Performance Evaluation of Cold Bituminous Mix Reinforced with Coir Fibre

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ABSTRACT

Cold bituminous mix (CBM), which is a mixture of bitumen emulsion and aggregate that is mixed together at ambient temperature, has several advantages like energy savings, easiness in preparation, environmental benefits, and high production at low investment. But there are certain limitations of CBMs like inferior mechanical properties, high air voids, weak early life strength, long curing time and poor coating that hinder its extensive usage. The possibility of improving mechanical performance of CBMs by the addition of coir fibre is attempted in this study. The objectives of the study are to assess the improvement in performance of CBM due to addition of coir fibre and to identify the optimum length and optimum content of coir fibre for CBMs. Three coir fibre contents and three coir fibre lengths were used in this study. Performance evaluation of CBM modified with coir fibre was done through Retained Marshall Stability (RMS) test and Hamburg wheel tracking test. Coir fibre was added to the aggregates and mixed before the addition of pre-wetting water and emulsion, to achieve uniform distribution and to avoid balling of coir fibres. When coir fibre was added to the mix, Marshall Stability increased up to a certain level of coir fibre content depending on fibre length. Highest Marshall Stability value was obtained at 0.2% content (by weight of total mix) of coir fibre of 15 mm length. Resistance to moisture damage was assessed by RMS test. It was observed that the addition of coir fibre improved the RMS value. From the Hamburg wheel tracking test, it was observed that the addition of coir fibre improved rut resistance. For all fibre lengths, CBM with 0.2 % coir content showed the highest rut resistance, with 10 mm fibre length showed the best performance. Hence, coir fibre is recommended as a feasible additive for mechanical performance improvement of CBMs.

Keywords: coir fibre, cold mix, bitumen emulsion, rut resistance

1 Introduction

Flexible pavement constitutes over 90 % of the total road network including airfield pavements in India (IRC: SP: 100 – 2014). Hot mix technology is mainly used for flexible pavement construction. In hot mix technology, various processes of road construction including heating of aggregates and binder, mixing, laying of the mix and the compaction are done at high temperature ranging from 120 °C to 165 °C. There are several drawbacks for hot mix technology such as environmental degradation, high energy consumption, increased carbon footprint, low laying work in rains and cold weather, limited construction period in a year, oxidative hardening of the binder, health and safety hazards to labour etc. In this context of disadvantages of hot mix technology, a new innovative, and productive flexible pavement technology, cold mix technology has been brought into existence. In cold mix technology, all the processes of road construction are done at ambient temperature. Cold mix technology, thus has many advantages like sustainability in construction, low health hazard potential, less

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cost etc. Cold mix is presently being used mainly for low volume roads. The application of cold mix is limited due to its certain drawbacks like inferior mechanical properties and low rate of curing. The research in this area is now focused mainly on improving its mechanical strength and increasing the rate of curing. The present study is concerned with the experimental investigation of cold bituminous mix reinforced with coir fibre.

2 Literature Review

There are many studies conducted on the use of different fibres in hot mix. But the studies on the usage of fibres in CBM for its performance improvement are limited. In a study by Hayder (2018), four different fibres – glass, hemp, jute and coir were used to reinforce CBM. The result indicated that the indirect tensile stiffness modulus and resistance to rutting improved significantly for all fibre reinforced CBM mixture. Rough fibre surface was observed to be the reason for improved mechanical properties due to good interlocking between the fibres and the mix. Performance evaluation of high performance cold bituminous mix reinforced with 3 types of fibres – cellulose, glass-cellulose, and nylon-polyster-cellulose done by Ferrotti (2014) showed that fibre type and content strongly influence CBM performance. It was found that the cellulose fibre reinforced mixture ensures higher performance in short term curing. But Benedito (2003) observed that addition of fibres to cold densely graded emulsified bituminous mixes reduces dry density and Marshall Stability as well as lead to reduction of resilient modulus of fibre reinforced mixture when compared with plain mix. Study conducted by Shanbara (2018) using jute and coir fibre in CBM indicated that reinforcement of CBM with natural fibre is effective in mitigating permanent deformation and thus helps in extending the service life of flexible pavements. Liu (2020) used different methods to etch the glass fibre to be used in CBM. It was found that etching roughened that surface of glass fibre and this improved the adhesion between the glass fibre and mix. The improvement in adhesion leads to performance enhancement.

Sayyed (2010) evaluated the performance of bituminous fibre reinforced with different types of fibres. It was observed that fibre reinforcement improves fatigue life and retards future rutting by increasing resistance to cracking and permanent deformation. Sigit (2013) evaluated the characteristics of bituminous mix with coir fibre by using fibre with varying length and quantity. The study showed that 0.75 % coconut fibre content provided the enhanced mix performance. In the study using Sisal fibre, Dash (2016) observed that with the increase in fibre content and fibre length upto a certain level, air void and flow value decreased whereas Marshall quotient increased. The study indicated improvement in rut resistance. Bonica (2016) in the study on performance of bituminous mastic reinforced with fibre suggested that fibre improves the performance of mastic, particularly with respect to the prevention of rutting phenomena at high service temperature. Mohammed (2020) used glass and steel fibre to investigate its effects on the performance of bituminous mix. It was inferred that there was improvement in low temperature cracking resistance with the addition of fibre. Also, fibres provided slight improvement in the fatigue life of fibre reinforced bituminous mixture.

Inferior mechanical properties, low early age strength, higher air void content, and long time for achieving full curing are some of the problems inherent with the CBMs. As these problems hinders its wide usage, it is necessary to find solution to these problems in order to make use of this sustainable technology to its full potential. In this study, an attempt is made to reinforce the CBM using coir fibre in order to check the potential of the fibre to improve the mechanical strength characteristics. The major objectives of the study are: to identify the feasibility of using coir fibre for the performance improvement of CBM and to find the optimum length and quantity of the fibre to enhance the performance of CBM. The study mainly focused on the potential of coir fibre in improving rutting resistance of modified CBM.

3 Materials and Methods

Aggregate used in the study was granite type from the local quarry. The aggregate gradation was taken from MoRTH specification for Nominal Maximum Particle Size (NMPS) 13.2 mm. The designated gradation is given in Figure 1. Cationic medium setting bitumen emulsion was used for the study. Coir fibre used was procured from local coir processing industry. Aggregates used in the study were tested based on Indian Standard Specification. The result of the test is given in Table 1. Various tests of cationic medium setting bitumen emulsion were done as per IS 8888-2007. The results of the test conducted on bitumen emulsion are given in Table 2.

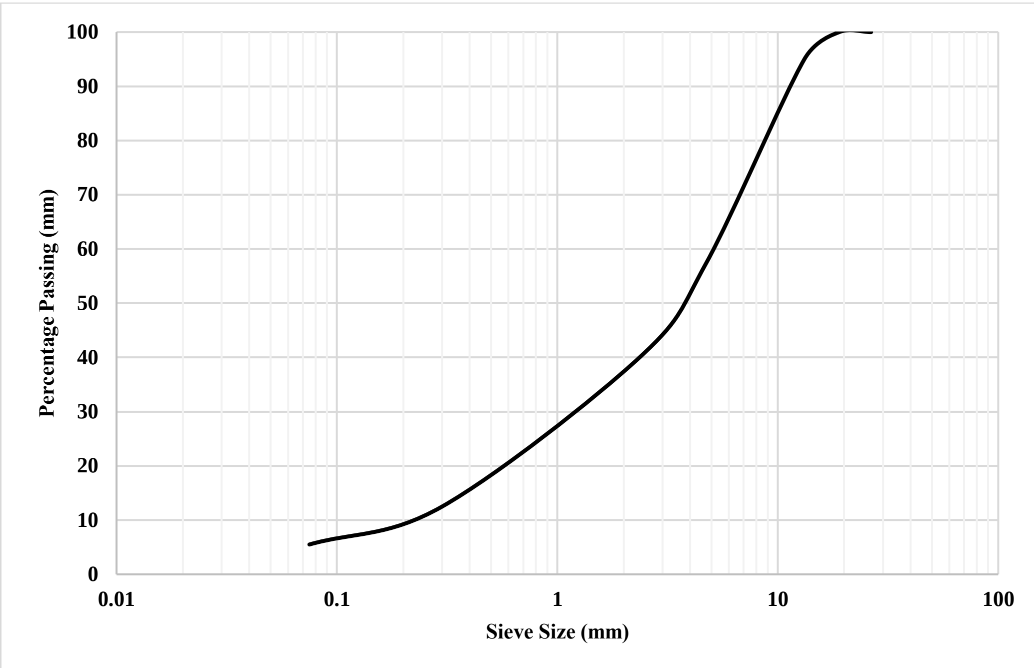

Figure 1. Aggregate Gradation Curve

Table 1 Aggregate Test Results

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 Cationic Medium Setting Bitumen Emulsion

Name of the Test	Test Results	Bitumen Emulsion Specifications as per IS 8887-2004
Residue on 600 micron (%)	0.01	Max 0.05
Coagulation at low temperature	Nil	Nil
Storage stability after 24 hours (%)	0.97	1
Coating ability and water resistance Coating, dry aggregates	Good Fair	Good Fair
Coating, after spraying		
Residue by evaporation (%)	65.34	Min 65
Viscosity by Saybolt Furol viscometer, at 50$°C$ (sec)	175	50-300
Tests on Residue		
Penetration (mm)	112	60-150
Ductility (cm)	65	Min 50
Specific gravity	1.01	Min 0.99

Coir fibre with different lengths – 10 mm, 15 mm and 20 mm was used for the study. The fibre contents (by weight of mix) considered for the study were 0 %, 0.1 %, 0.2 % and 0.3 %. Fibre was checked for its moisture absorption property [Appendix C, IS: 9308(Part 1)-1987] by keeping the coir fibre sample in oven and finding the weight difference after drying. No significant difference in weight was observed which indicated that the coir fibre was free from moisture. From the Scanning Electron Microscopy (SEM) analysis, it was observed that the coir fibre is cylindrical with diameter varied between 0.18 mm and 0.43 mm (Figure 2). The density of coir fibre was found to be 1.4 gm/cc.

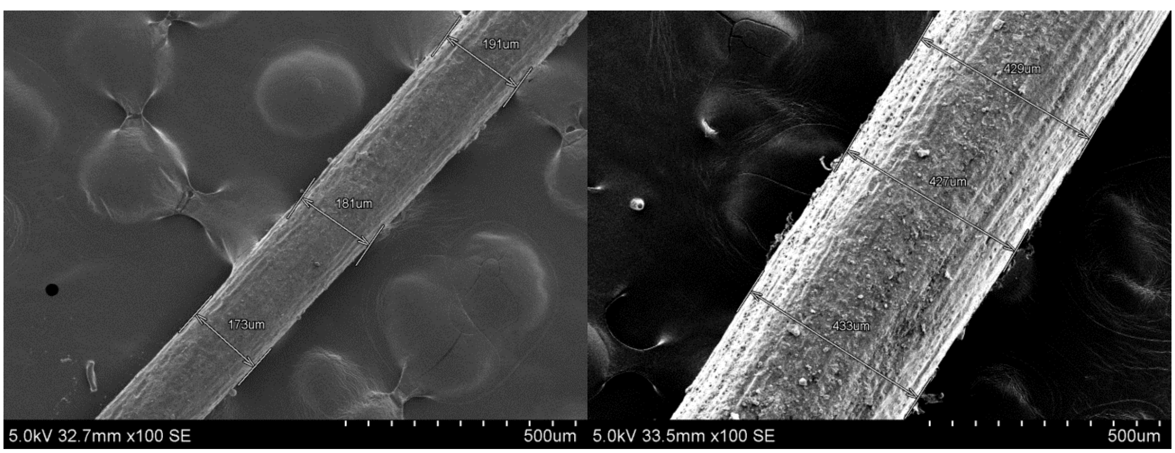

Figure 2. SEM Images of Coir Fibre

4 Mix Design

After the selection of aggregate gradation, Initial Emulsion Content (IEC) for the selected gradation was calculated using formula as per IRC:SP:100-2014 (Equation 1).

$$IEC = 0.05A+0.1B+0.5C \quad (1)$$

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 for the aggregate used was found to be 9.2%.

Thereafter, the optimum pre-wetting water content was fixed based on coating test. Mixes were then prepared keeping the quantity of bitumen emulsion constant, as determined from Equation1 and varying the water content. Binder coating on the aggregate surface was visually observed. The minimum water content at which at least 50 % of the aggregate surface was coated is considered as the Optimum Pre-wetting Water Content (OPWC) required for premixing of aggregate to be used for CBM. The OPWC was found to be 2%.

Marshall mix design was used for finding the optimum emulsion content. Specimens with 63.5 mm height and 100 mm diameter were used for Marshall mix design. Specimens were cured for 1 day at room temperature and 3 days in oven at 40 °C before conducting the Marshall Stability test. Details of mix and specimen curing for different tests are given in Section 6.

5 Tests Conducted

Following the mix design using Marshall method, Retained Marshall Stability (RMS) test and rutting test were conducted to ascertain the performance of CBM modified by coir fibre.

5.1 Retained Marshall Stability Test

To evaluate the moisture resistance of CBM reinforced with coir fibre, RMS test was conducted. Test was conducted with samples of 63.5 mm height and 100 mm diameter. The Marshall test was conducted for dry and wet specimens and the ratio of wet stability and dry stability values is taken as RMS value (Equation 2). The wet specimens were water conditioned (capillary soaking). In this procedure, half the thickness of each compacted specimen was soaked in water at room temperature for 24 hours, the specimen was then inverted, and the other half was soaked for a further 24 hours. During soaking, the samples would rest on a bed of approximately 15 to 20 mm coarse sand. The samples were subsequently towel dried and then tested for Marshall Stability at room temperature.

$$\text{Retained Marshall Stability} = \left(\frac{\text{Soaked Stability}}{\text{Dry Stability}}\right) * 100 \quad (2)$$

5.2 Hamburg Wheel Tracking Test

Hamburg wheel tracking test was done to evaluate the effectiveness of coir fibre on resisting permanent deformation (rutting). Specimens of 150 mm diameter and 60 mm height were used for wheel tracking test. In wheel tracker, there is a specimen holder with dimension 295 x 365 x 60 mm in which the 2 specimens were placed and tested simultaneously. A steel wheel, 47 mm wide and loaded under 705 N makes 30 passes over each specimen per minute. There is an electronic interface display attached to the device where the initial commands like test temperature, number of passes, rut depth at which the device has to automatically stop, etc., can be fed.

6 Curing Protocol

Mix with and without coir fibre was kept under fan for 1 hour immediately after preparation. Then it is cured at 40 °C in an air oven for 2 hours. Thereafter, the specimens for different tests were prepared using the cured mix. After specimen preparation, they were kept in room temperature for 1 day and then at 40 °C for 3 days. For wet stability specimens in RMS test, the water curing as described in 5.1 was done after dry curing.

7 Results and Discussion

7.1 Marshall Stability Test

The Optimum Emulsion Content (OEC) obtained for the gradation taken for this study was 8 %. The OEC was used for CBM specimens prepared with coir fibre. The Marshall specimens were prepared and tested with varying coir fibre lengths (10 mm, 15 mm and 20 mm) and coir fibre contents (0 %, 0.1 %, 0.2 % and 0.3 %). The result of Marshall Stability test of CBM with different coir fibre length and content is given in Figure 3. It can be seen that coir fibre with 15 mm length and 0.2 % coir fibre content gave the maximum stability value. It can also be observed that the stability value increased with increase in coir fibre content in the mix upto a certain limit and reduced thereafter. The increase in the stability value is due to the reinforcement effect of coir fibre and also because addition of fibre provide additional tensile and shear strength in the resulting mixture and develops appropriate amount of strain resistance. But as the coir fibre content increases after a certain limit, balling of coir fibre with mastic will occur, which lead to the reduction in stability value. The use of coir fibre increased the Marshall Stability value of reinforced CBM by 24.10 % as compared to unreinforced CBM.

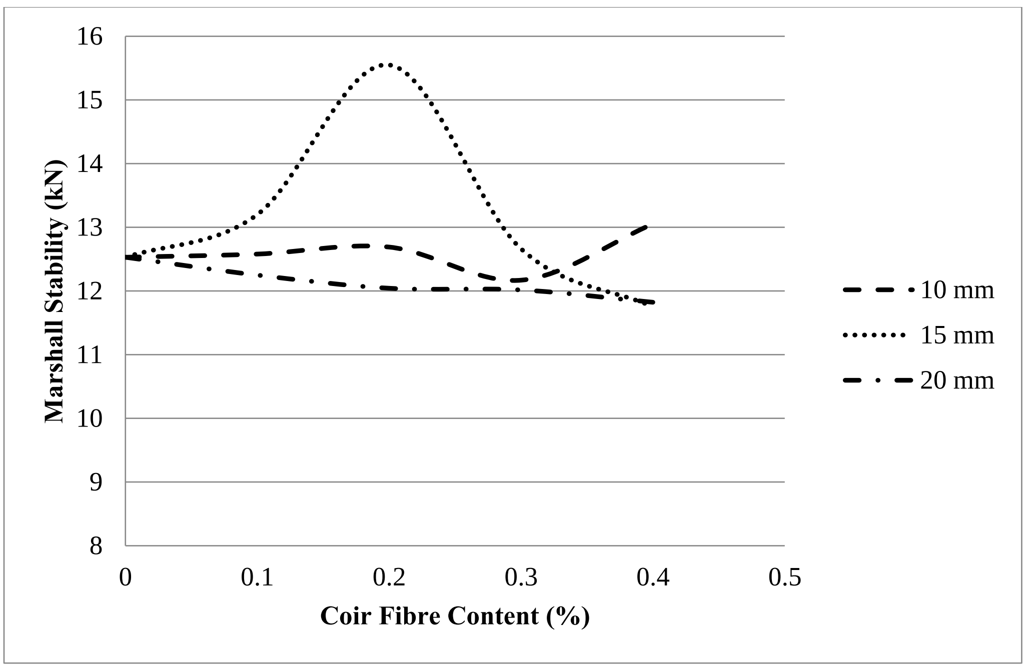

Figure 3. Marshall Stability Graph for Different Lengths and Contents of Coir Fibre

7.2 Retained Marshall Stability Test

Retained Marshall Stability (RMS) test was conducted at different coir fibre lengths and contents. For RMS test, both dry and wet stability tests were conducted. The test results are given in Figure 4. It can be observed that RMS value of all the specimens with and without coir fibre was above 85 %. The result indicates that the reinforcement of CBM with coir fibre enhances its moisture resistance.

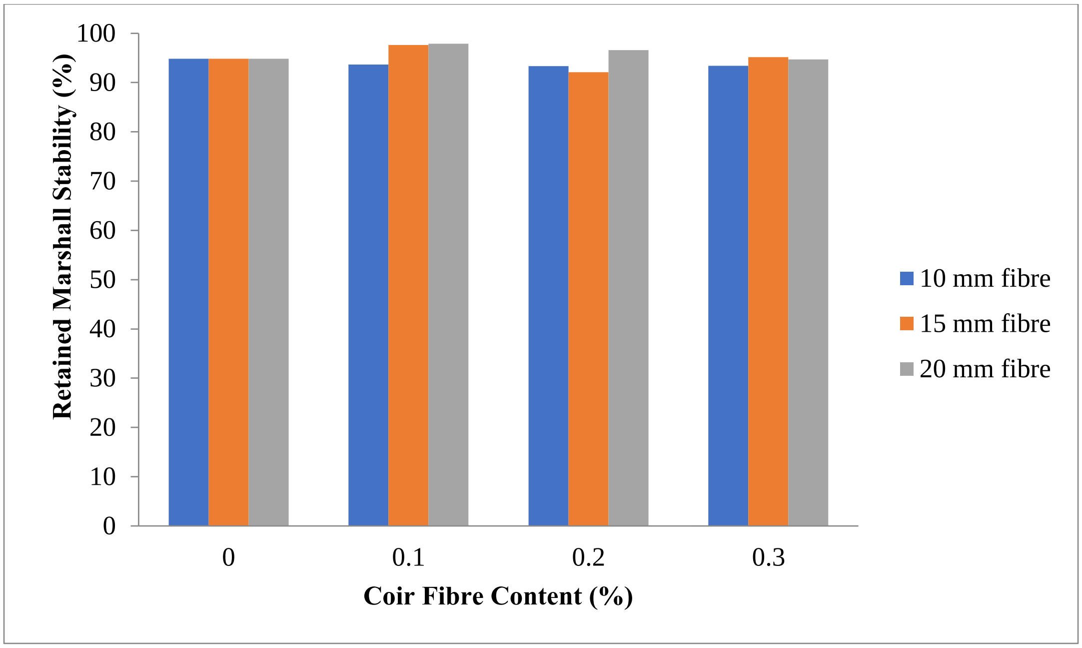

Figure 4. Variation of Retained Marshall Stability with Coir Fibre Content (%)

7.3 Hamburg Wheel Tracking Test

Hamburg wheel tracking test was conducted to evaluate the potential of coir fibre to improve rutting resistance of CBM. The test was conducted till the rut depth reached to 12.5 mm, for all the variations of coir fibre lengths and contents. The specimens were prepared at OEC of 8 % with various coir fibre contents (0 %, 0.1 %, 0.2 % and 0.3 % by weight of total mix) and various fibre lengths (10 mm, 15 mm and 20 mm). The graphical representation of wheel tracking test result with and without coir fibre is shown in Figures 5 to 9.

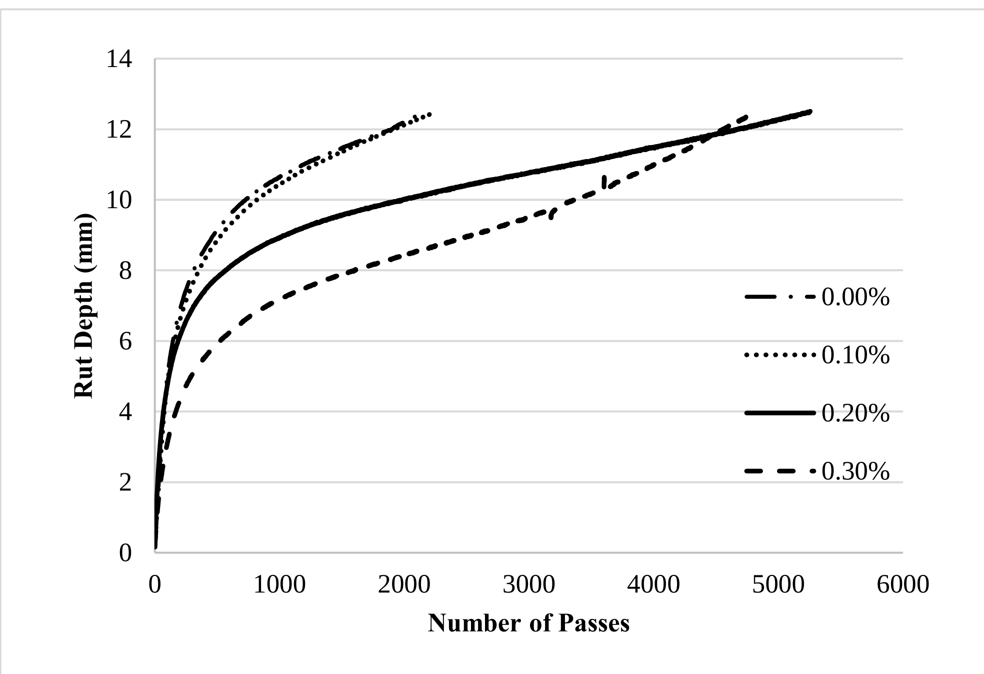

Figure 5. Rutting Characteristics of CBM with Coir Fibre Length of 10 mm

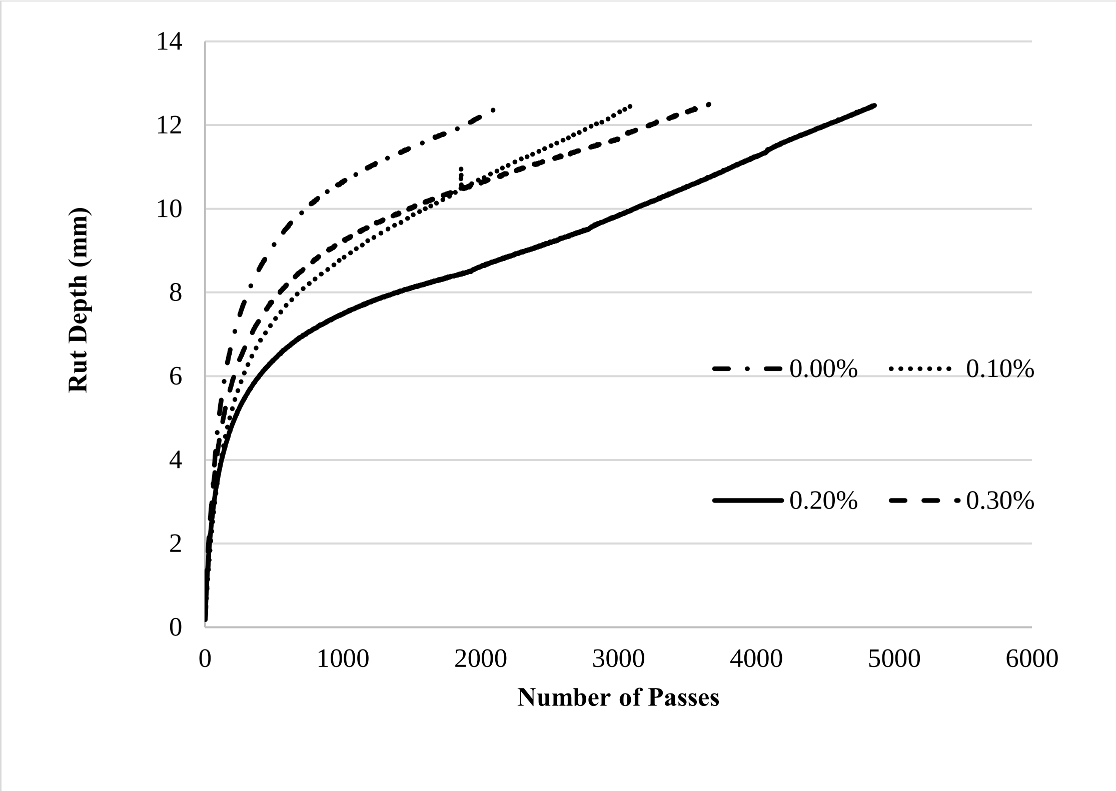

Figure 6. Rutting Characteristics of CBM with Coir Fibre Length of 15 mm

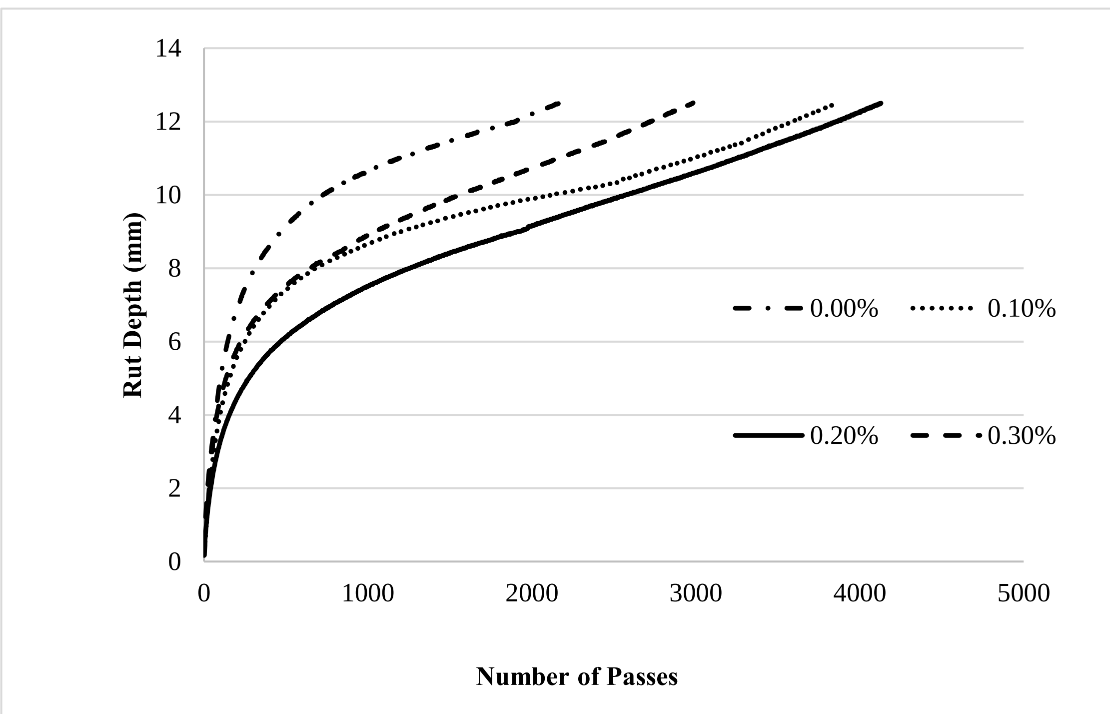

Figure 7. Rutting Characteristics of CBM with Coir Fibre Length of 20 mm

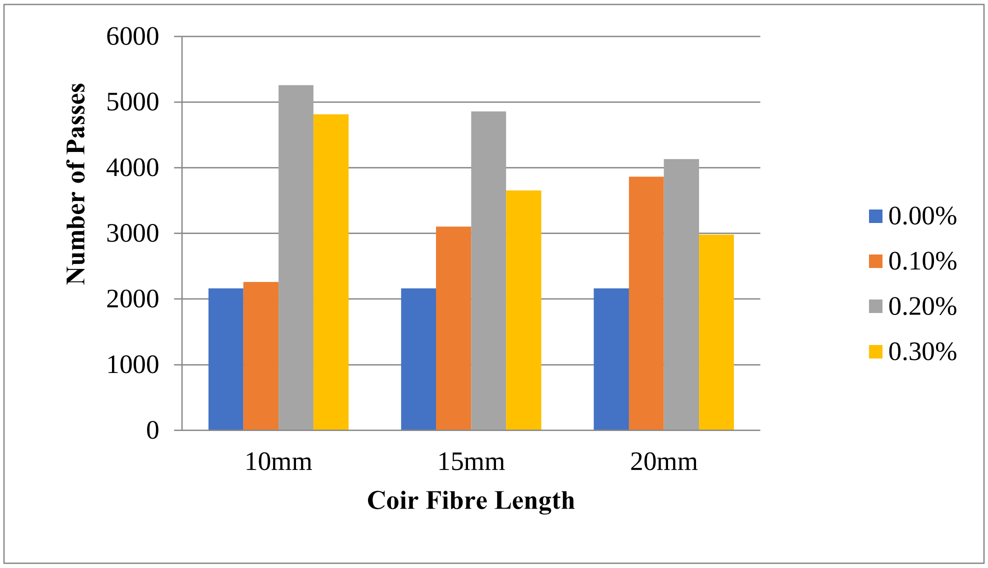

Figure 8. Variation in the Number of Passes for 12.5 mm Rut Depth for CBM

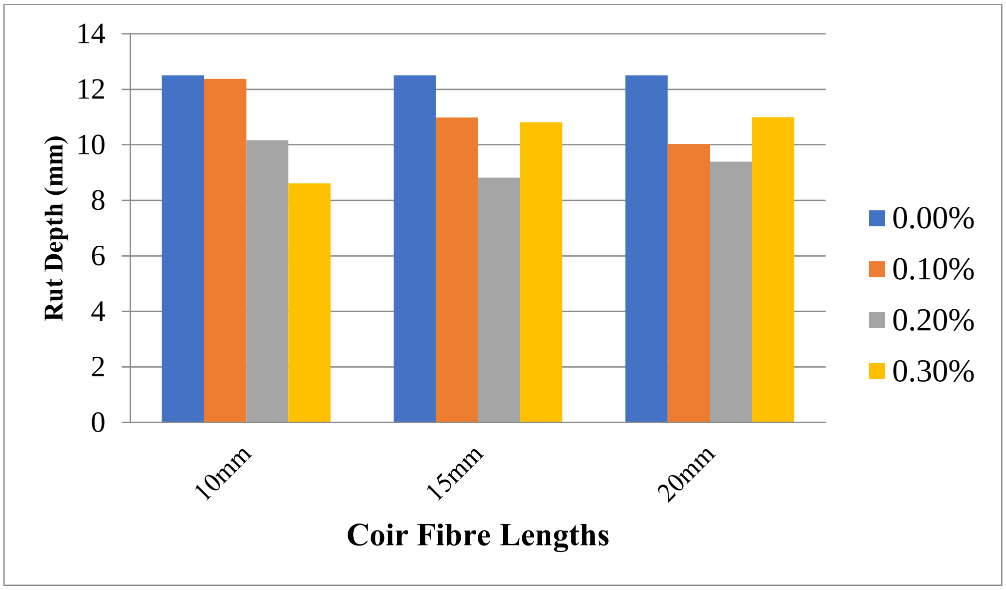

Figure 9. Deformation After 2162 Passes

From Figures 5 to 9, it can be observed that at 0.1 % coir fibre content, rut resistance increased with increase in coir fibre length. But this trend was not observed at 0.2 % and 0.3 % 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 in CBM. But at lower coir fibre content, as the coir fibre length increases, the rutting resistance also increases due to the reinforcement effect. Also, CBM with 0.2 % coir fibre content showed highest rutting resistance among all coir fibre lengths. This is because, at 0.2 % coir fibre content, the distribution of fibre in the mix was uniform and there was no ball formation. At 0.3 % coir fibre content, increase in coir fibre length resulted in decrease in rut resistance. This occurs due to the non-uniformity in fibre distribution and ball formation due to the combination of higher fibre content and increase in fibre length.

8 Conclusions

For the selected aggregate gradation, 8 % was found to be the OEC. Mix was prepared with and without coir fibre at different fibre contents (0 %, 0.1 %, 0.2 % and 0.3 %) and fibre lengths (10 mm, 15 mm and 20 mm). Retained Marshall Stability and Hamburg wheel tracking test was done to evaluate the moisture resistance and resistance to permanent deformation. It was observed that the Marshall Stability value increased by 24.10 % with the addition of coir fibre. Also, RMS value was found to be more than 85 % for all the variations of coir fibre, showing enhancement in moisture resistance. Rutting resistance improved with the addition of coir fibre in CBM. The maximum rutting resistance was shown by 0.2 % coir fibre content at all the lengths of coir fibre. Based on the study, it can be inferred that the addition of coir fibre improved the performance of CBM. The optimum coir fibre length was found to be 15 mm, and 0.2 % was the optimum coir fibre content.

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