EFFECT OF COIR FIBRE LENGTH ON MECHANICAL PROPERTIES AS BITUMINOUS FIBRE IN HIGH STRENGTH CONNRETE

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ABSTRACT: In India, the flexible pavements acquire most of the total road network. Hot mix technology has numerous drawbacks. Some of them are the liberation of greenhouse gases, high consumption of energy, health hazards to construction labours, etc. Compared to hot bituminous mixes, fewer studies have been done to ascertain the effect of fibre on the performance of cold bituminous mixes. This study aims to assess the performance of CBM by adding a natural fibre (coir), which is abundant and cheaper in India. The objectives of the study are to identify the Optimum In the present study, an attempt has been made to study the effect of coir fibre used as an additive in CBM. Bitumen emulsion content is varied from 7% to 9%, and fibre content is varied from 0.1% to 0.3%. The fibre length varied from 10 mm to 20 mm. Marshall Specimens are prepared for NMPS 13.2 mm gradation with and without coir fibre. Based on the results, Optimum Emulsion Content is 8%. Coir fibre free from moisture is added to the aggregates in a dry process to achieve homogeneity in dispersion and avoid the balling problem. Maximum Marshall Stability is observed at 0.2% of 15 mm length coir fibre. It is observed that the addition of coir fibre had improved Retained Marshall Stability value. Rutting resistance is studied by conducting wheel tracking test with and without fibre. Rutting resistance of the mix is improving with the addition of coir fibre when compared to conventional mix.
Keywords: Cold bituminous mix, coir fibre, Nominal maximum particle size.

INTRODUCTION

Cold mix is the bituminous mixture containing mineral aggregate, water, and binder (bitumen emulsion) prepared by a suitable device like a concrete mixer or cold mix plant or a modified hot mix plant. In this technology, the mixing, laying, and compaction are done at ambient temperature. In cold mix technology, the bitumen emulsion comprising water will get coated on the surface of aggregates, and an adhesive bond is developed between the aggregates and binder. Although emulsion-based cold mixes overcome hot mix problems, due to their less satisfactory performance, they have attracted little attention and considered inferior to the hot mix as structural layers. Different research works have been carried out to improve the properties of the cold mix up to now. Various studies have been conducted to improve the cold mix properties so far. But still, they are very few in comparison to the same in case of hot mix.

The present study is concerned with the experimental investigation of Cold Bituminous Mix (CBM) reinforced with coir fibre. The fibre reinforcement improves fatigue life and retards future rutting by increasing resistance to cracking and permanent deformation.

The objectives of the study are:

- To identify the Optimum Emulsion Content (OEC) for selected aggregate gradation
- To identify the optimum length and optimum content of coir fibre for selected aggregate gradation
- To evaluate the performance of cold bituminous mix with and without coir fibre in terms of moisture susceptibility and rutting resistance
- To compare the conventional cold bituminous mix with cold bituminous mix containing coir fibre

In the present study, properties of the aggregate like aggregate impact value, aggregate crushing value, water absorption, specific gravity, and combined index are tested. The binder used are tested by standard testing procedure, i.e., the emulsion is tested for residue on 600-micron sieve, residue by evaporation, storage stability, viscosity by Saybolt Furol viscometer, coating and water resistance. Penetration, ductility and specific gravity tests are conducted on residual bitumen. Initial emulsion content is calculated for selected gradation and coating test is conducted to mix with and without coir fibre for selected gradation is studied by conducting Marshall Stability test, Retained Marshall Stability test, indirect tensile strength test and Hamburg wheel tracking test.

LITERATURE REVIEW

Cold mix technology, using bitumen emulsion contributes towards the overall economy in road construction because of ease of laying the mix and energy savings. The study was undertaken to investigate the structural properties of Emulsion Bitumen Mixes (EBM) in which the aggregates met the gradation of close graded premix carpet. The study aimed to contribute further towards the ongoing effort for the formulation of specifications and laying methodology of such constructions. Conducted tests with within Cold Bituminous Emulsion Mixtures (CBEMs) by using the waste materials and reported that improve the mechanical properties of CBEMs such as Indirect tensile strength, Fatigue resistance, lower temperature cracking and it was observed that improvement in strength of mix by increasing the curing periods 1 day, 7 days and 14 days. **G.Ferrotti et al. (2014)** This study focuses on optimising a high-performance cold mix asphalt by adding different types and fibre contents. Test results showed that fibre type and content had a strong influence on the performance of Cold Mix Asphalt mixture. **Anmar Dulaimi et al. (2016)** A binary blended filler material made from high calcium fly ash and a catalytic fluid cracking catalyst are very useful in providing microstructural integrity with a novel fast-curing asphalt concrete for the binder course mixture. Balanced oxide compositions were recognized as responsible for an improved hydration reaction within the novel filler, leading in a very high early strength and a substantial enhancement in permanent deformation and fatigue resistance. **Jinhai Yan et al. (2017)** Adding cement to the recycled asphalt emulsion mix improved its early-age

strength, moisture stability, high-temperature stability, and low temperature cracking resistance. The moisture stability, high-temperature stability, and strength of cold recycled mixes improve with the increase in cement content, while the cracking resistance at low temperatures increases first and then decreases.**Thulasirajan and Narasimha (2011)** used the coir fibre in bituminous concrete and found coir fibre shown improved Marshall Stability. In that study, 60/70 grade penetration grade bitumen with fibre proportions 0.3%, 0.5% and 0.7% by weight of aggregate and length varied 10mm, 15mm, 20mm is used. **Subramani (2012)** studied coir fibre in semi-dense bituminous concrete. In that study, 60/70 penetration grade bitumen with fibre proportions 0.3%, 0.5%, and 0.7% by weight of aggregate and length varied 10mm, 15mm, and 20mm are used. Marshall testing and volumetric analysis are done. He got Improved values for Marshall test by adding fibre. He studied the variation of fibre length in different properties**.**
Mahabir et al. (2013) research conducted with a frequently accessible standard VG 30 bitumen and another modified binder, namely CRMB 60, was used in combination with a non-conventional natural fibre, namely coconut fibre, which is abundantly accessible in India to provide enhanced engineering characteristics. For various engineering properties, the role of a particular binder and fibre about their concentrations in the mix is studied. Marshall Procedure was followed to determine the optimum binder and optimum fibre content as well as to study the comparative benefits of fibre addition in SMA mixtures. The engineering properties were then studied under both static and repeated load conditions and characteristics of moisture susceptibility. It is observed that the engineering properties of SMA mixes are significantly improved by adding only a marginal 0.3% coconut fibre.

3.0 METHODOLOGY

In this study, the aggregate gradation was taken based on the Nominal Maximum Particle Size (NMPS): NMPS 13.2 mm from Ministry of Road Transport and Highways (MoRTH) specification (2013). Medium setting cationic type bitumen emulsion and coir fibre were used for this study. The study methodology includes characterisation of aggregates and emulsion, determination of pre-wetting water content, volumetric analysis of mixes by Marshall Stability test, performance evaluation by Retained Marshall Stability (RMS) test and rutting test by using Hamburg wheel tracking device with and without coir fibre.

Table 1 Properties of aggregates

Experiment	Test Results	Permissible Value	IS Code
Specific Gravity (CA)	2.74	2.6-2.8	IS:2386 (Part III)-1963
Specific Gravity (FA)	2.67	2.6-2.8	IS:2386 (Part III)-1963
Aggregate Impact value (%)	28.72	Max. 30	IS:2386 (Part IV)-1963
Aggregate Crushing value (%)	29.20	Max. 30	IS:2386 (Part IV)-1963
Los Angeles Abrasion Test (%)	28.43	Max. 40	IS:2386 (Part IV)-1963

Combined Elongation and Flakiness index (%)	25.53	Max. 35	IS:2386 (Part I)-1963
Water absorption (CA) (%)	0.44	Max. 2	IS:2386 (Part III)-1963
Water absorption (FA) (%)	0.61	Max. 2	IS:2386 (Part III)-1963

Table 2 Properties of bitumen emulsion

Experiment	Sample No	Test Results	Permissible Value	IS Code
Residue on 600 micron (%)	1	0.0175	Max 0.05	IS:8887-2004
	2	0.0425		
	3	0.035		
	Average	0.031		
Coagulation at low temperature	1	Nil	Nil	IS:8887-2004
	2			
	3			
Viscosity by Saybolt Furol Viscometer in Furol Seconds	1	236	30-300	IS:8887-2004
	2	252		
	3	205		
	Average	231		
Storage stability after 24 hours (%)	1	0.96	Max. 1%	IS:8887-2004
	2	0.97		
	3	0.97		
	Average	0.96		
Coating ability and water resistance a. Coating, dry aggregates b. coating, after water spraying	1	Good Fair	Good Fair	IS:8887-2004
	2			
	3			
Residue by evaporation (%)	1	65.48	Min 65%	IS:8887-2004
	2	66.21		
	3	65.63		
	Average	65.77		
Tests on residue				
Penetration, mm	1	110	30-150	IS:1203-1978
	2	89		
	3	105		
	Average	101.33		
Ductility, cm	1	65	Min 50	IS:1208-1978
	2	68		

	3	76		
	Average	69.67		
Specific gravity	1	1.01	Min 0.99	IS:1202-1978
	2	1.03		
	3	1.01		
	Average	1.016		

3.5 CHARACTERISTICS OF COIR FIBRE

Coir fibre with different lengths such as 10mm, 15mm, and 20mm was used for the study. Fibre content was varied from 0.1% to 0.3%. Fibre was checked for its moisture absorption property by keeping a sample in oven and weight of the sample before and after drying is measured. There was no significant difference in weight of the sample. This indicated that fibre was free from moisture. The details of the test method are given in Appendix C IS 9308(Part-1)-1987.

Table 3 Chemical composition of coir fibre

Content	Percentage
Lignin	45.84
Cellulose	43.44
Hemicellulose	0.25
Ash	2.22
Water soluble	5.25

(Source: Coir Board, Ministry of MSME, Govt of India)

3.5.1 Density of Coir Fibre

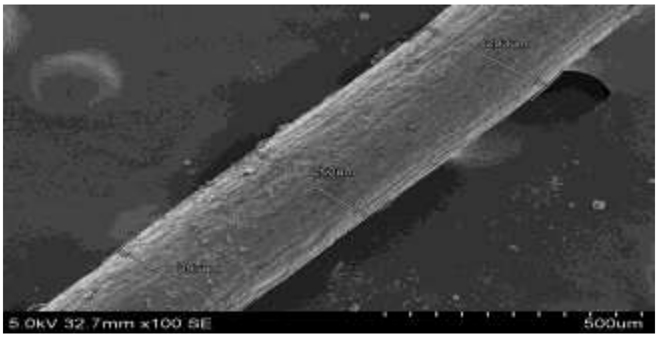


Figure 1 SEM Image of coir fibre

The material used in this work was defibering coir fibre. From Figure 3.2, it can be observed that the shape of coir fibre is cylindrical. The diameter of the coir fibre is varied from 0.18 mm to 0.43 mm. The selected coir fibre has the uniform diameter and predefined no of pieces, and each fibre was weighed in a precision balance. The density of each fibre was calculated considering a cylindrical volume of the fibre. The density of coir fibre is found to be 1.4 gm/cc.

4.0 EXPERIMENTAL FRAMEWORK

Marshall Stability test was conducted on cold bituminous mixes with cationic medium setting bitumen emulsion. In this present study, aggregate gradation was taken from MoRTH specification (2013). Initial Emulsion content for selected gradation was calculated using formula as per IRC: SP: 100-2014. Coating test was conducted for selected gradation with constant IEC and varying water content. Marshall specimens were prepared with 100 mm diameter and compacted with SUPERPAVE gyratory compactor. Specimens were prepared for selected gradation with different percentage of bitumen emulsion content to get the Optimum Emulsion Content (OEC). Specimens were prepared using optimum emulsion content by varying coir fibre contents and lengths to get optimum coir fibre content and length. Specimens were tested for Marshall Stability test at room temperature, and the volumetric properties of mixes were analyzed and Retained Marshall Stability was also conducted. Samples of 150 mm diameter and 60 mm height were prepared with SUPERPAVE gyratory compactor at OEC with and without coir fibre, for doing the Hamburg wheel tracking test.

Aggregate gradation and size

Aggregate particle size distribution is one of its most important influential characteristics in the bituminous mix, including the density, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. The maximum size of aggregate is defined as the smallest sieve through which 100% of the aggregate particle pass. NMPS is the largest sieve that retains some of the aggregate particles but not more than 10% by weight. Cold bituminous mix with a nominal maximum size of 13.2 mm for the surface course with a nominal layer thickness of 36-50 mm is chosen for the study. Gradation for the mix is given in table 4.1. The middle limit values of the cumulative percentage of total aggregate passing were used in the preparation of cold bituminous mix.

Table 4 Aggregate gradation of NMPS 13.2 mm

Sieve size (mm)	Cumulative % by Weight of Total Aggregate Passing	Middle value
19	100	100
13.2	90-100	95
4.75	45-70	57.5
2.36	25-55	40
0.3	5-20	12.5
0.075	2-9	5.5

Preparation of test specimens

The mixes were prepared according to the IRC: SP: 100-2014 cold mix design procedure. The whole process illustrated in the next paragraphs**.**

1. Properties of aggregates and bitumen emulsion were tested.
2. IEC was calculated for NMPS 13.2 mm gradation by using the formula, i.e., equation 4.1.
3. Optimum Pre-wetting Water Content (OPWC) was determined by the coating test. OPWC is the water content added to aggregate from no amount of water and changing the water content percentage with an increment of 1% then after adding emulsion to aggregate. By visual observation, find water content at which mix is coated not less than the 50%.
4. OPWC added for dry aggregates and mixed within 2 minutes, and then emulsion was added to the wetted aggregate, which was found by the formula (IEC).

5. The loose mix was dried for about one hour using a fan. The loose mix was then kept in an oven at 40°C for 2 hours.
6. The loose mix was then transferred into the SUPERPAVE Gyratory compactor mould with a filter paper on a base plate and compacted to the specified height of the sample.
7. The samples prepared using gyratory compactor were left for 24 hours under normal temperature and cured in an air oven at 40°C for 72 hours before subjecting to different tests.
8. The Marshall specimens were prepared with different percentage of emulsion contents by weight of aggregate.
9. Marshall Stability test was conducted at room temperature, and volumetric properties like air voids, voids in mineral aggregate, voids filled by bitumen, etc. were evaluated.

Determination of Initial Emulsion Content (IEC)

$$IEC = 0.05A+0.1B+0.5C$$

Where, IEC = Initial emulsion content (%)
A = Percentage of aggregate retained on 2.36 mm sieve
B = Percentage of aggregate passing 2.36 mm sieve and retained on 75-micron sieve
C = Percentage of aggregate passing on 75-micron sieve
IEC for NMPS 13.2 mm is 9.2%.

Determination of Optimum Pre-Wetting Water Content by Coating Test

Pre-wetting of the aggregate is necessary because by adding the water initially to aggregate, it will become an optimum moist state so if bitumen emulsion added to the aggregate, it will not absorb the water content in the emulsion. If aggregate absorb the water from the emulsion, workability will reduce and very difficult to mix, and it won’t provide the better coating. The coated aggregates are then visually observed for the coated area of the aggregate by the binder. The optimum water content is the water content at which the maximum coating of aggregate occurs. After carrying out several trials with water contents of 1, 2, 3, and 4%, the Optimum Pre-wetting Water Content was found to be 2%. This OPWC was adopted in this investigation for preparing cold bituminous mix specimens.

Method of the Addition of Fibre

The degree of homogeneity of dispersion of the fibres determines the strength of the mixtures. There are two methods for the introduction of fibres that is by dry process and wet process. The dry process is an easy way to add fibre, which minimises the problem of balling. So fibre was added to the aggregates in the mixer before adding bitumen emulsion and mixed well to get a homogeneous mixture.

Compaction by SUPERPAVE Gyratory Compactor

SUPERPAVE Gyratory Compactor (SGC) is used for compacting sample. The primary operating parameters for the SGC include the pressure applied to the specimen during compaction; the speed of gyration/rotation; the number of gyrations applied to the specimen; and the angle of gyration. Values for these parameters were established during the development of the super pave system under the Strategic Highway Research Program. After mixing, the sample was transferred to the gyratory compactor mould. A number of gyrations and the desired thickness

(63.5mm) was given in the machine as input. Gyratory showed density and shear stress applied as output after compaction of each sample.

Figure 2 SUPERPAVE Gyratory compactor

The SUPERPAVE Gyratory compactor is a device which can be used to fabricate test specimens by simulating the effect of traffic on the flexible pavement. Here the compaction was done by the compactor in such a way that there was an angular rotation type with an angle of 1.16˚. There was the constant application of load takes place to compact the mix. For the compaction of cold bituminous mixes, a porous mould was used. In the present investigation, a mould of 100 mm and 150 mm diameter was used for the preparation of cold mix specimens. The purpose of the pores in the mould was to expel out the water during the compaction process.

Marshall mix design method

The Marshall Stability and flow test is the performance prediction measure for the Marshall mix design method. The resistance of a compacted cylindrical sample of the bituminous mixture to plastic deformation is measured in this method when the sample is loaded diametrically at a rate of 50 mm per minute. There are two significant features of the Marshall method of mix design. (i) density-voids analysis and (ii) stability-flow tests. The Marshall Stability of the mix is defined as the maximum load carried by the specimen at the specified standard test temperature. The flow value is the deformation undergone by the test specimen while loading up to the maximum load. The apparatus consists of the mould assembly, sample extractor, compaction pedestal, and hammer, breaking head, loading machine, flow meter, and water bath. Three compacted samples are prepared for each binder content in the Marshall mix design test method. To get the optimum binder content, at least five binder contents are to be tested. The following tests are carried out on all compacted specimens: determination of bulk density, stability and flow test and analysis of density and voids of the mix.

Performance parameters

In order to improve pavements performance, it is necessary to understand the behaviour of bituminous mixes, which depends on their composition. To study the composition of the bituminous mixes, the use of mix design methods is required. Nowadays, mix design methods are based on the use of mechanical tests which simulate the behaviour of bituminous mixes in the pavement. Thus, it is possible to understand the composition of the bituminous mixture, which will optimise the behaviour required in service like rutting resistance, fatigue cracking resistance, moisture susceptibility, low temperature cracking resistance, adhesion, and wearing resistance.

The performance of a bituminous mix is primarily measured in terms of its resistance to moisture damage and rutting. For knowing the resistance of mix for moisture damage, Retained Marshall Stability test was conducted, and for rutting resistance, Hamburg Wheel Tracking test was conducted.

Retained Marshall Stability (RMS) Test

It is well known that the presence of moisture in a bituminous mix is a critical factor, which leads to premature failure of the flexible pavement. The loss of adhesion of aggregates with bitumen emulsion is studied by utilising Retained Stability Test to examine the effect of additive on resistance to moisture induced damage. Retained Marshall Stability is the ratio of soaked stability to dry stability. Both soaked stability and stability samples are prepared at OEC. After having been subjected to oven curing as explained for dry stability samples (Chapter 4.4). The dry samples were water conditioned (capillary soaking). In this procedure, half the thickness of each compacted specimen is soaked in water at room temperature for 24 hours, the specimen is then inverted, and the other half was soaked for a further 24hours. During soaking, the samples would rest on a bed of approximately 15 to 20 mm coarse sand. The samples are subsequently towel dried then tested for Marshall Stability at room temperature. The Marshall Stability test results obtained are referred to as Soaked Stability values. Retained Marshall Stability is calculated from Equation .

$$\text{Retained Marshall Stability} = \left(\frac{\text{Soaked Stability}}{\text{Dry Stability}}\right) * 100$$

In this device, there is a specimen holder with dimension 295 x 365 x 60 mm in which two specimens with 150 x 60 mm dimension can be placed and tested simultaneously. A steel wheel, 47 mm wide and loaded under 705 N makes 30 passes over each sample per minute. Specimens were prepared using 2338 grams of aggregate for selected gradation at their OEC. Loose mix was kept 1 hour under the fan and then kept in an oven at 40℃ for 2 hours. The mix was compacted with SUPERPAVE Gyratory compactor to get specimen with dimensions 150 mm height, and 60 mm dia. The compacted specimen was kept in the oven for 3days at 40℃. After that the rutting test was conducted without water.

Figure 3 Hamburg Wheel Tracker

5.0 ANALYSIS OF RESULTS AND DISCUSSION

For the purpose of knowing the stability of the cold bituminous mix (CBM), the standard Marshall Stability test was conducted as per IRC:SP:100-2014. In order to investigate the optimum emulsion content (OEC) for NMPS 13.2 mm gradation, the Marshall specimens were prepared with the dimensions of diameter 100 mm and height 63.5 mm by using gyratory compactor. After casting, the specimens were kept at ambient temperature for a period of 24 hours. After that, the specimens were kept in the hot air oven for 72 hours at a temperature of 40˚C. The CBM samples were prepared using varying emulsion content of 7.0%, 7.5%, 8.0%, 8.5%, and 9.0% for identifying the optimum emulsion content. Volumetric analysis was done using the result obtained, and optimum emulsion content was found out. Emulsion content corresponding to highest Marshall Stability and bulk density of mix was taken as optimum emulsion content. The optimum emulsion content was found to be 8% for NMPS 13.2 mm gradation. Marshall values for NMPS 13.2 mm gradation with different percentages of emulsion are shown in table 5.1, and the graphical representation of the results are shown in Figure.

Table 5.1 Marshall Stability test results for NMPS 13.2 mm gradation

Bitumen emulsion (%)	Sample No.	Marshall Stability (kN)	Flow (mm)	Bulk density (gm/cc)	Air Voids (%)	VMA (%)	VFB (%)
7	1	11.34	3.41	2.190	13.836	23.423	40.930
	2	11.23	4.29	2.209	13.070	22.742	42.530
	3	11.21	3.81	2.212	12.970	22.654	42.745
Average		**11.26**	**3.84**	**2.204**	**13.292**	**22.940**	**42.068**
7.50	1	11.89	4.63	2.188	13.491	23.723	43.129
	2	12.27	3.96	2.233	11.741	22.179	47.065
	3	11.76	3.20	2.245	11.248	21.744	48.274
Average		**11.97**	**3.93**	**2.222**	**12.160**	**22.549**	**46.156**
8	1	12.63	5.07	2.261	10.190	21.432	52.452
	2	13.07	5.21	2.260	10.230	21.466	52.344
	3	11.89	4.23	2.230	11.422	22.509	49.257
Average		**12.53**	**4.84**	**2.250**	**10.614**	**21.802**	**51.351**
8.50	1	9.63	5.15	2.255	9.991	21.869	54.312
	2	11.40	5.68	2.261	9.768	21.675	54.934
	3	10.99	5.93	2.230	11.005	22.749	51.623
Average		**10.67**	**5.59**	**2.249**	**10.255**	**22.098**	**53.623**
9	1	9.84	6.96	2.210	11.393	23.678	51.883
	2	10.35	6.80	2.290	8.186	20.915	60.863
	3	10.96	6.21	2.220	10.992	23.333	52.889
Average		**10.38**	**6.66**	**2.240**	**10.190**	**22.642**	**55.212**

The CBM samples were also prepared with coir fibre for Marshall Stability test to identify the optimum coir fibre content and optimum coir fibre length. The length of coir fibre was varied as 10 mm, 15 mm and 20 mm, and coir fibre content was varied as 0.1%, 0.2% and 0.3% by weight of the total mix. The Marshall Stability results of CBM with coir fibre are shown in table 5.2, and the graphical representation of the results are shown in Figure 5.2. From Figure 5.2, for coir fibre length of 15 mm and the coir fibre content of 0.2%, the Marshall Stability value was more compared to other combinations with and without coir fibre. Therefore, based on Marshall Stability value, optimum coir fibre content and optimum coir fibre length is 0.2% by the total weight of mix and 15mm length, respectively.

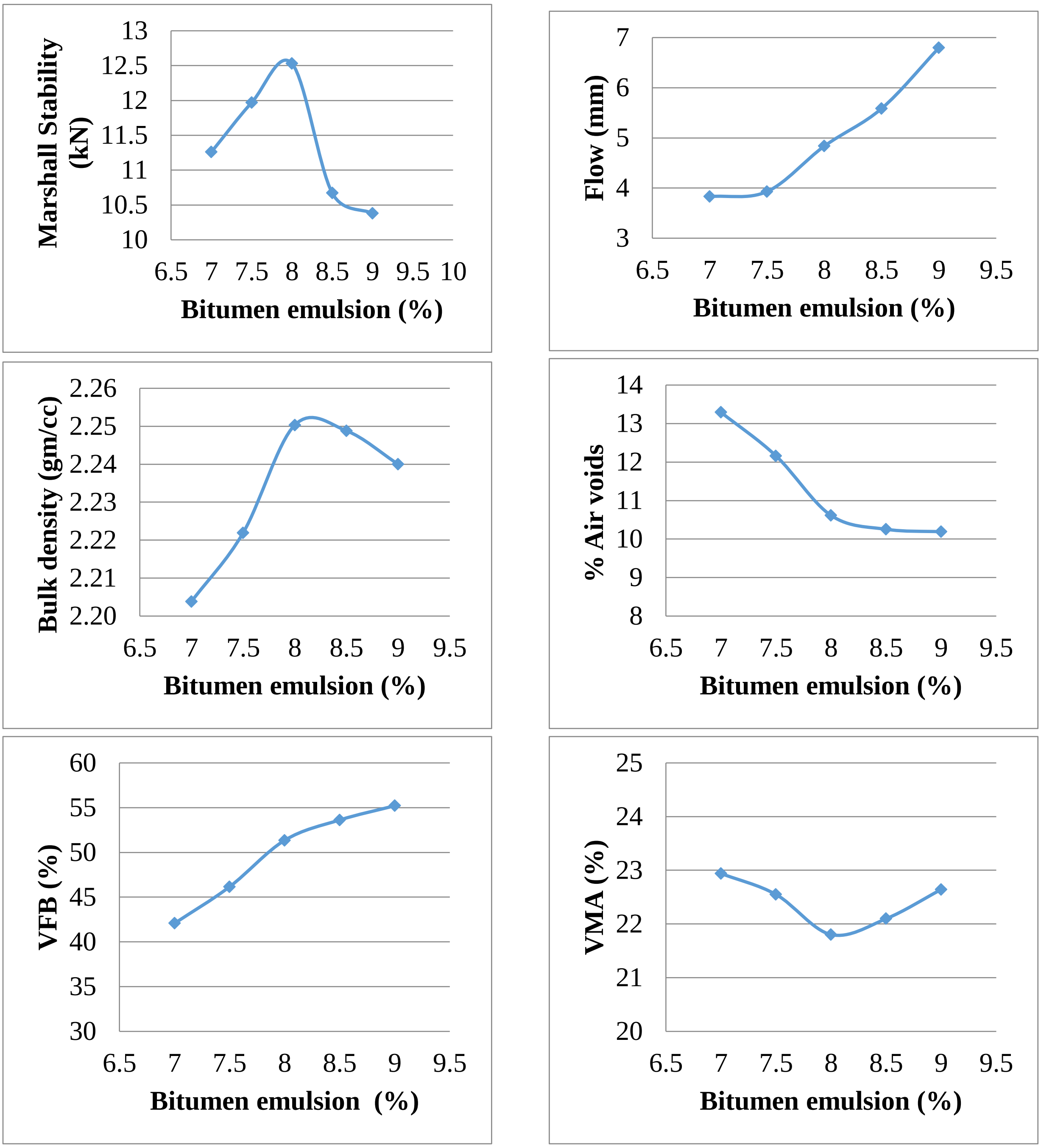


Figure 5.1 Marshall graphs for NMPS 13.2 mm gradation

Table 5.2 Marshall Stability test results of CBM with coir fibre

Coir fibre Content (%)	Sample No.	Marshall Stability (kN)		
		Coir Fibre length of 10 mm	Coir Fibre length of 15 mm	Coir Fibre length of 20 mm
0.00	1	12.63	12.63	12.63
	2	13.07	13.07	13.07
	3	11.89	11.89	11.89
Average		**12.53**	**12.53**	**12.53**
0.1	1	12.71	13.57	12.01
	2	12.46	12.96	12.69
	3	12.51	13.07	12.05
Average		**12.56**	**13.20**	**12.25**
0.20	1	12.48	16.75	12.62
	2	13.05	15.35	10.82
	3	12.54	14.55	12.69
Average		**12.69**	**15.55**	**12.04**
0.30	1	11.96	13.64	11.79
	2	12.23	11.92	11.30
	3	12.31	12.43	12.96
Average		**12.17**	**12.66**	**12.02**
0.40	1	15.37	11.84	11.57
	2	11.68	11.54	12.19
	3	12.11	11.88	11.71
Average		**13.05**	**11.75**	**11.82**

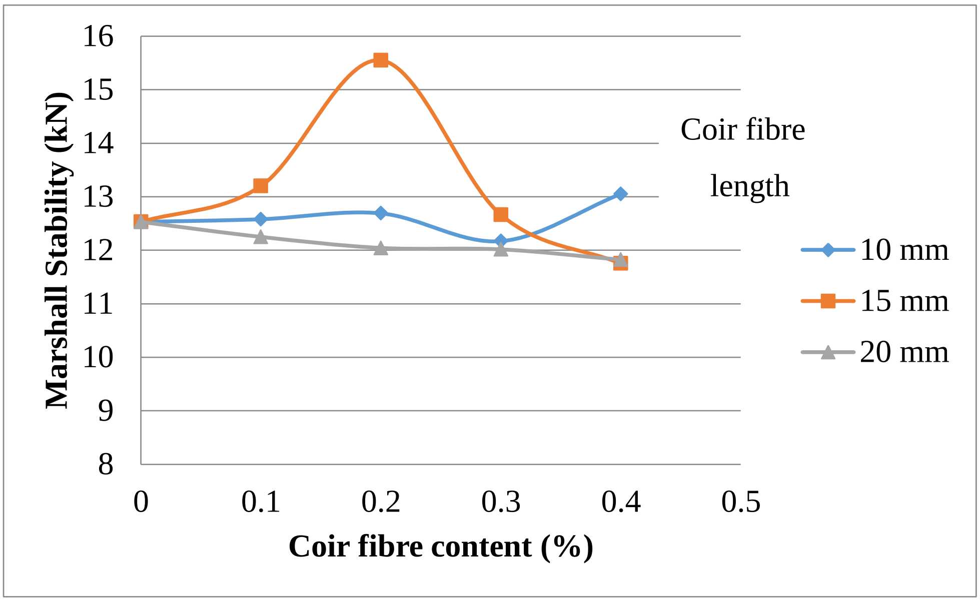


Figure 5.2 Marshall Stability graph for different lengths and contents of coir fibre

Effect of Stability

Stability value increases initially with an increase in bitumen emulsion content but decreases gradually. This can be attributed to the fact that with the increase in bitumen emulsion content, the aggregate bitumen emulsion bond gradually gets stronger, but with further increase in bitumen emulsion content, the applied load is transmitted as hydrostatic pressure, keeping the fraction across the contact points of aggregates immobilized. This makes the mix weak against plastic deformation and the stability reduced. Flow is the deformation undergone by the specimen at the maximum load where failure occurs. The flow value increases with the increase in the bitumen emulsion content. The air voids decrease with increase in the bitumen content. Because with the increase in bitumen content, it goes on filling the air voids progressively. The VFB of a mix generally increases with the increase in the bitumen content. Because increase in bitumen content causes more and more bitumen to fill the voids present in the mix as well as that inside the aggregates causing the overall increase in the bitumen inside the voids or VFB.VMA decreases slowly with increase in bitumen content due to the reorientation of aggregates in the presence of bitumen. At very high bitumen content, due to thicker bituminous film aggregates slightly moves apart resulting in an increase in VMA. From Table 5.2, it can be observed that the presence of coir fibre in the CBM mixtures effectively improves the stability values. This result indicates that the mixture using coir fibre would result in higher performance than using the conventional mixture (without coir fibres). Figure 5.2 indicates that the stability of coir fibre stabilized mixtures increases initially, reaches a maximum value and then decreases with increasing fibre content. The CBM with coir fibre is showing the increase in the Stability value with increase in the percentage of coir fibre content in the mix, and reducing after reaching maximum value by a further increment of the coir fibre content. This incorporating the fact that coir fibre is providing the reinforcement to the mix, reducing the air voids with the increase in the coir fibre content, hence the Stability value is increasing. But increase in the coir fibre content, the homogeneity of coir fibre is not uniform in the mix and giving balling effect to the mix reducing the Stability value. Use of coir fibre resulted in Marshall Stability value as high as 15.55 kN in CBM. It is higher by 14.55% than conventional mixtures. Soaked stability test conducted after soaking half thickness of the sample in water for one day and reversed for one day. Dry stability values were found to be higher than the soaked stability values. Retained Marshall Stability specimens were prepared with and without coir fibre at optimum emulsion content of 8%. The length of coir fibre was varied as 10 mm, 15 mm and 20 mm, and coir fibre content was varied as 0.1%, 0.2% and 0.3% by weight of the total mix. The test results are shown in table 5.3 to 5.5. RMS was found to be higher than the 80 % for all variations with and without coir fibre in CBM. These results show that the presence of coir fibre in cold bituminous mix leads to increases the moisture resistance of CBM.

Table 5.3 Retained Marshall Stability test results of CBM with 10mm coir fibre

Optimum emulsion content (%)	Coir fibre content (%)	Sample No.	Soaked Stability (kN)	Dry Stability (kN)	Retained Marshall Stability (%)
8	0	1	12.67	12.96	
8	0	2	13.14	13.83	
8	0	3	12.90	14.02	
Average			**12.90**	**13.60**	**94.85**
8	0.1	1	12.83	13.92	
8	0.1	2	12.92	14.10	
8	0.1	3	13.25	13.63	
Average			**13.00**	**13.88**	**93.64**
8	0.2	1	13.12	14.02	
8	0.2	2	13.40	14.06	
8	0.2	3	12.73	14.09	
Average			**13.08**	**14.06**	**93.08**
8	0.3	1	13.52	14.30	
8	0.3	2	13.28	14.49	
8	0.3	3	13.10	13.91	
Average			**13.3**	**14.23**	**93.44**

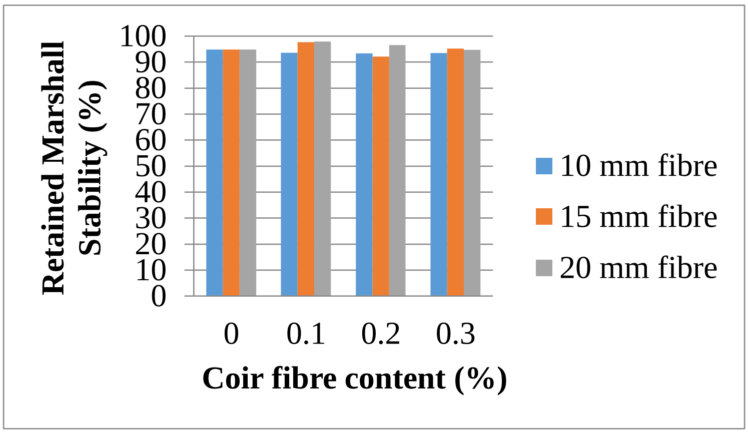
Table 5.4 Retained Marshall Stability test results of CBM with 15mm coir fibre

Optimum emulsion content (%)	Coir fibre content (%)	Sample No.	Soaked Stability (kN)	Dry Stability (kN)	Retained Marshall Stability (%)
8	0	1	12.67	12.96	
8	0	2	13.14	13.83	
8	0	3	12.90	14.02	
Average			**12.90**	**13.60**	**94.85**
8	0.1	1	13.23	14.45	
8	0.1	2	13.78	13.83	
8	0.1	3	13.83	13.55	
Average			**13.61**	**13.94**	**97.63**
8	0.2	1	14.45	15.74	
8	0.2	2	15.12	16.33	
8	0.2	3	14.91	16.21	
Average			**14.83**	**16.09**	**92.13**
8	0.3	1	13.89	13.32	
8	0.3	2	13.50	14.56	
8	0.3	3	13.24	14.81	
Average			**13.84**	**14.23**	**98.48**

Table 5.5 Retained Marshall Stability test results of CBM with 20mm coir fibre

Optimum emulsion content (%)	Coir fibre content (%)	Sample No.	Soaked Stability (kN)	Dry Stability (kN)	Retained Marshall Stability (%)
8	0	1	12.67	12.96	
8	0	2	13.14	13.83	
8	0	3	12.90	14.02	
Average			**12.90**	**13.60**	**94.85**
8	0.1	1	14.12	13.89	
8	0.1	2	14.36	14.60	
8	0.1	3	13.91	14.81	
Average			**14.13**	**14.43**	**97.90**
8	0.2	1	13.07	14.47	
8	0.2	2	13.96	13.41	
8	0.2	3	14.12	14.71	
Average			**13.72**	**14.20**	**96.62**
8	0.3	1	12.84	13.91	

8	0.3	2	13.23	14.19	
8	0.3	3	13.85	14.05	
Average			**13.31**	**14.05**	**94.71**



Variation of Retained Marshall Stability with coir fibre content (%)

The dry stability, as well as soaked stability values, are increasing with the coir fibre content increment for 10 mm length of coir fibre. For length of 15 mm coir fibre, soaked stability and dry stability is increasing with an increment of coir fibre content having a maximum value of 14.83 kN and 16.09 kN respectively at 0.2% coir fibre content, afterwards, at 0.3% of coir fibre content both the values are getting reduced. With 20 mm coir fibre, dry stability and soaked stability of CBM is increasing with an increment of coir fibre having maximum value for 0.1% coir fibre content 14.43 kN and 14.13 kN respectively and further increment of coir fibre content in the CBM showing the decreasing trend of stability values.

Retained Marshall Stability value of more than 80% is suggested as a criterion for a mixture to be resistant to moisture induced damages. The dry stability values are higher than soaked stability values representing the moisture-induced effects in the mix. It is observed that for all the combinations of coir fibre contents with CBM, Retained Marshall Stability values are higher than the 90%, passing the suggested criterion for moisture susceptibility.

HAMBURG WHEEL TRACKING TEST

Hamburg wheel tracking device was used for measuring rutting resistance. The test was conducted till the rut depth reaches 12.5 mm, for all variations by changing coir fibre length and coir fibre content. The test procedure for the wheel tracking test is given in Chapter 4.10. For comparing the rutting characteristics of conventional CBM with fibre modified CBM samples were prepared. The length of coir fibre was varied as 10 mm, 15 mm and 20 mm, and coir fibre content was varied as 0.1%, 0.2% and 0.3% by weight of the total mix. The graphs were plotted between the rut depth and the number of passes for all variations of CBM with and without coir fibre. The rutting curve is drawn based on data obtained from the Hamburg Wheel Tracking test. All the specimens were prepared at OEC of 8% by weight of the total mix. The graphical representation of `wheel tracking test results of CBM with and without coir fibre are shown in Figure 5.4 to Figure 5.8.

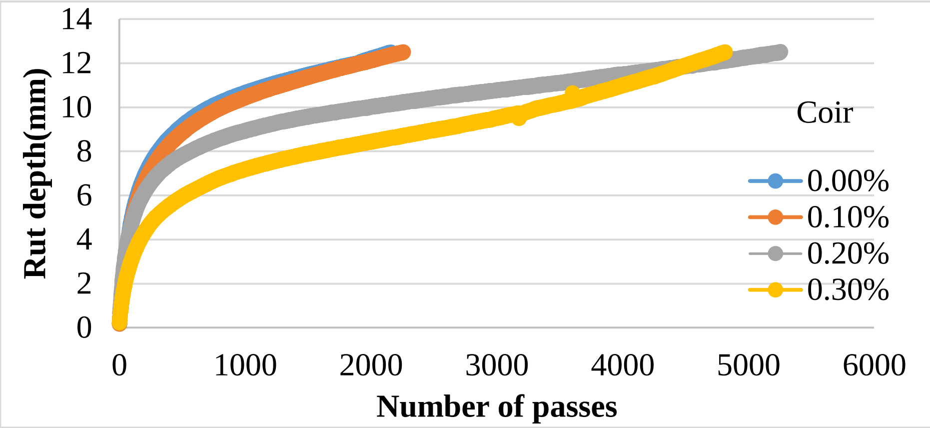


Figure 5.4 Rutting characteristics of CBM with a coir fibre length of 10 mm

The number of passes required for reaching 12.5 mm rut depth for conventional CBM was 2162. From the Figure 5.4, it can be observed that the number of passes for 10 mm coir fibre length at 0.1% content was almost similar to conventional CBM and the slope of the two curves is identical. Therefore, at lower content and a small length of coir fibre, the coir fibre will not have any influence to the mix. From Figure 5.3, it can be observed that the number of passes required for reaching 12.5 mm rut depth increased with the increase in coir fibre content and then further decreased. The samples prepared with 0.2% coir fibre content showed high rutting resistance at 10 mm coir fibre length. The samples prepared with 0.3% coir fibre content were showing less rutting resistance compared with samples prepared at 0.2% coir fibre content in 10mm coir fibre length. From Figure 5.5, for 15 mm coir fibre length and at 0.1 % coir fibre content, the number of passes required for reaching 12.5 mm rut depth was found to be more than conventional CBM. From Figure 5.4, it can be observed that the number of passes needed for 12.5 mm rut depth increased with the increase in coir fibre content and then further decreased. The samples prepared with 0.2% coir fibre content are showing high rutting resistance in 15 mm coir fibre length. The samples prepared with 0.3% coir fibre content were showing less rutting resistance compared with samples prepared at 0.2% coir fibre content in 15 mm coir fibre length.

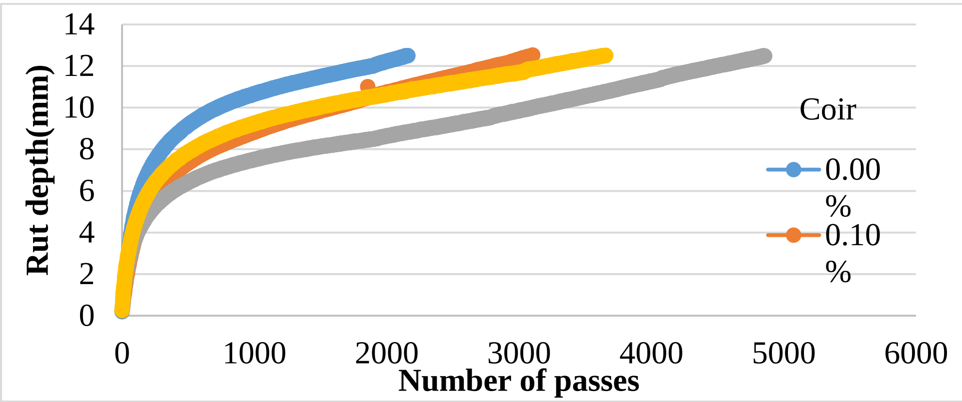


Figure 5.5 Rutting characteristics of CBM with a coir fibre length of 15 mm

From Figure 5.5, for 15 mm coir fibre length and at 0.1 % coir fibre content, the number of passes required for reaching 12.5 mm rut depth was found to be more than conventional CBM. From

Figure 5.4, it can be observed that the number of passes needed for 12.5 mm rut depth increased with the increase in coir fibre content and then further decreased. The samples prepared with 0.2% coir fibre content are showing high rutting resistance in 15 mm coir fibre length. The samples prepared with 0.3% coir fibre content were showing less rutting resistance compared with samples prepared at 0.2% coir fibre content in 15 mm coir fibre length.

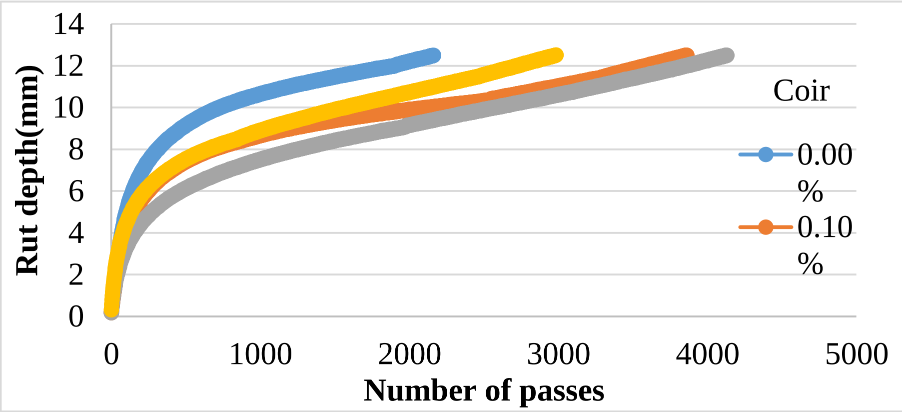


Figure 5.6 Rutting characteristics of CBM with a coir fibre length of 20 mm

From Figure 5.6, for 20 mm coir fibre length and at 0.1 % coir content, the number of passes required for 12.5 mm rut depth was found to be more than conventional CBM. From Figure 5.4, it can be observed that the number of passes needed for 12.5 mm rut depth increased with the increase in coir fibre content and then further decreased. The samples prepared with 0.2% coir content showed high rutting resistance in 20mm coir fibre length. The rutting resistance of the samples prepared with a coir fibre content of 0.3% and coir fibre length of 20 mm is less compared with the samples prepared with coir fibre lengths of 10 mm and 15mm at the coir fibre content of 0.3%.

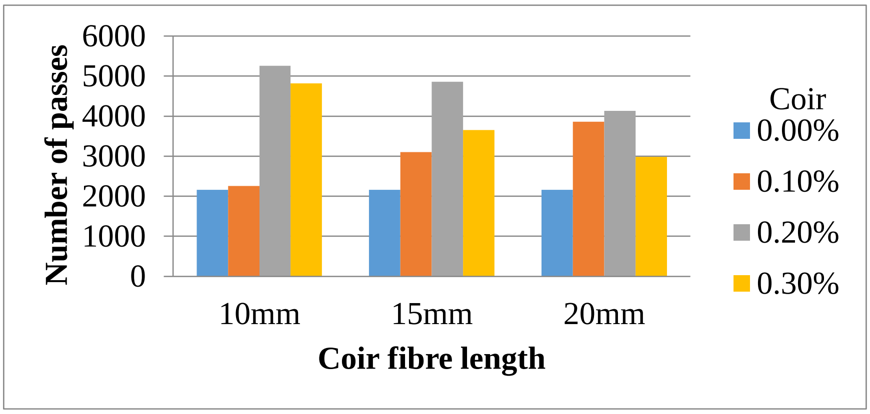


Figure 5.7 Variation in the number of passes for 12.5 mm rut depth in CBM

From Figure 5.7, it can be observed that at 0.1% coir fibre content, rutting resistance increased with the increase in coir length. This trend was not observed at 0.2% and 0.3% of coir fibre contents. This is because, at lower coir fibre content and smaller coir fibre length, the coir fibre will not act as reinforcement material to the mix. But at lower coir fibre content, the rutting resistance increases with the coir fibre length due to the reinforcement effect. For all lengths of coir fibre, 0.2% of coir fibre content showed the highest rutting resistance. This is because at this content, distribution of coir fibre was uniform and there was no ball formation of coir fibre in the mix. At 0.3% coir fibre content, increase in coir fibre length, and higher fibre content resulted in non-uniformity in fibre distribution and fibre ball formation. When coir fibre is mixing with aggregate and emulsion, because of more length of fibre and more content, the fibre is not mixing uniformly in the mix and fibre ball formation was occurring.

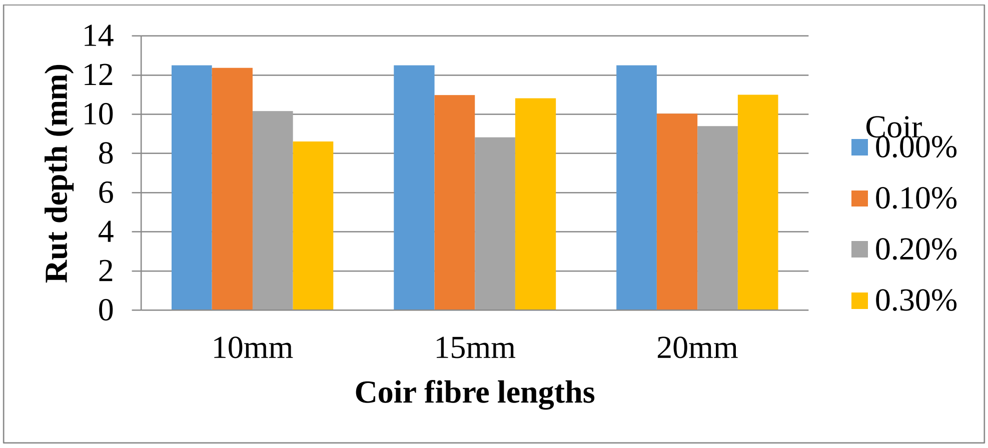


Figure 5.8 Deformation after 2162 passes

The rut depth achieved by all the CBM samples prepared with and without coir fibre after completion of 2162 passes is shown in Figure 5.8. The samples prepared without coir fibre are achieving 12.5 mm rut depth early than the samples prepared with coir fibre at 2162 passes. Rut depth for 10 mm coir fibre length is 8.61 mm at 0.3% coir fibre content after completion of 2162 passes, which has the highest rutting resistance. Lowest rut depth observed to be 8.82 mm and 9.39 mm at 0.2% of coir fibre content after completion of 2162 passes for 15 mm and 20 mm coir fibre lengths. A higher number of passes gives high rutting resistance. From wheel tracking test results, it could be observed that when coir fibre is added to the mix the number of passes is found to be increased considerably. With the addition of coir fibre, it is noted that the rutting resistance of the mix started to increase to a certain point and then decreases. This is mainly because the addition of fibres beyond optimum dosage will form lump with bitumen emulsion, so that void spaces increases and density decreases, resulting in less rutting resistance.

CONCLUSIONS

Addition was taken based on NMPS 13.2 mm from Ministry of Road Transport and Highways (MoRTH) specification. The study was conducted to evaluate the effect of fibre in the cold bituminous mix through laboratory investigations. Aggregate and binder tests were conducted to assess the suitability of the material used in the study, volumetric analysis of mixes by Marshall Stability test, performance evaluation by Retained Marshall Stability (RMS) test and rutting test by using Hamburg wheel tracking device.

Based on laboratory tests, the following conclusions were drawn:

1. Optimum emulsion content of cold bituminous mix based on Marshall Stability is 8% by weight of the total mix for selected gradation.
2. Use of coir fibre resulted in an increase of Marshall Stability value by 14.55% when compared with the conventional CBM.

3. The optimum coir fibre content is 0.2% by weight of total mix, and optimum fibre length is 15 mm based on Marshall Stability value.
4. Moisture resistance is found to be more than 90 % for all variations with coir fibre.
5. Rutting resistance of the mix is improving with the addition of coir fibre when compared to conventional mix. The rutting resistance is more at 0.2% of coir content at all lengths (10 mm, 15 mm&20 mm).
6. Based on Marshall Stability results and wheel tracking test results, the optimum length of coir fibre is 15 mm, and the optimum coir fibre content is 0.2%.

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