Structural behaviour of large size compressed earth blocks stabilized with jute fiber

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ABSTRACT

Modern earth buildings constructed of Compressed Earth Blocks (CEBs) are of low-cost, energy efficient, and sustainable. Environmental regulations are suggested for zero emission of greenhouse gases. The strength of CEBs is usually enhanced with the addition of 5 to 10% of cement whose manufacturing may be harmful to the environment. A novel composite of soil (i.e., clay, sand, and jute fiber) is used to produce CEBs without addition of cement. The jute fiber was added by weight from 0.5 to 2% to a mixture of pulverized clay, sand, and water. The CEBs were tested for compressive strength, tensile strength in terms of modulus of rupture, load vs deflection response, shrinkage, drying time, and development of cracks. With the addition of jute fiber, (*i*) the compressive strength, deflection, drying time, shrinkage, and cracks were reduced, (*ii*) the modulus of rupture slightly increased, and (*iii*) the load at failure was almost same. The addition of 0.5% of jute fiber was enough to minimize the drying cracks. The CEBs were reinforced with jute fiber dried in about half the time taken by those without fiber. The average compressive strength, tensile strength, and linear shrinkage of the CEBs are within acceptable limits prescribed by available guidelines. This paper shows that the CEBs manufactured using clay, sand, and jute fiber could be used for construction of earth buildings instead of those stabilized with cement.

Keywords: Compressed earth blocks; compressive strength; cracks; jute fiber; shrinkage.

INTRODUCTION

Worldwide, approximately 33% of people are living in earthen homes. In developing countries, more than 50% of the population live in earthen homes. Vast deposits of earth (combination of clay, silt, and sand) are available in various regions of the world. Earthen homes are cost-effective and energy efficient as compared to those made of concrete and steel (Minke, 2012).

The population of Pakistan is increasing with a growth rate of 2.1% annually and has reached 200 million today. On the contrary, the number of houses constructed annually is less than required to shelter the present population of the country. Further, it can be estimated that the number of houses required in the next five years can increase to 20 million units. The discouraging factor in the construction of required housing units is the increased cost of traditional materials of construction such as stone, timber, concrete, and steel. In addition, per capita income of Pakistan is about 1600 US dollars, which is not enough for common men to build houses made of conventional materials.

In plains of Pakistan, summer lasts for about eight months, during which temperature is usually above 35^0C at day time. Generally, the duration of peak temperature during day time in summer lasts for about five hours in plains of the country. When the outside temperature is higher, the outer heat is transferred to the interior of a building through conduction from the walls and roof. The thermal conductivity of conventional materials of construction (e.g., concrete, stone, and steel) is high enough to absorb the exterior heat and transfer it to the interior of a building well before this duration. The interior heat of a building is so high that it is not affected by any drop in the outside temperature during nights. Therefore, the buildings constructed using traditional materials of construction need air conditioning even at night, which consumes too much energy. There is shortage of electricity and it is very costly for common people to afford electricity bills. The earthen houses are energy efficient (Pacheco-Torgal & Jalali, 2012; Deboucha & Hashim, 2011; Reddy & Jagadish, 2003; Morel *et al.*, 2001; Alam *et al.,* 2015). This is because the earth houses absorb heat slowly such that the heat gained by a building is not of the same intensity as that of the outside temperature.

Earth (combination of clay, silt, and sand) has been used as low cost, sustainable and recyclable material of construction in the history of mankind (Calkins, 2008), because it is easily available at construction sites with minimum hauling and excavation costs. Earth becomes mouldable when mixed with water; it becomes hard on drying and can be used for construction of load bearing walls of buildings (Snell & Callahan, 2005). The houses constructed using clay could last for thousands of years (Snell, & Callahan, 2005). Fired clay has been used in construction of buildings since thousands of years ago (Staubach, 2013). Generally, the masonry work is carried out using fired bricks. However, due to increased cost of energy and emission of carbon dioxide, unfired stabilized clay bricks are being used as building construction material (see, e.g. Oti *et al.,* 2012, and Oti *et al.,* 2009).

In order to protect the environment, the modern trend is to utilize unfired bricks for construction of houses. To enhance compressive strength of unfired bricks, fibers have been added. It is to be noted that the addition of certain minimum amount of fiber in soils results in increase in compressive strength of Compressed Earth Blocks (CEBs), whereas, with addition of more quantity of fibers, the compressive strength of CEBs is reduced (Taallah *et al.,* 2014). The literature shows that the addition of fiber reduces drying time and shrinkage (Ismail & Yaacob, 2011; Li, 2002; Bouhicha *et al.,* 2005; Hejazi *et al.*, 2012). Saleem *et al.* (2016) conducted a study on compressed earth bricks of size 228 x 114 x 76 mm reinforced with jute fiber. They concluded that the compressive strength of the bricks reinforced with jute fiber was increased to 2.75 times as compared to those without fiber.

There is still another problem of low compressive strength of masonry units constructed of unfired bricks. The compressive strength of brick masonry is generally lower than that of an individual brick because of presence of more joints due to small size of bricks. To resolve this problem, the idea is to utilize Compressed Earth Blocks (CEBs), which are sufficiently larger than a standard size brick.

Nowadays, Compressed Earth Blocks (CEBs) are being utilized for construction of modern earth buildings (Heathcote, 2002). The earth used for manufacturing of CEBs consists of wide range of soils, i.e., 15% gravel, 50% sand, 15% silt, and 20% clay (Auroville, 2018). The CEBs cast out of such soils are usually stabilized with 5 to 10% of cement by weight (Jayasinghe & Kamaladasa, 2007; Morel & Walker, 2007). It is to be emphasized here that, during production of cement, greenhouse gases are emitted, which may be hazardous to the environment (Damtoft *et al.*, 2008). To eliminate the use of cement in CEBs, a greater percentage of cohesive soil is to be utilized instead of gravel. In this respect, the authors (Lakho *et al.,* 2017) conducted a preliminary study to cast CEBs out of clay and pit sand in a ratio of 7:3 by weight without addition of cement. The size of these blocks was 1980 mm x 300 mm x 150 mm. This study concluded that these CEBs took 150 days to dry with linear shrinkage of about 2%. Although the shrinkage of the CEBs was within acceptable limits (see, e.g., DachverbandLehme, 2009), yet the drying time was excessive. These blocks were covered in plastic sheet to reduce possibility of drying shrinkage cracks.

Gunnysacks of jute fiber are commonly used in Pakistan for packing of grains, flour, and for various other items. The old gunnysacks are useless and may create problem of disposal. Such gunnysacks could be chopped and used as fiber in CEBs to reduce drying time and shrinkage. In this study, how the basic structural properties of CEBs, without cement, vary when different percentages of jute fiber were mixed to the raw material, i.e., clay and pit sand, was examined.

MATERIALS AND METHODS

Preparation of soil mixture

Clay and pit sand were obtained locally near Nawabshah city. The clay was excavated at 2 m depth. Generally, the excavated clay is in shape of varied sizes of lumps (Figure 1). To achieve workability and proper mixing, it was necessary to pulverize the quarried clay lumps. Therefore, the clay was ground using Pulverizer. The fine powder of clay after being pulverized is shown in Figure 2. Pit sand contained small hair-like roots of plants, broken shell of snail, and small quantity of clay clods. These impurities were separated from pit sand using sieve No. 50. Clay and pit sand (Figure 3) were mixed in a predetermined ratio of 7:3 by weight, respectively. The liquid limit and plastic limit of this blended soil were 33% and 17%, respectively. The maximum dry density and optimum moisture content of the blended soil were 21 kN/m^3 and 12.5%, respectively. The liquid limit and plastic limit tests were conducted by using ASTM D4318. The maximum dry density and optimum moisture content of the blended soil were determined by using standard Proctor Test (ASTM D698).

Old gunnysacks were purchased from local market and were chopped to obtain jute fiber (Figure 4). The content of the jute fiber was varied from 0.5 to 2 % by weight of the clay pit sand mixture with each increment of 0.5 percentage. Four batches of moist clay and pit sand mixtures were prepared by adding 22% of water. The moist mixture of soil was mixed in a pan mixer (Figure 6) for 20 minutes. Three CEBs were cast and compacted using each of these batches.

Fig. 1. Excavated clay in form of lumps.

Fig. 2. Pulverized clay powder.

Fig. 3. Pit sand.

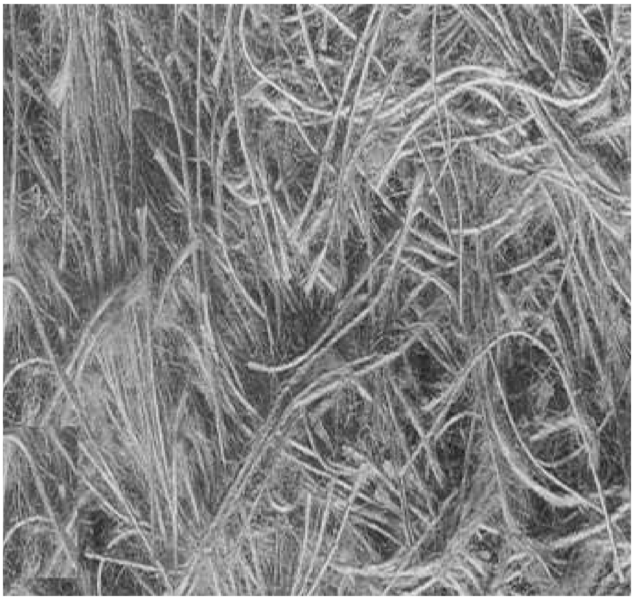

Fig. 4. Jute Fiber chopped from old gunnysacks.

Moulding of earth blocks

Earth blocks were moulded and compressed in a steel mould (Figure 5) of Mechanized System (Lakho *et al.*, 2015). This mould was 1980 mm long, 165 mm wide, and 400 mm deep. The moist clay was laid in the mould in four layers, with each having depth of 100 mm (Ansari, 2008). Each layer was tamped with a wooden pad before placing the next one. The upper surface of each layer was scratched with a steel nail after completion of tamping. A slight shower of water was sprayed between the successive layers. This was done to develop a bond between the layers, so that the beam must behave like a monolithic compacted earth block. After the mould was filled with moist soil, it was railed in the compacting chamber of the Mechanized System (Figure 6) and the moist earth was compacted using a wooden plunger. Initially, a compactive pressure of about 2 MPa was applied to the moist earth blocks. As a result, the layers of the soil were compressed and became smooth in shape. Then the mould was railed out of the compacting chamber and the moist clay block was demoulded. At this stage, a propylene fabric sheet was wrapped around this demoulded compressed earth block. After that, the mould was again railed into the compacting chamber for compaction. Now, the compacting load was increased to 6 MPa. The load on the moist earth blocks was maintained for 24 hours. During this period of loading, added moisture in the CEBs continued to drain out with decreasing rate continuously during the application of the load. After this, the drainage of the added water stopped after 24 hours. The depth of the CEBs was found to be compressed averagely about 310 mm because of this loading. The CEBs were then demoulded and moisture content was determined. The water content of the CEBs was almost close to the optimum moisture content of the blended soil, which was found to be 12.5%. These CEBs were dried in an aired hall (Figure 7).

Fig. 5. Mould for casting earth blocks.

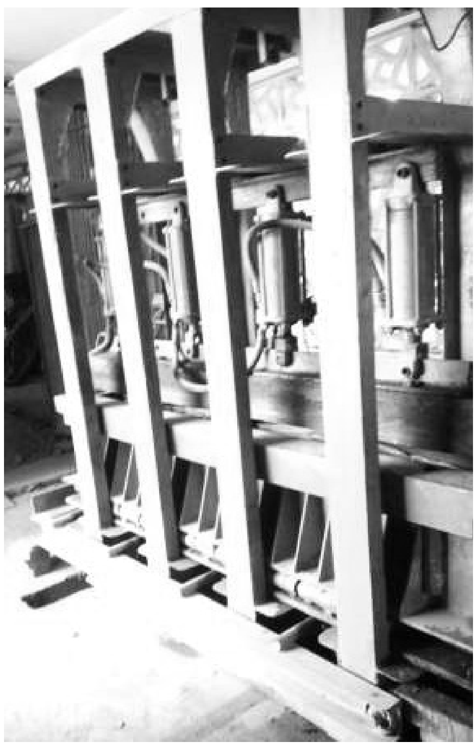

Fig. 6. Mechanized System for compression and consolidation of earth blocks.

Fig. 7. A Compressed Earth Block is being dried in shade.

Test specimens

As mentioned before, the CEBs were dried in a ventilated hall. After drying, the specimens were cut from the CEBs. Since the objective of this study was to determine the effect of jute fiber on compressive strength, modulus of rupture, load -deflection response, shrinkage, drying time, and cracks in CEBs, the drying time, shrinkage, and cracking behaviour were observed during the drying phase of the CEBs. To determine modulus of rupture, one beam specimen having size of 900 mm x 300 mm x 150 mm (length, width, and depth, respectively) was cut from each CEB. Cubes of 150 mm were sawed using cutter machine (Figure 8). Cylinders having height of 300 mm and diameter 150 mm were drilled out of the CEBs using core cutter machine (Figure 9). Load-deflection response of the beams was measured during modulus of rupture tests. The summary of various specimens is presented in test matrix (Table 1).

Table 1. Test matrix for various types of specimen cut from Compressed Earth Blocks.

Batch	Specimen	No. of specimens	Fiber content by weight of soil (%)
1	CEBs	3	0.5
	Beams	3	
	Cubes	5	
	Cylinders	5	
2	CEBs	3	1
	Beams	3	
	Cubes	5	
	Cylinders	5	
3	CEBs	3	1.5
	Beams	3	
	Cubes	5	
	Cylinders	5	
4	CEBs	3	2
	Beams	3	
	Cubes	5	
	Cylinders	5	

TESTING PROGRAM

Linear shrinkage of the CEBs was recorded during drying period. Compressive strength of both the cubes (Figure 10) and cylinders (Figure 11) was determined using Universal Testing Machine. Modulus of rupture of the CEBs was determined using Universal Beam Testing Machine (Figure 12). For determination of modulus of rupture, the total and the effect lengths of a beam were taken as 900 mm and 850 mm, respectively. According to the guidelines of ASTM C293, the Modulus of rupture (R) is mathematically defined as

$$R=1.5PL/bd^2 \quad (1)$$

where b and d are length and width of the beam, L is the effective length of the beam, and P is the failure load.

Fig. 8. Cutter machine utilized for sawing cubes from Compressed Earth Blocks.

Fig. 9. A cylinder is being cut from a portion of Compressed Earth Block.

Fig. 10. Cube crushing strength is being performed in Universal Testing Machine.

Fig. 11. A cylinder cut from a compressed earth block is being tested for compressive strength in Universal Testing Machine.

Fig. 12. A Compressed earth block is being tested for modulus of rupture in Universal Beam Testing Machine.

RESULTS AND DISCUSSIONS

As mentioned before, three CEBs were cast out of each of the four batches of moist soil that were prepared using 0.5, 1, 1.5, and 2% jute fiber, respectively. The results illustrate the effect of jute fiber on the following structural properties: compressive strength, modulus of rupture, load versus deflection, shrinkage, drying time, and development of cracks.

Compressive and tensile strength

The compressive strength of both the cubes and cylinders is presented in Figure 13. As expected, the compressive strength is reduced due to the addition of jute fiber. This is because the randomly placed jute fiber facilitated escape of water during drying process leaving behind voids in the soil. The density of the soil decreased due to the presence of voids, since the compressive strength of the soil depends on density, which was reduced due to addition of the fiber. The cube crushing strength is about two times higher than that of cylinders. This type of relationship between crushing strength of cubes and cylinders is helpful to establish the ratio of cube to cylinder strength.

The cube compressive strength of 2.4 MPa was calculated for jute fiber content of 2%. The international codes on compressed earth blocks suggest that the minimum dry compressive strength of a CEB should be 2 MPa (BIS, 1982; ARSO 1996; AFNOR, 2001; ICONTEC, 2004; NMAC, 2016; AENOR, 2008; ASTM E2392, 2016). It is to be noted that the CEBs discussed in this study are planned to be used as a walling material for single storey houses.

The average modulus of rupture of the CEBs was calculated to be 0.69, 0.7, 0.72, and 0.74 MPa for 0.5, 1, 1.5, and 2% addition of the jute fiber, respectively. The values of the modulus of rupture increased with the increase in fiber content. The reason is that the fiber acted as reinforcement, which controlled development of cracks, which ultimately resulted in increased tensile strength. Available guidelines (BIS, 1982; ARSO 1996; AFNOR, 2001; ICONTEC, 2004; NMAC, 2016; AENOR, 2008; ASTM E2392, 2016) suggest that the compressive strength of CEBs should be at least 2 MPa, and the modulus of rupture (NMAC, 2016) of 0.34 MPa is acceptable.

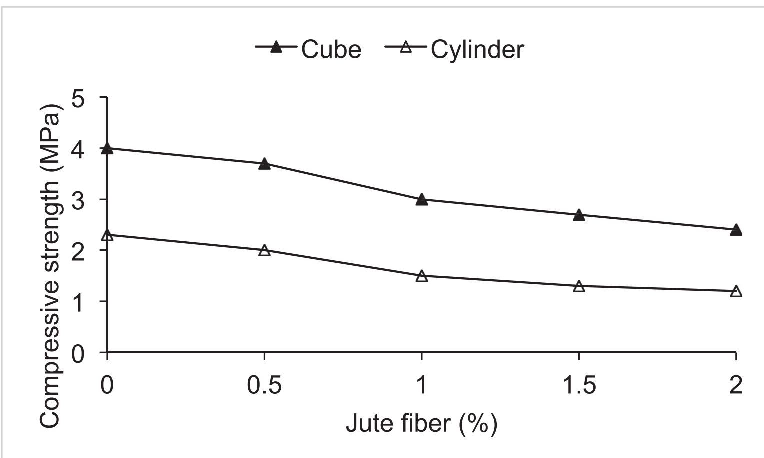

Fig. 13. Effect of dosage of jute fiber on compressive strength of cubes and cylinders.

Load deflection response of compressed earth blocks

The load deflection behaviour of CEBs having effective length of 850 mm is presented in Figure 14. As expected, the deflection of the CEBs was reduced due to addition of jute fiber. The deflection of the CEBs reinforced with 2% jute fiber was one-half of the deflection exhibited by the blocks having 0.5% fiber. This is because the randomly laid jute fiber controlled the development of cracks in the blocks. The CEBs failed at mid-span showing flexural mode of failure (Figure 15).

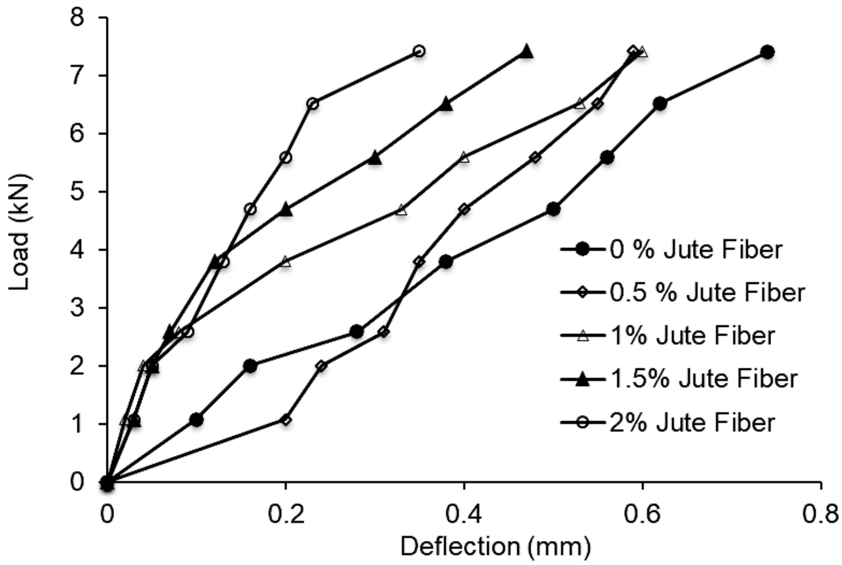

Fig. 14. Effect of jute fiber content on load deflection behaviour of compressed earth blocks.

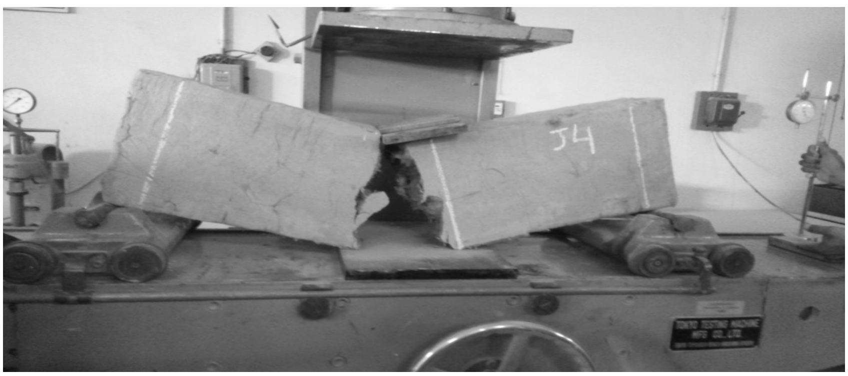

Fig. 15. Flexural mode of failure of a Compressed Earth Block reinforced with 2% jute fiber.

Shrinkage of compressed earth blocks

The shrinkage behaviour of CEBs reinforced with jute fiber is illustrated in Figure 16. The shrinkage of CEBs was reduced from 2% to about 1% with the increase in the fiber content from 0.5 to 2%, respectively. This is because the randomly distributed jute fibers developed paths for evaporation of water through surface. According to German Earth Building Code (DachverbandLehme, 2009), for CEBs linear shrinkage up to 4.75 % is permissible.

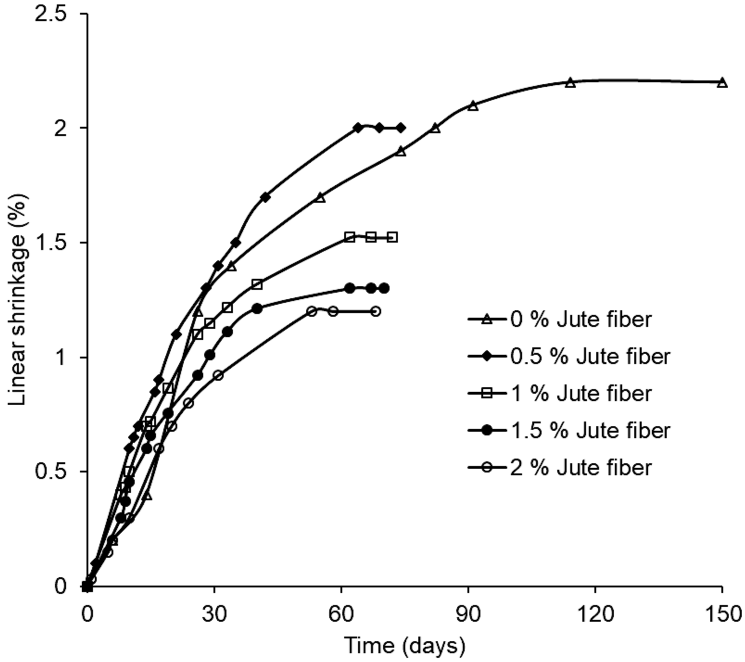

Fig. 16. Effect of jute fiber on linear shrinkage of compressed earth blocks.

Drying time and cracks in compressed earth blocks

The CEBs having 0.5 to 2% jute fibre were dried in shade in about 70 days. On the other hand, the controlled CEB without fibre took 150 days to dry. The drying time of the CEBs reinforced with jute fibre was almost one-half of those without fibre. This reduction in drying time is attributed to jute fibres, which facilitated the moisture to escape through surface of the blocks. Moreover, the inclusion of 0.5 % jute fibre was even sufficient to curtail development of cracks in CEBs.

CONCLUSIONS

In this study, the effect of jute fiber was investigated on structural properties of Compressed Earth Blocks (CEBs). The following main conclusions were drawn from this study:

1. The average value of compressive strength of cubes cut from CEBs having 0.5 to 2% jute fiber decreased from 3.7 MPa to 2.4 MPa, respectively.
2. The tensile strength of the CEBs having 0.5 to 2% jute fiber increased from 0.69 to 0.74 MPa, respectively.
3. The CEBs having 2% jute fiber exhibited two times less deflection as compared to the ones with 0.5% fiber.
4. Linear shrinkage of the CEBs having 0.5 to 2% jute fiber decreased from 2 to 1%, respectively.
5. The drying time of the CEBs with 0.5% jute fiber was even reduced to one-half of those without fiber.
6. Available guidelines on earthen building materials recommend that the properties of CEBs such as compressive strength, tensile strength, and linear shrinkage are within the permissible limits.
7. This study shows that the soil composite (i.e., 70% clay, 30% pit sand, and 0.5% jute finer) could be utilized for manufacturing of CEBs without the need for stabilization with cement.

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