Pak. J. Engg. & Appl. Sci. Vol. 19 July, 2016 (*p.* 83–90)

Jute Fiber Reinforced Compressed Earth Bricks (FR-CEB) – A Sustainable Solution

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Abstract

Compressed earth bricks can play an important role in rural housing industry especially in the developing countries. To strengthen these bricks, the use of fibers is a functional and economical option. This research aims to reinforce the compressed earth brick with jute fibers in order to investigate the effect of these fibers on their compressive strength. Bricks were cast in the laboratory in similar fashion as adopted in an industrial brick fabricating plant; however, compression was applied using a compression machine. Different proportions of water and jute were added in the soil for fabricating the standard size bricks (9×4.5×3 inches). After 28 days of sun drying, the compressive strength tests were performed on the brick specimens. The result showed improved strength behavior due to jute fiber addition. Up to 2.75 times increase in compressive strength was achieved with jute fiber compared to that of bricks without fibers. Moreover, cost comparison between un-burnt fiber-reinforced bricks, un-burnt bricks without fibers and burnt bricks without fibers was also carried out in order to demonstrate the potential applicability of un-burnt fiber-reinforced compressed earth bricks in the remote areas. The results demonstrate that the compressed earth bricks incorporating jute fibers dramatically increased the strength and can prove to be more sustainable than conventional mud homes.

Key Words: Compressed earth bricks, jute fibers, reinforced, compressive strength.

1. Introduction

Masonry work has been employed in construction industry for thousands of years. Approximately 1/3rd of the world's population is living in the earthen masonry structures [1]. In a developing country, the masonry work is very important and considered as the back-bone of housing construction. Earthen masonry structures are preferred in construction because they are economical, recyclable, energy efficient, provide thermal and acoustic insulation, easy to construct and made of local available materials. Furthermore, no high skilled labor is required unlike the concrete or steel construction. In the past, it was used to make multi-story buildings, mosques, forts etc. Nowadays, its use is limited to one story buildings because of the availability of high strength materials which fulfills the demand of both engineering and economics.

In Pakistan, the use of masonry structures is still very common especially for residential buildings. Compressed bricks using locally available materials have several advantages. For instance, they eliminate the transportation cost of raw materials for their manufacturing. Furthermore, they show higher strength and improved durability over adobe and requiring low embodied energies [2]. Compressed earth bricks are resistant to sound, fire, insect damage and durable if properly protected [3]. Therefore, it can be concluded that these earth bricks are energy efficient and environment friendly. However, if mixture ingredients for the manufacturing of these earthen masonry bricks are not properly optimized and designed, it may lead to poor response when subjected to intense loading during seismic events and may reach to unacceptable performance level leading to structural collapse [4, 5]. Generally, earthen masonry bricks have low tensile strength and ductility [6]. Therefore, fibers (organic or synthetic) can be used to reinforce these bricks in order to improve its tensile strength, durability characteristics, resistance against shrinkage cracking and enhance ductility [2, 6-10]. Straw has been used since long to improve tensile strength of mud bricks [6]. Fiber content in earthen masonry also enhances its water permeability properties.

Binici et al. (2005) reported that the compressive strength of fiber reinforced earthen bricks was higher compared to that of the conventional earthen bricks without fibers. This can be attributed to the resistance against deformation in longitudinal and transverse directions due to randomly distributed fibers. Therefore, the shape of the earthen bricks can be preserved. Furthermore, edge cracking and spalling of fiber reinforced earthen bricks can be reduced due to holding of mud mixture with fibers leading to increased strength properties [6].

In recent past, research has been conducted on compressed earth bricks (CEBs) reinforced with fibers in Turkey, India and Bangladesh [2, 6]. The selection of reinforcing fibers in CEBs involves many factors, specially its availability and cost. In Pakistan, jute fibers are easily available and are economical as well. Therefore, this study mainly focuses on the CEBs reinforced with jute fibers. Use of jute fibers in the construction materials dates back to seventeen century or may be earlier. Mughal emperors have been using jute fibers in mortars. For instance, in the reign of Emperor Shah Jahan (1592-1666) Masjid Wazir Khan was constructed in 1635 AD in the Walled City of Lahore near Delhi Gate and jute fibers were used in the lime mortar (**Figure 1**). Use of jute fibers can also be witnessed in other buildings constructed during that era.

Fig. 1 Jute fibers used in mortar

2. Research Significance and Objectives

Construction is the fundamental part of development and progress. Concrete and steel structures are safe from engineering point of view but are very expensive for common people. These materials have high demands and complex factors are involved to maintain their strength and durability. On the other hand, bricks are economical choice for construction. Neither very skilled labor is required nor is any complexity involved in the construction. Bricks are dimensionally uniform, durable and provide reasonable strength if properly burnt in kiln. However, industrial kilns are required for manufacturing these burnt bricks. Maintaining higher temperature in those industrial kilns requires a huge energy, involving significant investment. Furthermore, transportation cost is also involved to transport these bricks from kiln to the construction sites. Therefore, for small houses in rural areas, compressed earth bricks may be used which are prepared using locally available resources and are cheaper than the burnt bricks. However, these bricks are not very strong and are susceptible to cracking, breaking or other damages, especially during floods. In this study, jute fibers were introduced in compressed earth bricks in order to improve their cracking and compressive strength behavior. These fiber-reinforced bricks can be easily employed for constructing small housing schemes especially in remote rural areas, and also for temporary construction at project sites. In Northern hilly areas of Pakistan, where destruction takes place due to floods and earthquakes, the use of fiber-reinforced bricks may prove to be economical and sustainable solution. In terms of strength and durability, FR-CEBs lie between the uncompressed mud used in adobes (**Figure 2**) and brunt bricks.

Fig. 2 A typical mud house

The main objective of this research is to reinforce the compressed earth bricks with jute fibers and study its effect on compressive strength. Furthermore, this study investigates the appropriate and effective ratio of water and jute fibers in compressed earth bricks.

3. Experimental Work

3.1 Materials and Test Matrix

The soil used in this research was acquired from an industrial brick manufacturing plant situated in the suburbs of Lahore, Pakistan. Sieve analysis results of the soil are shown in **Table 1,** which indicate that the soil was sandy. Existing moisture content of the soil was found using the oven dry method which was in the range of 5 to 11%. Existing amount of moisture were subtracted from required quantity of water to get the mixing water percentage. Jute was purchased in the form of long threads and was then cut into small pieces (fibers) of 25 mm length (**Figure 3**). The typical properties of jute fibers are shown in **Table 2**.

To fulfill the objectives of research, a detailed test matrix consisting of a range of fiber and water content was developed and is presented in **Table 3**. This matrix is little different from the one initially conceived. The reason is that some of the specimen with high fiber content and low water content were not workable and were therefore, dropped from the test matrix. It was learnt during the mixing that when fibers more than 0.125% were added, lumps of fibers started forming. Therefore, 0.125% was set as the upper limit of the fiber content. Similar approach was adopted to decide the maximum water content. It was observed that beyond the water content of 11%, the mix became very plastic. Therefore, 11% was set as the upper limit of the water content.

Table 1: Sieve analysis results of used soil

Sieve #	Sieve size (mm)	Soil retained on sieve (%)	Cumulative retained (%)	Fines (%)
10	0.425	35.20	35.20	64.80
40	0.300	36.32	71.52	28.48
100	0.150	21.38	92.90	7.10
200	0.075	5.80	98.70	1.30
Pan	0	1.10	99.80	0.20

a) Jute strands b) Jute fibers

Fig. 3: Jute strands and fibers

Table 2: Properties of jute fibers

Properties	Value
Density (g/cm^3)	1.3
Elongation (%)	1-1.2
Moisture Absorption after 24 h (%)	6-9
Specific Gravity	1.3
Tensile Strength (MN/m^2)	442
Young's Modulus (MN/m^2)	55.5
Specific Strength (MN/m^2)	340
Specific Modulus (GN/m^2)	42.7

Table 3: Test matrix

Jute Content by Weight of Soil	Water Content				
	5%	6.5%	8%	9.5%	11%
0.00%	3*	3	3	3	3
0.05%	3	3	3	3	3
0.075%	3	3	3	3	3
0.10%	3	3	3	3	3
0.125%	3	3	3	3	3

* Number of Specimens

3.2 Preparation of Bricks and Testing

For preparing 3 unique specimens of each mix proportion, 15 kg of soil was taken and the lumps were broken using hammer (**Figure 4**). Afterwards, the soil was placed in an oven to determine the moisture content. Jute threads were separated from each other and were later mixed with soil in dry condition (**Figure 5**). Fibers were added in increments and were successively mixed with hand after each increment, in order to avoid lumps formation. The mixing was continued until fibers were uniformly dispersed in the soil. Afterwards, water was added and mixed thoroughly.

a) Soil before preparation

b) Soil during preparation

Fig. 4 Preparation of the Soil

Fig. 5 Mixing of jute with soil

A steel mold was specially prepared to achieve smooth surfaces and right size (**Figure 6**). The bricks had to be compressed, therefore steel mold with bolted connections was preferred over the wooden mold. Mold was oiled before casting. It was then filled with prepared soil mixture in three equal layers. Gentle amount of pressure was applied on each layer with hands. After completely filling the mold, it was then placed in compression machine to further compress the mixture. More mud was successively added to fill the mold which now had some space due to reduction in volume after compression. This process was repeated until the soil was fully compressed and the mold was completely filled. In the real production, a manual compression machine would be used, which is already available in the market (**Figure 7**). The specimen was then de-molded and placed in open air for sun drying. The specimens were covered with polythene sheets in order to protect them from rain (**Figure 8**).

Fig. 6 Mold for casting bricks

Fig. 7 Manual compression machine for bricks

After 28 days of sun drying, brick specimens were brought back to the laboratory. Frogs were filled with gypsum plaster in order to provide a smooth contact surface for uniform application of load. Gypsum plaster was given 5 hrs to get dry. Afterwards, brick specimens were tested in the compression machine (**Figure 9**).

a) Stacking of bricks in Open Air

b) Bricks Covered with Plastic Sheet

Fig. 8 Sun drying of bricks

4. Results and Discussion

The results of compression tests on FR-CEBs at 28 days are presented in **Table 4**. Each strength value represents the average of three specimens. In addition to FR-CEBs, three specimens of un-burnt bricks made by traditional procedure at the manufacturing plant were also tested. Their average compressive strength was found as 436 psi. These bricks did not contain fibers.

a) Compression test

b) Tested brick

Fig. 9 Testing of bricks

Table 4 Average compressive strength (psi) results

Water Content	Fiber content (%)				
	0.00	0.05	0.075	0.10	0.125
5.0%	406	436	474	645	805
6.5%	424	534	561	692	833
8.0%	350	645	829	811	861
9.5%	410	436	778	833	885
11.0%	438	590	795	845	1198

For the 5% water content, the compressive strength of bricks increased from 406 psi to 805 psi for the fiber content of 0.00% to 0.125%, respectively. This is an increase of 98%. For the water content of 6.5%, 8%, 9.5% and 11% the respective increase in compressive strength is 96%, 146%, 116% and 173%, respectively. **Figures 10** to

15 show the effect of increasing the fiber content on the compressive strength for various percentage of water. Although, some of the compressive strength values do not follow the trend, however, a general tendency of increase in compressive strength with the increase in fiber content can be clearly seen from the data. The data shows a nearly linear trend in the increase of strength with fiber content. The absolute maximum strength achieved was 1198 psi for the water content of 11% with a fiber content of 0.125%. This increase in compressive strength of bricks due to jute fiber addition is mainly attributed to its transverse and longitudinal restrained against deformations provided by fibers [6]. The inconsistency in some of the strength values can be attributed to poor workmanship, especially in measuring of water and application of force to compress the bricks.

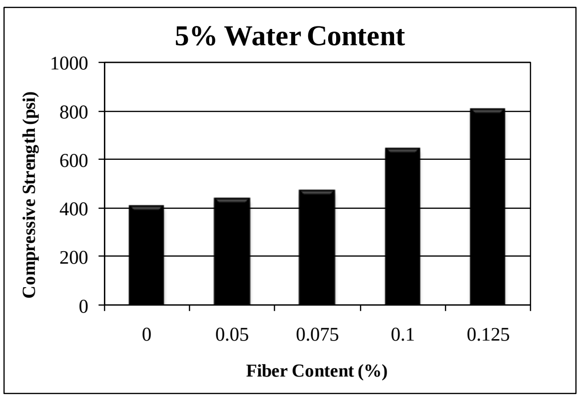

Fig. 10 Fiber content versus compressive strength at 5% water

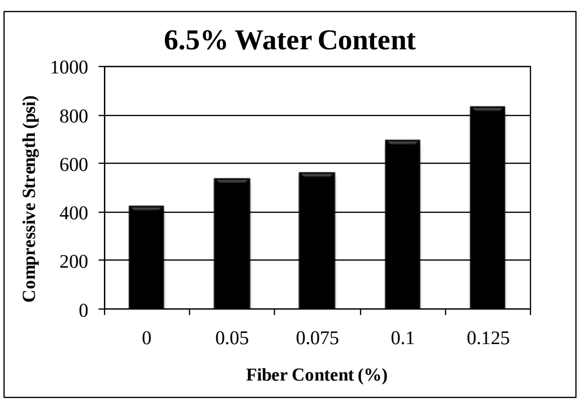

Fig. 11 Fiber content versus compressive strength at 6.5% water

Figure 16 presents the combined plots of the change in compressive strength with the variation of fibers for all the water contents. It can be clearly seen that for the fiber contents of 0%, 0.05% and 0.075%, the compressive strength variation does not follow a pattern with the increase in water content. However, for the fiber contents of 0.10% and 0.125%, the compressive strength increases with the increase in water content. It can be inferred from this trend that the optimum dosage of fibers may exist between 0.10% and 0.125% fibers. It may also be concluded that for higher dosages of fibers, the higher water content results in better compaction, ending up with higher compressive strength. For all the water contents, the average compressive strength achieved for 0% fiber was 406 psi and for 0.05%, 0.075%, 0.10% and 0.125% fibers were 528, 688, 765 and 916 psi, respectively.

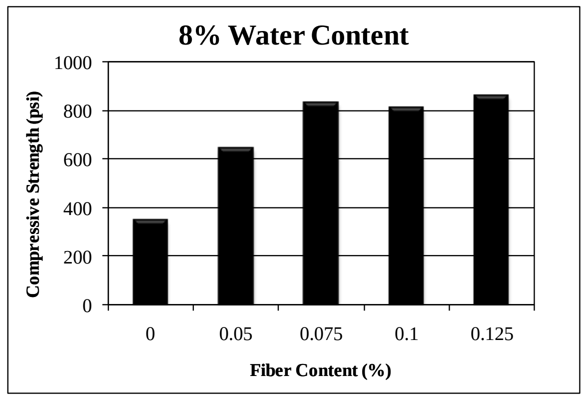

Fig. 12 Fiber content versus compressive strength at 8% water

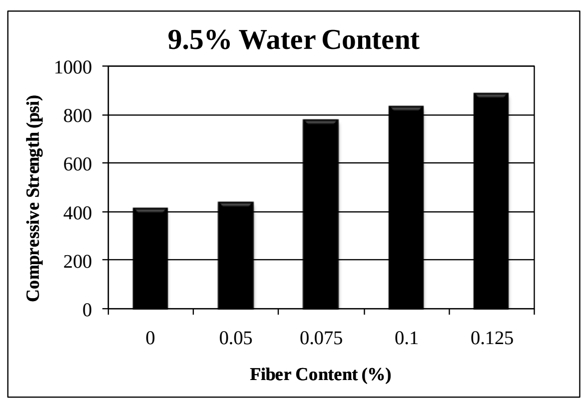

Fig. 13 Fiber content versus compressive strength at 9.5% water

The average compressive strength of the entire test matrix comes out to be 661 psi. All the specimens with 0.1% and 0.125% fibers, except one set, have strength more than the average. All the specimens with 0.125% fibers achieved compressive strength more than 800 psi. Although 800 psi is not a standard benchmark for the minimum compressive strength, however, looking at the data of the current matrix, 800 psi can be taken as a reasonable strength of bricks to be used in construction. It can be recommended that for actual use, a combination of 0.125% fibers and water content of 8 to 11% may be a suitable choice for the preparation of a brick having compressive strength greater than 800 psi.

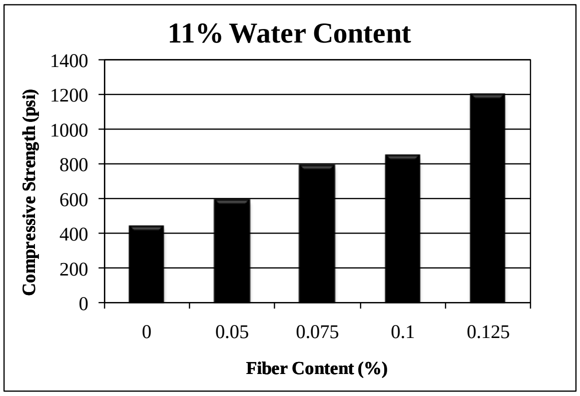

Fig. 14 Fiber content versus compressive strength at 11% water

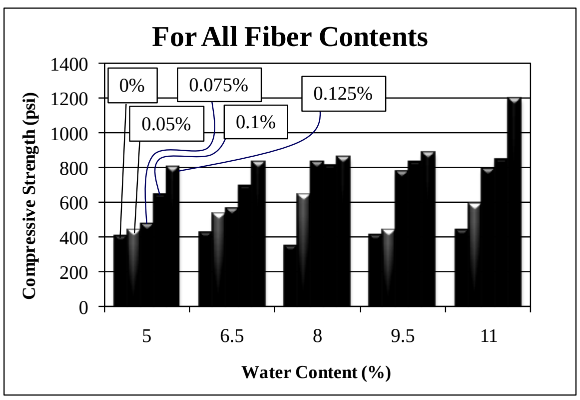

Fig. 15 Water content versus compressive strength for all fiber contents

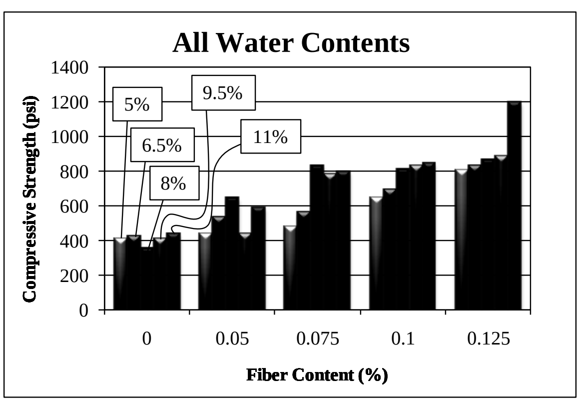

Fig. 16 Fiber content versus compressive strength for all water contents

Fibers provide more ductility to the mud bricks, therefore, FR-CEBs can dissipate more energy, making these bricks suitable for earthquake prone regions [6].

5. Cost Comparison

The approximate unit cost of FR-CEB with 0.125% fibers is estimated as Rs. 3/- as compared to the burnt (pakka) brick which is available at the rate of Rs. 7/- to 8/-. The major reduction in the price of FR-CEB is due to absence of burning process. The cost of installation of kiln, price of land, maintenance cost and the running cost significantly impact the final price of burnt brick. FR-CEBs can therefore be an economical solution for remote areas where burnt bricks may not be locally available and the transportation cost further increases the unit price.

6. Summary and Conclusions

The objective of this study was to explore the suitability of sun-dried mud bricks with fibers for the remote/rural areas, where people cannot afford the expensive kiln burnt bricks. For this purpose, the jute fiber reinforced compressed earth bricks with twenty five different combinations of water and fiber contents were subjected to compressive strength tests at the age of 28 days. The study revealed that the compressive strength of un-burnt sun-dried bricks can be increased up to 2.75 times (from 436 psi to 1198 psi) by compressing them and adding 0.125% jute fibers with 11% water content. The transverse and longitudinal restrain provided by the fibers against the crack propagation is the major contributing factor towards the increase in compressive strength. For the smaller fiber contents (0.05% and 0.075%), the compressive strength behavior does not follow a pattern with the increase in water content, however, for the higher fiber contents (0.1% and 0.125%), the compressive strength increases with the increase in water content. It can be concluded that the optimum dosage of fibers may exists between 0.10% and 0.125%. The improved compressive strength of FR-CEBs demonstrates their feasibility as a sustainable alternative solution to the conventional mud construction. These bricks will perform better than the mud walls against the environmental hazard like heavy rains and floods, high temperatures and heavy snow falls.

The current research work mainly focuses on strength evaluation of FR-CEBs, however, work is still needed to evaluate the other standard properties e.g. water absorption, efflorescence characteristics and durability behavior. It is worth mentioning that the compression tests performed indicate only the compressive strength of individual brick specimen and not of the masonry [11]. Establishment of strength of masonry requires further investigation.

6. Acknowledgements:

Authors are grateful to Mujtaba Haider, Shafqat Hussain, Azhar Ali and Ambreen of Session 2010, Civil Engineering Department, UET Lahore for their contribution towards the research work.

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