combination of content, length and binder content. The results of the Marshall test namely stability, flow, VIM and VFB for all thirty samples are presented in Table 5.

For the reference mix optimum bitumen content and corresponding stability, flow and volumetric properties are obtained from the following graphs.









Parameters	Corresponding bitumen content %
Maximum stability	6
Minimum flow	4
Mean void in mixture(vim)	5.25
Mean void filled with bitumen(vfb)	5.25
Corresponding average bitumen content	5.125

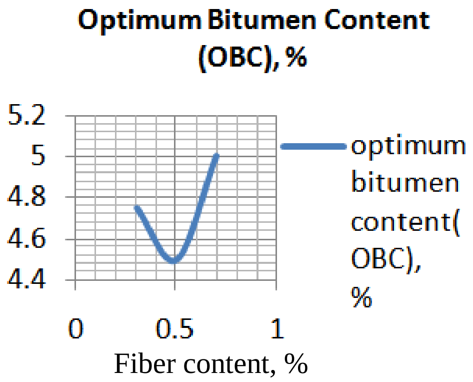
At bitumen content of 5.125 VFB value not satisfied to range (65~80) and reads 55%. So, new bitumen content chosen to satisfy standard requirements of all parameters. At 5.5% bitumen content requirements are satisfied and read such.

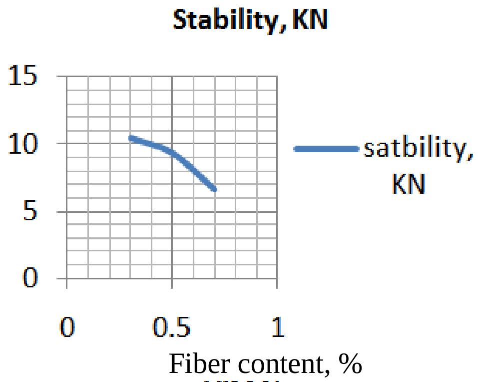
Optimum Bitumen Content(OBC), %	Stability (KN)	Flow (mm)	VIM %	VFB %
5.5	15.2	8.7	3.2	70

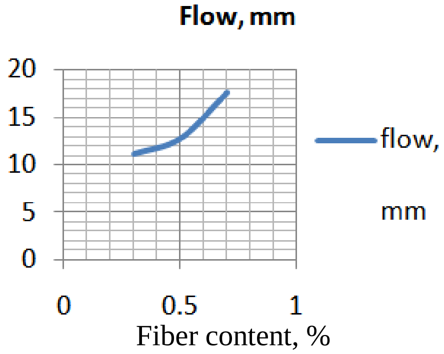
In the very similar fashion optimum binder content and corresponding stability, flow, VIM & VFB for different combinations (length & content) of fiber reinforced bitumen samples are recorded and presented below. To find the optimum fiber content corresponding to each fiber length similar Marshall analysis applied with the variable being fiber content as shown below for 10mm fibers:

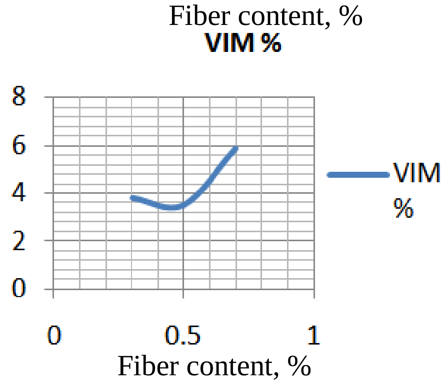
Table 6
Optimum bitumen content and corresponding parameters for different mix

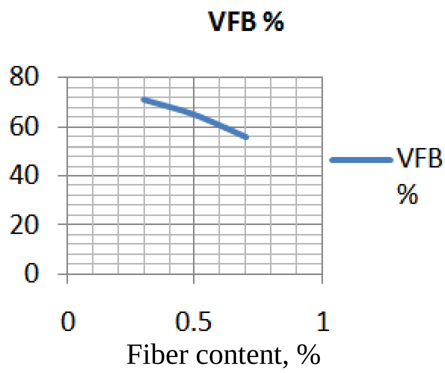
Sample	Fiber Content (%)	Optimum Bitumen Content (OBC) (%)	Stability (KN)	Flow (mm)	VIM (%)	VFB (%)
Reference mix	0	5.5	15.2	8.7	3.2	70
10mm fiber	0.3	4.75	10.4	11.2	3.8	71
	0.5	4.5	9.28	12.8	3.5	65
	0.7	5	6.6	17.6	5.9	56
15mm fiber	0.3	5.5	17	17.5	4.2	69
	0.5	5.75	11	15.2	4.2	68
	0.7	5.75	13.4	16.5	4.6	66
20mm fiber	0.3	5.25	21.2	15.6	3.2	68
	0.5	5.75	14	16.3	3.4	72
	0.7	6	9.6	18.72	4.3	68







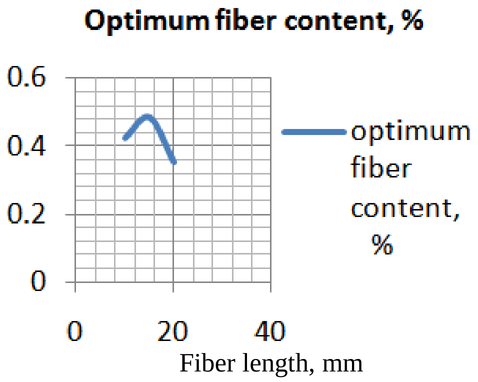


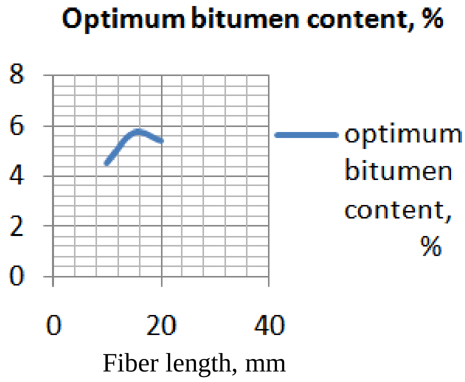


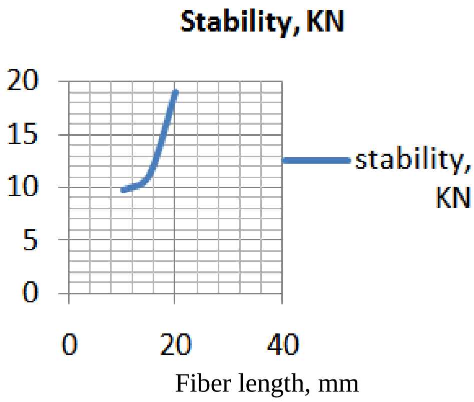
Parameters	Corresponding fiber content
Maximum stability	0.3
Minimum flow	0.3
Mean void in mixture (vim)	0.59
Mean void filled with bitumen (vfb)	0.52
Corresponding average fiber content	0.4275

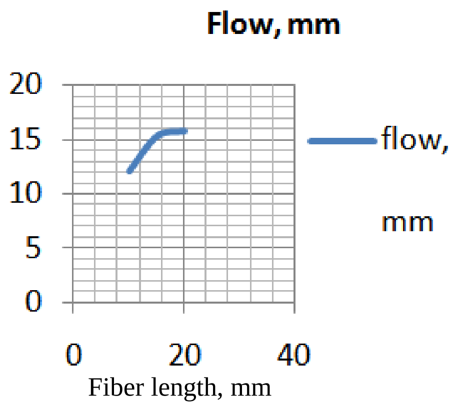
To three decimal pace let the chosen mean fiber content is 0.425%. At this proportion corresponding parameters meet the requirements as shown.

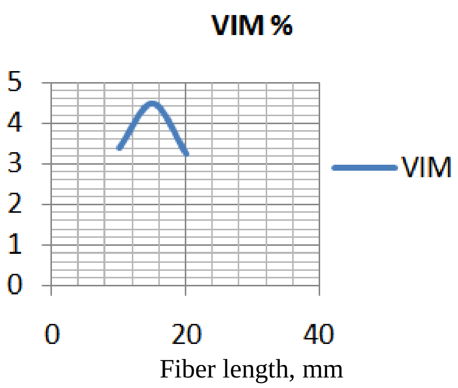
Fiber length, mm	Optimum fiber content, %	Optimum bitumen content, %	Stability, KN	Flow, mm	VIM, %	VFB, %
10	0.425	4.5	9.8	12	3.4	67

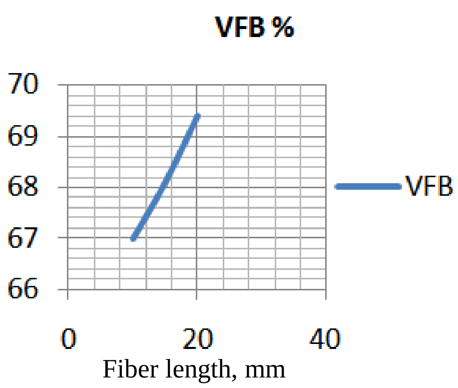












Parameters	Corresponding fiber length, mm
Maximum stability	20
Minimum flow	10
Mean void in mixture(vim)	18
Mean void filled with bitumen(vfb)	15.5
Corresponding average fiber length	15.875

Similarly optimum fiber content for other fiber length combination is derived and shown.

Table7
Optimum fiber content and corresponding parameters for variable coir length

Fiber length, mm	Optimum fiber content, %	Optimum bitumen content, %	Stability, KN	Flow, mm	VIM %	VFB %
10	0.425	4.5	9.8	12	3.4	67
15	0.485	5.735	11.2	15.275	4.5	68.1
20	0.355	5.4	19	15.75	3.25	69.4

Finally, to achieve optimum fiber length and corresponding parameters, Marshall Analysis made with fiber length as variable are as shown.

Let selected fiber length be 16 mm. At 16 mm fiber length the parameters conforms such:

Optimum fiber length (mm)	Optimum fiber content (%)	Optimum bitumen content, %	Stability (KN)	Flow (mm)	VIM %	VFB %
16	0.475	6	12	15.5	4.4	68.4

Comparison of performance of coir mix with reference mix is presented below:

Parameters	Semi dense bituminous concrete(SDBC) requirements	Reference mix	Coir fiber reinforced mix	% increase/decrease
Bituminous content (%)	4.5 minimum	5.5	6	9.090909091
Marshall stability at 60'c(KN)	8.2 minimum	15.2	12	-21.0526316
Flow(mm)	8~18	8.7	15.5	78.16091954
Air voids in mix (%)	3~5	3.2	4.4	37.5
Voids filled with bitumen (%)	65~80	70	68.4	-2.28571429

In fiber mix the fibers in the matrix forms an interconnected network (at required length and proportion) that tends to hold the aggregates together and forms a barrier to load and inelastic deformation. It can be viewed as that of a spider net that has very high strength to weight ratio. A spider net can take on relatively large superimposed loads as the load is distributed over a large region due to interconnected network of mesh that reduces stress. Similar phenomenon is expected that for a fibered mix.

But in case of bituminous mix the friction generated by the fiber network should be in a balance with necessary minimum cohesion supplied by the binder to make a perfect blend. The optimum coir mix shows negative result compared to reference mix, with considerable loss of strength, increase of flow and higher bitumen content giving a non-economical mix. But it is observable from (Table 6) that at a coir content of 0.3% and length 20mm gives the most stable and durable mix. Stability creeps up to 21.2 KN and considerable flow of 15.6 so the mix is more consistent and less prone to cracking and brittleness. Bitumen requirement is lower compared to reference mix giving a more economical mix. It is also observable from same table that at lower coir length (10 & 15mm) strength is greatly reduced and flow increased. At lower length there are reduced connections of fibers with aggregates at its vicinity promoting lower frictional resistance at applied surcharge. For the very same reason downward deflection is not prevented to necessary scale and hence flow increased. Though at similar fiber content binder requirement for smaller fiber length is less compared to longer ones. This is because at longer lengths of same proportion more fiber is exposed and binder effectively coated around it along with aggregates, promoting cohesion and friction to its maximum. At lower length of same proportion the mix is clumsy and effective coating is not achieved. This is also another major reason for fall of strength of small length fibered mix, as necessary cohesion is not achieved. For the similar reason small fiber length mix gives rise to high proportion of void.

Also for each selected length combinations strength tends to fall and flow increases as fiber content increased. It justifies that high fiber content tend to decrease firmness of the mixture, as more fiber distribution reduces aggregate contact which is the primary volume and strength material. For the same reason flow also tends to increase. So, lower fiber content is justified for the mix. Fiber being lighter tends to occupy more volume so increased fiber content demands for increase of binder. The mix becomes less consistent and the evidence is reflected by the increased void.

The design mix of 20mm length 0.3% fiber at binder content of 5.25% gives the most desirable result. Due to long length, connections are bridged and maximum aggregate size being 13.2 mm there are at least of two aggregates bridged along with individual fiber, so a very distributed and rigid interconnected formwork built that tends to resist load as a whole, hence stability increases. As the unit flows as whole a more flexible mix is attained and at applied loads it tends to undergo large downward deflections, so flow value also tends to increase. Also the design fiber mix has lower optimum binder content requirement, so less cohesion hence more flow value. But still high strength, which signifies that fiber network generates more available and distributed friction. The necessary amount of friction and cohesion are in equilibrium for the design mix.

A combination of large stability along with flow makes the design mix less brittle and less prone to crack at heavy loading.

5. Conclusion and recommendations

The addition of coir fiber enhances the properties of bituminous mixtures by increasing its stability and also flow value, but within permissible range. Void content and VFB remains unchanged. The variation in stability and flow values make the bituminous concrete acquire the potential to improve structural resistance to distress occurring in flexible road pavement due to traffic loads. Fiber length of 20 mm with a fiber content of 0.3% and a binder content of 5.25% provides good stability and volumetric properties. It was observed that addition of coir fiber improves compressibility of the mix. This makes the mix more durable under moving wheel loads. A variety of available modifications to bituminous pavements could improvise its performance. Some are stated in the following:

- In our experiment we observed that the expected result was confined by maximum available fiber length of 20mm with minimum content of 0.3%. So we could further expand the work with higher fiber lengths, example 20~30mm and observe the performance. If better result obtained we should continue till the fall of performance. So the optimum length contributing to maximum strength could be achieved.

- Our experiment was performed using 80/100 grade bitumen. Performance of coir mix with variable grades of bitumen could be checked for consistency or the design coir mix pattern change with grade be observed.

The effect of rutting behavior is supposed to be overcome by polymerizing the bitumen with elastic materials like crumb rubber and wax. Such mix could be processed in laboratory to observe the performance. If positive result outbursts we could combine the polymerized bitumen with fiber to create the ideal mix that can withstand any sort of structural distress to road surface.

References

Kaloush, Zeiada, Biligiri, Rodezno, and Reed (2008), Paper on Evaluation Of Fibre-Reinforced Asphalt Mixtures Using Advanced Material Characterization Tests, Department of Civil Engg. , Arizona State University.

V. L. Narasimha and K. Thulasirajan / International Journal of Earth Sciences and Engineering ISSN 0974-5904, Volume 04, No. 06 SPL. October 2011, pp 835-838.

Stempihar, Souliman and Kaloush/ ACRP 11-04 Airport Cooperative Research Program – 2011 Graduate Student Award Program, Use of Fiber Reinforced Asphalt Concrete as a Sustainable Paving Material for Airfields.

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.

Tapkin, S., et al (2009) Repeated Creep Behaviour of Polypropylene Fibre Reinforced Bituminous Mixtures. *Journal of Transportation Engineering*, Turkey.

Yamuna Studies on Suitability of Coir Fibre Reinforced Cement Composite as a Pavement Quality Material, M.Tech. *Thesis*, Pondicherry University, 2008.

IS 73-2006, Paving Bitumen – Specifications, Third Revision, *Bureau of Indian Standards.*

MoRTH, Specifications for Road and Bridge Works, Upgradation of Third Revision, *Ministry of Road Transport and Highways.*