Rammed Earth Construction Using Cement & Coir Fibers

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Abstract – The paper aims to investigate the geotechnical and mechanical properties of rammed earth blocks by analyzing their compressive and tensile strength, density, and durability, while taking into account the effects of coir elongation and cement content. The specific aspects that were analyzed in the study are as follows**:**a) Effect of coir % & elongation on OMC and MDD, b) Effect on Consistency of sample, c) Combined effect of cement and coir on compressive strength, d) Combined effect of cement and coir on tensile strength. The objective of this investigation is to determine the optimum value of stabilizer for rammed earth blocks that will improve their geotechnical and mechanical properties while also fulfilling the principles of sustainability. The experiment used 8% cement as a stabilizer and 8% coir as reinforcement in lengths ranging from 20 mm to 40 mm. Based on the results of the experiment, it was found that the characteristic dry compressive strength of the rammed earth blocks improves up to 1% coir of 20 mm length, and then gradually decreases as the length and percentage of coir increase. In addition, the strength ratio drops by about 3.05%–6.27% as the coir length increases from 20 mm to 40 mm.These results suggest that the optimum value of coir reinforcement for improving the mechanical properties of rammed earth blocks is 1% with a length of 20 mm. However, it is important to note that the sustainability of the technique should also be considered when determining the optimum value of stabilizer and reinforcement. Overall, the investigation demonstrates that the use of coir reinforcement along with cement stabilization can be an effective approach for improving the geotechnical and mechanical properties of rammed earth blocks. However, further research is needed to optimize the coir percentage and length to achieve the desired strength properties while ensuring sustainability.

Keywords**: Rammed earth construction, Fiber (Coir), OMC (optimum moisture content), MDD (Max. dry density, Characteristic compressive strength, tensile strength & Durability, Stabilization, Eco-friendly structure.**

I. INTRODUCTION

With the present condition of environmental destruction and natural resource exploitation, the demand for environmentally responsible construction techniques and materials is swiftly enlarging [1,2]. Many nations have begun to look for alternative construction materials that are less harmful to the environment; this situation has resurrected the idea of using nearby available soil and coconut husks (coir) for rammed earth construction. Historically, rammed earth can be found in almost every part of the world [3]. Rammed earth is a building technique which involves compacting soil at its optimal moisture content between **Avila F. et al**. [4] explored the compaction and physical properties of cement stabilized rammed earth and arrived at the conclusion that formwork [1,4]. Cement neutralization can significantly improve the strength and durability properties of unstabilized rammed earth [1,2,4,5]. To reach optimal durability and durability, cement content must be greater than admissions in reputed varsity.

II. LITERATURE REVIEW

with a 10-hour time lag, cement stabilized rammed earth (CSRE) plummeted by 50%. The characteristics of cement stabilized rammed earth Blocks with cement %s varying from 0% to 10% were researched by **Tripura and Singh** [5]. For 10% cement stabilized Blocks, the maximum characteristic compressive strength of 6.43 MPa was attained. The wet-to-dry compressive strength ratio fluctuated between 0.45 and 0.6. **Ciancio et al. (2014)** [6] conducted a study to investigate the strength and stiffness of lime stabilized rammed earth using various geotechnical property tests (UCS, OMC MDD, Plastic Limit, Liquid Limit, Characteristic Compressive Strength) to improve the durability and strength. The researchers performed tests on samples with different percentages of lime (0%, 2%, 3%, 4%, 5%, etc.). They discovered an optimum lime content (OLC) of 4% for samples tested under ambient conditions (not oven-dried), above which no improvement in UCS or stiffness was observed with an increasing lime concentration. Samples tested under natural lighting exhibited a compressive strength peak value at a porosity/lime (n/L) ratio value corresponding to a lime concentration between 3% and 4%. In their work, **Raavi and Tripura** [9] investigated the strength, density, and durability of rammed earth blocks, including the effects of coir (1-5%), length (25-50mm), and cement content (10%). They predicted the parameters using statistical regression analysis and X-Ray Diffraction (XRD) analysis. The results showed that adding coir up to 1% with a length of 25mm improved the characteristic dry compressive strength of rammed earth samples. However, increasing the coir percentage and length decreased the compressive strength, but increased the tensile strength of the samples. Cement stabilization reduced the microstructure porosity, thereby improving the strength and durability properties of rammed earth samples. Adding coir reinforcement with cement stabilization further enhanced the efficiency of rammed earth samples. The study suggests that coir reinforcement and cement stabilization could be a promising approach to improve the strength and durability properties of rammed earth samples(9-19). However, optimizing the coir percentage and length is crucial to achieve the desired strength properties (9-15). To improve the seismic performance of soil, fibrous materials such as straw have been used for reinforcement since prehistoric times. However, there are currently no established standards, and the length, diameter, shape, and amount of fiber used affect its performance (11,19). Natural fibers like sisal, coconut, palm, jute, and barley have been utilized by earlier researchers in a variety of proportions [9-23]. When comparing the durability characteristics of untreated and treated fibers, **Ghavami et al.** **[16]** found that bitumen water repellent treatment increased the durability of the fibers in order to evaluate the durability properties.

Aquino and colleagues(2020)[17]conducted a study in which they added coconut fibers to compressed earth blocks (CEB). The addition of 0.5% coconut fibers increased the flexural strength of the material by 12%, decreased its thermal conductivity by 12%, and reduced swelling with water by 2%. Moreover, the abrasion resistance of the CEB was improved by 30%. When coconut fibers were added to the CEB with a pressure greater than 1,700 psi, the compressive strength of the material improved by 34% compared to CEB without fibers[17,19]. Coir, the natural fiber used in the study, has good strength, stiffness, hydrogeologic properties, and resistance to biodegradation. Due to its high lignin concentration, which mainly consists of both cellulose and hemicellulose, coir degrades more slowly than other natural fibers. After six months of being implanted in clay, coir retained 80% of its tensile strength and maintains a large portion of its tensile strength even when wet. The fiber is moth-proof and fungi-resistant, which gives it an infield service life of 4 to 10 years.**Narani et al. (2021)** [51] investigated the cyclic behavior of rammed earth by imposing strain controlled cyclic loads. RE samples comprise plain soil, Waste Tire Textile Fiber (WTTF)-reinforced specimens (FR), cement-stabilized specimens (CS), and simultaneously reinforced and stabilized (CSFR) specimens. Cyclic properties and responses such as maximum stress, plastic strain, dynamic elastic modulus, damage, and plastic strain energy are evaluated. Max. stress value in the first loading cycle decreases as fiber content is increased in specimen.

Raj et al. (2017)[52] conducted an investigation to determine the optimal proportion of coconut fiber and cement suitable for rammed earth wall construction. The study examined the impact of coconut fiber on stabilized rammed earth blocks' performance. The soil was stabilized by adding Ordinary Portland Cement (2.5%, 5.0%, 7.5%, and 10.0% by weight of soil), while coconut fiber in lengths of about 15 mm was added as reinforcement (0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by weight of soil). Thirty different mixes were created by adding different proportions of cement and fiber to locally available soil and compacting the mix in three layers with a Proctor rammer at constant compaction energy. The results indicated that using 0.8% fiber and 5-10% cement by weight of soil would achieve significant strength. This research could be useful in areas such as green and sustainable housing, waste management, and so on**.**According to study results, coir improves the soil's robust modulus more than synthetic fibers [9,14,21]. As a result, using coir as reinforcement in rammed earth building will have positive effects on the environment, the economy, and society [19]. **Fagon M. et al.** [26] and **Shwetha Prasanna, Nevil Macedon Mendes**[27] are two

The efficacy of composite soil reinforced with rice bran ranging from 0% to 3.5% with varied length of 10-20 mm, 20-40 mm, and 40-60 mm was examined by **Bouhicha et al.** [17]. While a minor effect of fiber length on compressive strength was observed, it was found that soil reinforced with 1.5% fiber of length 20–40 mm enhanced compressive strength by roughly 10–20% compared to 0% fiber reinforced sample.

Danso et al. [19] examined how the aspect ratio of bagasse, oil palm, and coconut fibers affected the mechanical properties of crushed soil Blocks and found that coir fibers of 50 mm or longer boosted the soil Blocks' compressive and tensile strengths. The Blocks' resilience, however, was not addressed. **Hejazi et al.** [53] confirmed that fiber lengths more than 51 mm do not significantly improve soil qualities and make work more difficult due to localized aggregating (clumping) and folding of fibers (balling).

Sangma and Tripura [28] conducted a study on cob blocks that were reinforced with coconut coir and paddy straw. They varied the amount of fiber added to the blocks from 0% to 10% by weight of dry soil, and found that blocks containing 5% fiber and dropped from a height of 0.75 meters were the strongest. Previous literature has extensively investigated the engineering properties of adobe blocks, composite soil, cob, and compressed soil blocks reinforced with fibers, but only a few studies have focused on the characteristics of fiber-reinforced rammed earth blocks.**Raj and colleagues(2017)**[22] studied rammed earth blocks that were reinforced with coconut fiber. The researchers varied the amount of coconut fiber added to the blocks, ranging from 0% to 1.0% by weight of dry soil. They found that when the blocks contained 0.8% coir and 10% cement, they had the highest compressive strength of 10.42 MPa and a tensile strength of 0.2 MPa. However, the study did not investigate the effect of fiber length on the strength of the blocks or the long-term durability of the fiber-reinforced rammed earth blocks.

III. OBJECTIVES

The goal of the current study is to determine the optimal coir percentage and length for coir-reinforced rammed earth blocks. The study will also investigate the impact of coir reinforcement on the compressive and tensile strength, as well as the durability, of the rammed earth blocks through experimental analysis. To achieve this goal, the study will use a range of coir percentages and lengths, varying from 0% to 8% for coir percentage and 20mm to 40mm for coir length. The study will analyze the effect of coir reinforcement on the optimal moisture content (OMC) and maximum dry density (MDD) of the rammed earth blocks, as well as the consistency of block production.

Fig. Rammed Earth Block(REB).

IV. RESEARCH METHODOLOGY

A. SOIL & STABILIZER

The soil sample used in the current study was obtained from my village at a depth of 1.5 m. The soil was free of organic materials and its particle-size distribution, liquid limit, and plastic limit were determined according to IS 2720 Part IV and V [29, 30]. The particle size distribution curve of the soil is shown in Fig. 1. The ideal moisture content (OMC) and maximum dry density (MDD) of the soil were calculated according to IS 2720 Part VII [31]. Previous research [33-35] has indicated that a wide range of soil parameters are suitable for rammed earth construction, including clayey soil with a percentage of 4% to 35%, silt with a percentage of 12% to 36%, sand with a percentage of 37% to 80%, liquid limit ranging from 25 to 30%, and plasticity index ranging from 8.7% to 10.7%. Table 1 shows the characteristics of the soil used in the current study, which fall within these acceptable ranges. To stabilize the rammed earth blocks, Portland cement of 43 grade confirming to IS 8112 [35] was used.

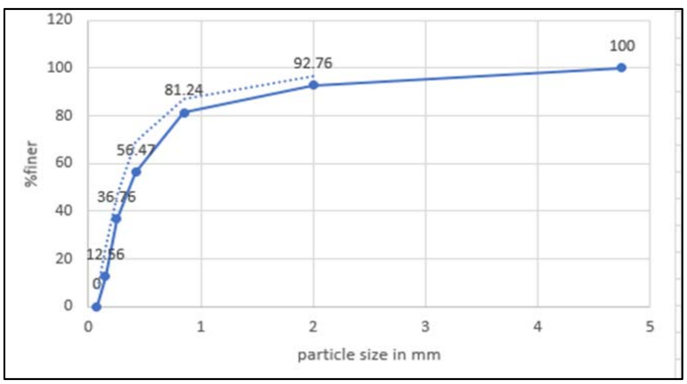


Fig. 1. Particle size distribution curve depicted for sample soil.

Geotechnical Property	Parameters	% Details
Grain size distribution	Sand Silt Clay	65.07% 23.81% 11.12%
Atterberg Limits of soil sample	Liquid limit, WL Plastic limit, PL Plasticity index, Ip	21.05% 13.85% 11.30%
Proctor test	OMC MDD	16.40% 1740 kg/m3
Cement	Initial setting time(t_i) Final setting time(t_f)	75 min 180 min
Coir	Mean diameter Density Tensile strength	0.30 mm 1250 kg/m3 70Mpa
Aspect ratio of coir	20 mm length 40 mm length	55.50 120

Table 1 Geotechnical properties of soil, cement and coir used in rammed block specimen.

B. COIR AS FIBER

Table 1 displays the coir's physical attributes. Coir with average diameters of 0.3 mm and 20 mm was used (Fig. 2). 1% and 3% of coir were considered in the study additionally 5% by weight of dry soil.

Fig.2 Measuring of coir fiber.

C.OMC & MDD

In this study, the Proctor test was conducted in accordance with IS 2720 Part VII [31] for each change in coir percentage and length. The results of the test, including the OMC and MDD, were recorded in Table 2. It is important to note that the ultimate dry density of rammed earth blocks is significantly influenced by the moisture content of the soil. Therefore, it is crucial to ensure that the moisture content is appropriate, as per the guidelines outlined in NZS 4298 [36]. To measure the water content of the soil specimens, the moisture meter method was adopted.

D. PREPARATION OF BLOCK

The dry ingredients, including soil, fiber, and cement, were first mixed in a dry state for both CSCR and USCR blocks. Then, the appropriate amount of water was added to the mixture to attain the desired moisture content for compaction. The compaction process was carried out using a Proctor rammer in accordance with ASTM D-698-12 standard procedure [37]. Before each layer was compacted, a thin metal plate was placed above it to ensure uniform distribution of load on the compacted earth. The test blocks were then left to dry in the shade for the USCR blocks, and under wet gunny bags for the CSCR blocks, for a total of 28 days. All the blocks were then given a 10-day lab drying period to remove any extra moisture content before testing. The weight batching method was used for the entire soil mixing and placement procedure to ensure consistency in the mix. The quantity needed to prepare three cubes at once was chosen to minimize the time gap between mixing, placing, and compacting of the mixture. Compaction energy was determined using the ASTM D-698-12 standard procedure, as stated by D.D Tripura & Singh [5], who noted that it plays a crucial role in mm. Before battering with a Proctor rammer, a thin metal plate of size 96mm × 96 mm × 18 mm was placed above each layer to ensure uniform load distribution on the compacted earth. The specific representative production run data can be found in Table 3. After unmolding, the US blocks were left to dry in the shade, while the CS blocks were dried for a total of 28 days under wet gunny bags. Prior to testing, all blocks underwent a 10-day lab drying period to eliminate any extra moisture content. [5]

E.TESTING PROCEDURE

Universal Testing Machine (UTM) with a capacity of 450 kN to test the strength of the blocks, and a loading rate of 3.0 kN/min was used. The dry compressive strength was estimated according to IS 4332 Part V [43]. The water absorption and saturated strength of all blocks except USR were determined according to HB 195 [40]. The tensile strength of the blocks was evaluated using IS 5816 [41], and the dry density of the cubes was determined in accordance with IS 4332 Part V [43].

Fig. Universal Testing Machine(UTM) to perform various testing.

F. ANALYSIS & RESULTS

a) Effect of coir % & elongation on OMC and MDD

The addition of coir to rammed earth blocks can have a significant effect on the optimum moisture content (OMC) and maximum dry density (MDD) values of the blocks. As the percentage of coir increases, the OMC values tend to rise, while the MDD values decrease. This is because coir has the ability to absorb manufacturing water, leading to an increase in OMC, while its ability to resist compaction at greater volume can lead to a decrease in MDD.The OMC and MDD values of US blocks range from 16.40% to 21.60% and 1740 to 1520 kg/m3, respectively, while the values of CS blocks range from 16.20% to 21.00% and 1750 to 1560 kg/m3, respectively. The OMC rises as the coir content increases, while the MDD decreases. The increase in OMC can be attributed to coir's ability to absorb manufacturing water, while the decrease in MDD can be attributed to coir's ability to resist compaction at greater volume. According to Fig. 4, the values of 13.28% and 3.24%-12.13%, respectively. The passage also notes that the values of OMC for US and CS blocks rise with the increase in coir length from 20 mm to 40 mm, while the values of MDD drop. This phenomenon is due to the longer coir pieces interfering with soil conditions mixing and compaction, leading to the development of high porosity blocks. Overall, the passage suggests that there is a direct relationship between the length and coir %, with OMC being proportional and MDD being inversely related to blocks of rammed earth made with coir.

Fig. Indian Standard Light Compaction Test.

Material composition	**% Coir used**	**OMC (%) & MDD (Kg/m3)**
Soil added 20 mm coir	0% 1% 3% 5%	16.40, 1740 18.00, 1710 19.00, 1600 21.50, 1530
Soil added 40 mm coir	0% 1% 3% 5%	16.40, 1740 18.10, 1700 20.00, 1580 21.60, 1520
Soil added cement & 20 mm coir	0% 1% 3% 5%	16.20, 1750 16.28 ,1720 19.30, 1650 20.21 ,1560
Soil added cement & 40 mm coir	0% 1% 3% 5%	16.20, 1750 16.30, 1710 19.63 ,1630 21.00, 1560

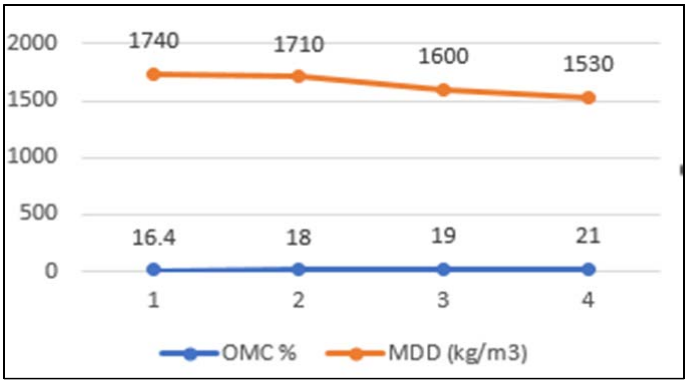


Fig. Soil added 20 mm coir.

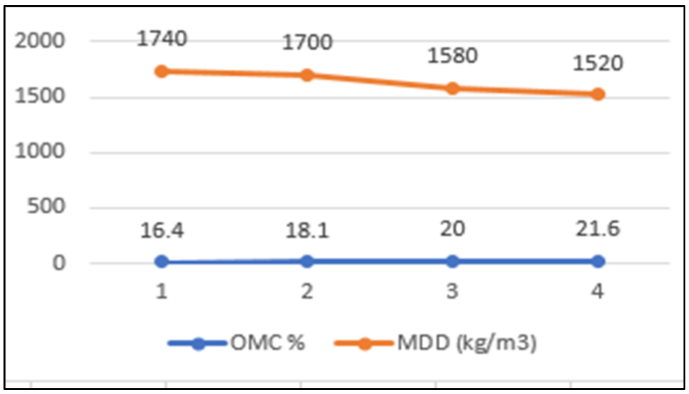


Fig. Soil added 40 mm coir.

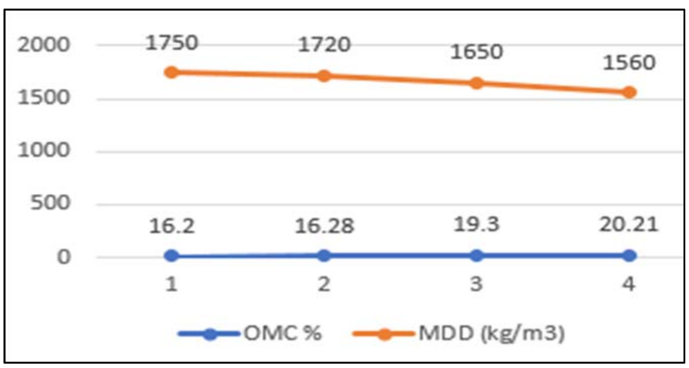


Fig. Soil added cement & 20 mm coir.

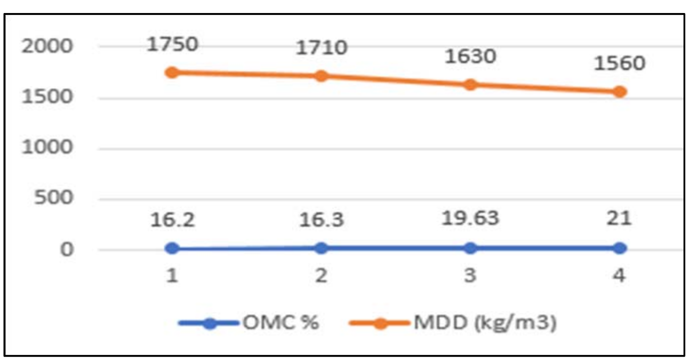


Fig. Soil added cement & 40 mm coir.

USCR = UNSTABILIZED COIR REINFORCEMENT BLOCK

Table 3 Sample production run.

Specimen	Coir (%) used	Coir length (mm) used	Cement content (%)	No. of specimen
USR	0	-	0	20
US1CRR20	1	20	0	20
US3CRR20	3	20	0	20
US5CRR20	5	20	0	20
US1CRR40	1	40	0	20
US3CRR40	3	40	0	20
US5CRR40	5	40	0	20
CSR	0	-	8	20
CS1CRR20	1	20	8	20
CS3CRR20	3	20	8	20
CS5CRR20	5	20	8	20
CS1CRR40	1	40	8	20
CS3CRR40	3	40	8	20
CS5CRR40	5	40	8	20

Table 4 Summary of test results.

Specimen Details	Avg. Wet Compressive Strength (MPa)	Standard Deviation (MPa)	Avg.Dry Comp. Strength (MPa)	Standard Deviation (MPa)	Avg. Char. Dry Compressive strength (MPa)
USR	-	-	3.62	0.12	3.43
US1CRR 20	0.62	0.03	4.28	0.26	3.60
US3CRR 20	0.38	0.03	4.05	0.24	3.45
US5CRR 20	0.26	0.06	3.41	0.21	2.72
US1CRR 40	0.33	0.03	4.25	0.31	3.56
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

US5CRR 40	0.23	0.01	2.71	0.22	2.05
CSR	3.32	0.46	6.42	0.20	5.9
CS1CRR 20	3.62	0.24	7.61	0.15	7.10
CS3CRR 20	2.75	0.14	7.04	0.36	6.26
CS5CRR 20	1.84	0.16	6.50	0.45	5.23
CS1CRR 40	3.00	0.38	6.63	0.42	5.42
CS3CRR 40	2.32	0.06	6.43	0.42	5.23
CS5CRR 40	1.65	0.30	6.05	0.52	4.54

US: UNSTABILIZED
CR: COIR REINFORCED
CS: CEMENTSTABLIZED

1, 3 and 5 represent % coir.
20 and 40mm represent coir length.

Table 5 Results after various testings.

Avg .Tensile Strength (MPa)	Standard Deviation (MPa)	Avg. Moisture content at the tme of testing (%)	Avg. Calculated dry density (kg/m3)	Dry density variation with respect to Proctor value (%)	Ratio of wet to dry compressive strength	Water absorption (%)	Standard Deviation (%)
0.14	0.03	2.84	1725	<1.12	-	-	-
0.25	0.03	2.85	1700	<0.57	0.14	0.17	0.55
0.39	0.05	3.46	1585	<0.62	0.09	0.08	0.60
0.42	0.10	3.56	1515	<0.64	0.07	0.05	0.15
0.31	0.05	3.24	1680	<0.57	0.07	0.10	0.27
0.61	0.06	3.52	1575	<0.40	0.07	0.05	0.27
0.74	0.25	3.86	1500	<0.62	0.8	0.05	0.64
0.99	0.10	2.95	1770	=0.00	0.51	0.50	0.80
1.05	0.03	2.96	1735	>1.18	0.47	0.46	0.55
1.20	0.06	3.62	1600	>2.57	0.28	0.26	0.80
1.08	0.04	3.18	1720	>1.20	0.45	0.43	0.34
1.17	0.05	3.41	1650	>1.85	0.36	0.35	0.34
1.20	0.04	3.95	1580	>1.94	0.27	0.25	0.28

b) Effect on Consistency of sample

The density of the blocks is an important parameter that reflects their strength and durability. The dry density of the blocks is calculated based on the weight and dimensions of the blocks after they have been dried in an oven. The method used for calculating the dry density in this study follows the Indian Standard IS 4332 Part V [43]. The results of the dry density measurements for the various types of blocks are presented in Table 4.

$$\gamma_d = 100W/AL(100+w)$$

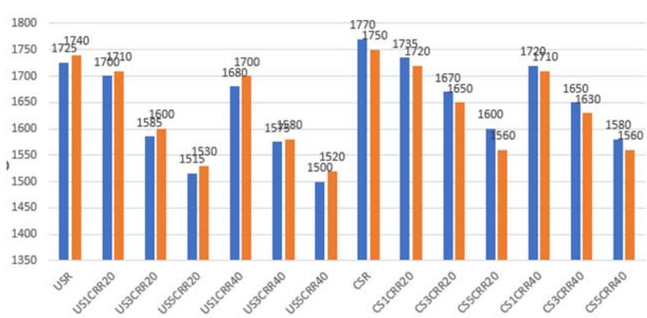
Where W = weight of the sample (g)

A = Cross-sectional area (cm2)

L = length of the specimen (cm)

w = water content of the specimen in %

The average moisture content of US and CS blocks during testing of The moisture content and dry density values of the blocks vary depending on the type of block and the amount of coir used. For example, the moisture content of the blocks ranges from 2.84% to 3.86% and 2.95% to 3.95%, while the density ranges from 1500-1725 kg/m3 and 1580-1770 kg/m3, respectively. The variations in dry density obtained by Tripura and Singh are slightly higher than the standard Proctor values due to compaction [5]. In the case of CS blocks, the dry density values decrease, which may be due to resistance from the coir. On the other hand, the dry densities of US blocks are closer to the standard Proctor values, ranging from 0.40% to 1.12% and 0.00% to 2.57% weight of dry density [5]. These values can be attributed to proper hydration and filling of the pores by the hydration products of cement during curing. During block testing, there were some mechanical ruptures between the coir and matrix in a few places, and numerous cracks were seen close to the pulled-out coir, which may indicate a tight link between the coir and the matrix [46].



c) Combined effect of cement and coir on compressive strength

The test results are reported in Table 4 as well as the typical unconfined compressive strength that was computed from NZS 4298 [36].

$$f = (1-1.5Ps/Pa)*P_1$$

Where f = characteristic UCS (MPa)

Ps = standard deviation of a series values.

Pa = average of a values and X1 = minimum result

The dry compressive strengths of US and CS blocks were found to be between 2.05 and 3.60 MPa and 4.54 and 7.10 MPa, respectively. On the other hand, the wet compressive strength for US and CS samples ranged from 0.23 to 0.62 MPa and 1.65 to 3.62 MPa, respectively. The disintegration of the US sample after water absorption did not allow for the assessment of its strength. The CS1CR20 block exhibited a slightly higher typical dry compressive strength compared to that found by Tripura and Singh [5] for 10% cement-stabilized cured blocks, which can be attributed to the improved uniformity achieved during sample production. The addition of 8% cement resulted in a strength gain of all blocks by 35.06% to 57.57%. The rigid link between sand grains and coir is formed by the hydration gel filling the pores of the matrix, resulting in an increase in strength. The decrease in strength when the coir percentage is increased above 1% could be due to the formation of coir lumps in the mixture, which weaken the material. However, when the coir percentage is kept at or below 1%, the blocks show increased strength. The US1CR20 and US3CR20 blocks are stronger than the USR blocks by 16.25% and 6.98%, respectively, and the CS1CR20 and CS3CR20 blocks are stronger than the CSR blocks by 18.05% and 10.3%, respectively. This increase in strength could be due to the high adhesion between the soil-cement matrix and the coir, possibly due to friction or the looping of coir within the matrix. It is observed that the average strength of US and CS blocks decreases by 26.83% and 21.39%, respectively, which could be due to the presence of long coir fibers that interfere with the bonding between soil and cement nanoparticles, causing soil lumps to form while being mixed. The brittle mode of failure was observed in both USR and CSR blocks, where cracks started at the specimen's corner and spread throughout its length.

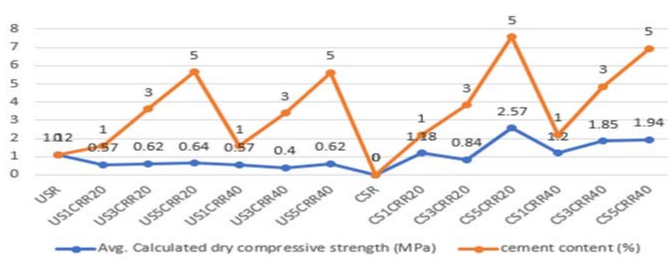


Fig. plot b/w Avg. dry comp. strength (MPa) v/s cement content(%) of samples.

Tensile strength was estimated as per IS 5816 [41] and the test results are shown in Table 4.

$$f_{ct} = 2P/\pi dl$$

Where fct = Tensile strength (MPa)

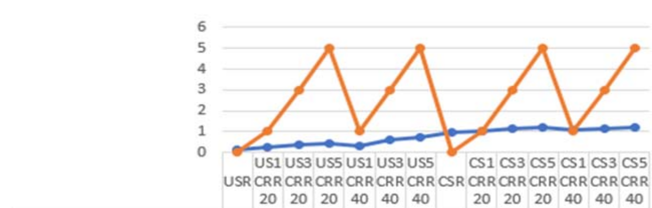
P = peak load applied on the sample (N)

l = length of the sample (mm)

and d = cross-sectional dimension of sample (mm)

US and CS blocks have average tensile strengths that range from 0.14 to 0.74 MPa and 0.99 to 1.20 MPa, respectively. CS blocks are between 38.56% and 85.58% stronger than US blocks. Cement stabilization increased tensile strength as a result.

This might be due to the cement hydration process during curing and the formation of a stiff link between the soil particles and the coir, which increased the blocks' tensile strength. In relation to Raj et al.. [22], the current study's tensile strength result is about 5.265 times higher. Moreover, it can be seen that the tensile strength of CS blocks improves from 6.05% to 21.78% with an increment in coir content from 0% to 5%. This improvement in tensile strength with the increase in coir content might be due to the coir fibers' ability to provide additional reinforcement and form bridges across cracks in the blocks, enhancing their capacity to resist tensile stresses. Moreover, the cement hydration process during curing may lead to the formation of a strong bond between the coir fibers and soil-cement particles, further increasing the blocks' tensile strength. The higher tensile strength of US5CR40 and CS5CR40 blocks compared to USR and CSR blocks might also be due to the additional reinforcement provided by coir fibers. CSCR20 and CSCR40 blocks showed even greater strength, indicating that the length of the coir fibers also plays a role in enhancing the blocks' tensile strength. In comparison, the strength differential between US Blocks, which vary from 0.22% to 42.88% for a respective 1% to 5% coir content, and CS Blocks reinforced with 20 mm and 40 mm coir length is greater. It might be because the soil matrix is held together by a stronger link between soil-cement particles and coir in CS blocks, which forms bridges all across blocks' fissures and increases their capacity [12,16,19]. The addition of coir as reinforcement improved both the tensile and ductile qualities of the blocks. This is because the coir fibers act as bridges across fractures, which adds extra strength and prevents complete splitting of the blocks even after reaching their maximum capacity. As the coir content and length increase, the tensile strength of the blocks also increases.



	USR	US1 CRR 20	US3 CRR 20	US5 CRR 20	US1 CRR 40	US3 CRR 40	US5 CRR 40	CSR	CS1 CRR 20	CS3 CRR 20	CS5 CRR 20	CS1 CRR 40	CS3 CRR 40	CS5 CRR 40
Avg. Calculated tensile strength (MPa)	0.14	0.25	0.39	0.42	0.31	0.61	0.74	0.99	1.05	1.16	1.2	1.08	1.17	1.2
cement content (%)	0	1	3	5	1	3	5	0	1	3	5	1	3	5

V. CONCLUSION

The following conclusions are reached in light of the experimental investigation:

- the addition of coir has a more significant effect on the tensile strength of the blocks compared to their compressive strength. CSR blocks, which have coir reinforcement, show higher compressive and tensile strengths than USR blocks without coir reinforcement. However, for both types of blocks, the compressive strength(54.50%) improves only up to 1% coir content, while the tensile strength(85.58%) steadily rises as the coir content increases.
- The wet-to-dry compressive strength ratio and maximum water absorption of CSR blocks reinforced with 1% and 3% coir, correspondingly, of 20 mm and 40 mm lengths, are both well within acceptable bounds.
- The 20 mm and 40 mm length blocks reinforced with 5% coir displayed negative impacts in terms of strength and durability.
- None of the US blocks satisfied the minimum requirement requirements, although coir reinforcement allowed the USCR Blocks to maintain their shape when completely immersed.
- Except for CS5CR blocks, the strength ratios of CSCR blocks are well within the allowed range. The strength ratio drops by about 3.05%–6.27% as coir length increases from 20 mm to 40 mm.
- The addition of coir to the soil-cement mixture increases the porosity of the resulting blocks, which leads to an increase in their ability to absorb water. The water absorption capacity of the blocks increases as the coir content and length increase. This is because the coir fibers create pathways for water to enter and exit the blocks, increasing their permeability.

VI. FUTURE SCOPE

- More research could help to establish how coir reinforcement affects the engineering qualities of rammed earth blocks made with different soil types, as well as the impact of treating the coir and the orientation of the coir fibers. This could help to expand the knowledge base on coir-reinforced rammed earth blocks and improve their application in construction projects.

- Exploring different types of fibers and stabilizers can provide valuable insights into the performance of earth rammed construction and potentially lead to more sustainable and efficient building practices. Some examples of fibers and stabilizers that could be explored in future research include jute, hemp, sisal, and lime.

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