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Experimental evaluation into improving the mechanical properties of adobe using palm fibers

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ABSTRACT: The relatively low compressive strength and negligible tensile resistance aligned with inadequate ductility are considered as major drawbacks of earthen buildings leading to their vulnerability against the gravity and lateral loading including seismic-induced forces. In this study, the possibility of using palm fibers as a natural reinforcement in order to improve the mechanical properties of adobe bricks including compressive strength, tensile strength and ductility are evaluated. To this end, adobe bricks with dimensions of 200 × 200 × 50 mm3 are made by adding palm fibers of 0, 0.25, 0.5, 0.75, and 1% of soil weight. Compressive properties are determined using cube samples with dimensions of 50 × 50 × 50 mm3 cut from the full-scale adobe bricks while the ductility factor is obtained using the compressive stress-strain curves. To evaluate the tensile strength of specimens, three-point flexural tests are conducted on prismatic specimens of 50 × 50 × 200 mm3 cut from the full-scale adobe bricks. The obtained results indicated adding 0.25% palm fibers can increase the compressive strength of adobe bricks by 50% and adding 1% palm fiber can twice the tensile strength. Further, based on the analysis of the results obtained from the compressive and three-point bending tests, analytical expressions are proposed to estimate the compressive and tensile strengths of adobe bricks reinforced by palm fiber (from 0 to 1%).

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1- Introduction

A considerable portion of residential buildings in our country, Iran, especially in desert and rural areas, are made of earth and adobe bricks which are still in everyday use. Compared to modern construction materials such as steel and concrete, adobe materials are more environmentally friendly and cost-effective while they offer rapid fabrication and local availability [1]. However, the performance of adobe buildings in previous earthquakes has been poor leading to enormous casualties and financial losses [2]. One of the most important weaknesses of adobe materials causing their vulnerability is their low tensile strength and insufficient ductility against seismic-induced forces. Due to the widespread use of this traditional building material, especially in the repair of historical buildings, further studies need to be conducted to improve the mechanical properties of this type of material. In particular, improving the mechanical properties of adobe bricks, which are also constitutive components of adobe walls, can improve the performance of the load bearing walls which in turn would result in upgrading the overall performance and integrity of adobe structure.

The use of natural additives such as straw in soil materials is one of the effective ways to improve the mechanical properties of adobe bricks and has long been considered in the past. According to the results of previous studies [3-6], the mechanical properties of adobe materials made with or without natural additives highly depend on various parameters such as the type of additive, the amount of additive, the shape of the samples and loading direction. In this experimental study, the effect of adding palm fibers as a natural reinforcement on improving the mechanical properties of adobe bricks including compressive strength, tensile strength and ductility is investigated and the results are discussed in detail.

2- Methodology

In order to evaluate the effect of adding palm fibers on the mechanical properties of adobe bricks, five soil mixes with different fiber to soil weight ratios of 0.25, 0.5, 0.75 and 1% were considered. The soil used was clayey soil provided by a local supplier and was the same as the one which is typically used to make adobe bricks. To make fiber-reinforced adobes, the fibers were first added to the dry soil and then water was added before it was covered by a plastic sheet to prevent evaporation. After 3 days, the paste was trampled and the adobe samples were molded by a mason according to traditional methods. The bricks were made with the dimensions of 50 × 200 × 200 mm^3 (Figure 1) and finally,

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Fig. 1. Adobe brick samplesm

Table 1. Results of compressive strength, ductility, and elastic modulus

Specimen	NF	0.25F	0.5F	0.75F	1.0F
Compressive strength (MPa)	3.36	5.03	4.75	4.43	3.94
Difference (%)	-	49.7	41.4	31.8	17.3
Ductility	1.62	1.92	2.90	2.19	2.04
Difference (%)	-	18.5	79	35.2	25.9
Modulus of elasticity (MPa)	465.23	672.19	604.75	557.65	550.46
Difference (%)	-	44.5	30.0	19.9	18.3

after complete drying, 6 cube specimens with dimensions of 50 × 50 × 50 mm^3 were tested for compressive strength and 6 prism samples with dimensions of 50 × 50 × 200 mm^3 was cut for the three-point bending test of each mix.

Compression tests were conducted in the form of the displacement-controlled loading with a constant speed of 0.01 mm / s as suggested in previous studies [7]. Finally, using the obtained strain-stress curves, compressive strength (f_c), strain corresponding to the maximum compressive stress, strain at the yielding (ε_y), final strain (ε_u), ductility and modulus of elasticity was determined for each specimen. The ductility coefficient is defined as the ratio of the final strain (ε_u) to the strain at the yielding point (ε_y) in the idealized bilinear curve [7]. The elastic modulus is determined as the secant modulus according to NP EN 1052–1 [8] which is the slope of the line connecting the origin to the point corresponding to one-third of the maximum compressive stress ($1/3f_c$).

In order to determine the tensile strength of prism specimens, the three-point bending test was performed with a displacement-controlled loading at a constant rate of 0.01 mm/s. The tensile strength is defined according to ASTM C348-14 [9] using Euler-Bernoulli theory as:

$$f_t = 1.5\frac{Fl}{bd^2} \tag{1}$$

Where (f_t) is the tensile strength in MPa, (F) maximum force on the sample in N, (l) net distance between supports in mm, (b) sample width in mm and (d) sample depth in mm.

3- Results and Discussion

The results of compression tests including the compressive strength, elastic modulus and ductility for adobe samples and their variations compared to the control sample, are summarized in Table 1. NF stands for the control specimens, and fiber-reinforced specimens are designated according to the fiber content (for example, 0.25F refers to the mixes reinforced with 0.25% fiber content).

According to Table 1, the samples reinforced with 0.25% fiber content (0.25F) offered the best performance in terms of compressive strength with nearly 50% higher strength than the control counterpart. In addition, the compressive strength values of all fiber-reinforced specimens were higher than the control specimens. A similar trend was also observed concerning the elastic modulus, with the highest improvement in the mix reinforced with 0.25% fiber content with about 45% increase compared to the control specimen. In terms of the ductility behavior, the optimal percentage was found for the samples reinforced with 0.5% fiber content, where 79% increase was obtained in comparison with the unreinforced specimen.

Table 2. Tensile strength of mixes

Specimen	Tensile strength (MPa)	Difference (%)
NF	0.55	-
0.25F	0.84	52.7
0.5F	0.99	80
0.75F	1.08	96.3
1.0F	1.12	103.6

A summary of the results obtained from the three-point bending test is reported in Table 2. The results indicate that the tensile strength of the specimens increased with adding the fiber content so that the maximum tensile strength was determined for the specimen reinforced with 1% fibers with an average of 1.12 MPa while the minimal tensile strength belonged to the control specimen (without fibers) with an average of 0.55 MPa.

4- Conclusions

Based on the obtained experimental results, the use of palm fibers by 0.25% weight percentage can increase the compressive strength and elastic modulus of adobe bricks up to 50% and 45% compared to the unreinforced samples, respectively. In addition, adding 0.5% weight percentage of palm fiber can improve the ductility by about 79% compared to the control sample. However, the results of this study showed that the use of fibers in excess of 0.5% (up to 1%) of soil weight could be less effective in improving the ductility behavior. On the other hand, the tensile strength of samples was continuously improved with increasing the fiber content.

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