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Uniaxial compression and tensile splitting tests on adobe with embedded steel wire reinforcement

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HIGHLIGHTS

- Addition of steel wire mesh increases the compressive strength of adobe.
- Tensile splitting failure mode becomes more ductile.
- Stress–strain response of adobe changes with the addition of steel wire mesh.
- Nonlinear post-peak softening response changes to bilinear post-cracking continuous hardening.

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ABSTRACT

Adobe has recently gained further significance, and the associated interest of engineers and researchers, due to its environment friendliness. Several studies can be found in the literature that focus on various aspects of the material behaviour of adobe. This article focuses on the investigation of the effects of wire mesh reinforcement on the compressive strength, uniaxial compression behaviour over the entire loading regime, and the tensile splitting strength of adobe specimens. A total of 30 cylindrical specimens with 150 mm diameter and 300 mm length were tested, 15 for tensile splitting and 15 for uniaxial compression. For each type of test, 5 specimens did not have any reinforcement, whereas 10 were reinforced with a single layer of steel wire mesh. It has been concluded that the adobe specimens reinforced with wire mesh do not suddenly split because of tensile stresses. It has also been concluded that the wire mesh reinforcement significantly increases the compressive strength of adobe specimens. The stress–strain response of adobe, which is non-linear with post-peak strain softening in the absence of any reinforcement, becomes bilinear in form with continuous post-cracking hardening when wire mesh reinforcement is added. The use of wire mesh reinforcement in adobe construction has great potential to further promote adobe as a construction material.

1. Introduction

Adobe is a readily available material without requiring extensive skills for its use and is commonly associated with low-cost construction. Several research articles, books, and reports have documented the historical use of adobe as a building material (e.g. [3,1,16,33]). It has been claimed that at present approximately 30% of the human population lives in earthen structures [11], and that more houses are made of earth than any other material in India [4].

There has been an increased interest in this construction material and method by scientific and engineering community [18] as can be witnessed through the about ten-folds increase in the published literature in this field within the period of a decade [31]. This is partly due to the fact that earth building provides a sustainable alternative to the other more polluting construction materials and techniques. Sustainability of construction materials and methods is presently being urged upon universally. Conventional building materials such as cement and steel have been termed as energy intensive [4]. The use of soil, on the other hand, is significantly more environment friendly [31]. The construction methods based on earthen materials also help towards efficient waste management [28]. The selection of appropriate building materials can reduce energy consumption [38,14,36]. A significant saving in the

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use of energy for construction can be achieved by the use of earthen materials because virtually no transportation is required as these are produced locally [5,29]. Embodied energy of earth buildings is found to be significantly lower than that of conventional construction [23,35]. Besides economy and environment friendliness, adobe also offers health benefits in the form of better sound and thermal insulation as well as better indoor air quality [43]. It has been reported that earthen blocks provide better moisture absorbance and hence, better humidity control [26,5,2]. This behaviour has been termed to be even more effective than ventilation [28]. Therefore, the need to promote earth construction as a sustainable alternative cannot be overemphasized.

The ubiquitous acceptance of earth as a primary building material is hindered by certain issues such as its vulnerability to extreme actions [7,15]. This is because the mechanical properties of adobe are difficult to ascertain due to there being wide ranges owing to several factors involved in the preparation of the material. This is, in turn, due to the absence of strict guidelines for the preparation of adobe. Several researchers have investigated and reported in the literature the mechanical properties of adobe. However, it has been reported that different testing standards for adobe vary significantly in procedures, specimen dimensioning, and other criteria [8,42,27].

The compressive response of adobe in laboratory tests depends upon the specimen form and size. Strength values derived from cubes and cylinders after application of shape correction factors were reported in a study to range from 0.6 to 1.75 MPa. Prisms, on the other hand, tend to overestimate the compressive strength due to platen restrain effects [19]. The inherent inhomogeneity and natural randomness of earthen materials as well as a lack of internationally accepted standardized testing procedures are the factors considered responsible for the large variance observed in the laboratory test results of adobe. Several researches can be found in the literature which have reported the compressive strength, flexural strength, and modulus of elasticity of adobe (e.g. [10,11,34,13,6,20,25,40,12,32,19,44]). However, most of the researchers have tried to use a unique composition of the material resulting not only in a wide range but also making it more difficult to standardize. The compressive strength of adobe has been reported in literature ranging from 0.5 MPa to about 7 MPa. There are relatively fewer studies measuring flexural strength, which has been reported to range from 0.5 MPa to about 1.5 MPa. Similarly, the number of studies reporting modulus of elasticity is also relatively low. The values of modulus of elasticity have been reported to range from about 100 MPa to 200 MPa. One study reported the tensile splitting strength of adobe being 0.16 MPa [37].

Clay is the most important component of adobe, whereas, coarse sand or straw is generally added to mud for making adobe bricks in order to control drying shrinkage [7]. Moreover, similar to concrete and other such materials, adobe is relatively stronger in compression while its tensile strength is very low, almost nonexistent. Efforts have been directed towards the improvement of tensile strength of adobe by adding various types of fibres and some reinforcements [46]. Mud bricks reinforced with plastic fibres, straw, and polystyrene along with a mix of clay, pumice, cement, lime gypsum and water produced significantly higher strengths [6]. The addition of hibiscus cannabinus (kenaf) fibres has been reported to have contributed to a homogenous microstructure with reduced pore sizes having positive effect on the mechanical properties of adobe [25]. The addition of straw has also been reported to act as shear reinforcement and increase energy absorption [39]. Similar effects have also been achieved through the addition of fly ash. Sheep's wool has also been found helpful in increasing compressive strength with a maximum value of 4.44 MPa reported for a specimen with 19.5% alignate, 0.5% lignum, 0.25% wool, and 0.25% water [12].

Steel wire mesh has been used as a reinforcement with different cementitious composites to form materials such as 'ferrocement' as can be found in literature (e.g.[22,21,30]). It has also been used on several occasions for externally strengthening adobe walls, especially corners (e.g. [17,24,9,45]). However, there is a lack of research as to how the use of steel wire mesh as embedded reinforcement would affect the behaviour of adobe bricks, and subsequently the structures constructed using these bricks. It would be interesting to find out the potential of the use of wire mesh as embedded reinforcement for structural members such as columns and walls. Therefore, the present study focuses on the investigation into the effects of steel wire mesh reinforcement on the compressive strength, the uniaxial compressive behaviour, and the tensile splitting strength of cylindrical adobe specimens. Although, as stated above, the shape and form of the test specimens is significant when it comes to the mechanical properties of adobe, since the present study is exploring the potential of the use of steel wire mesh as embedded reinforcement, therefore, conventional cylindrical specimens have been used. It can be assumed that, while different values may be obtained using other shapes and forms, the relative effects may remain the same. This assumption can later be verified through further research. The remainder of this paper presents the methodology adapted for the present research followed by the results and discussion, and finally, the conclusions drawn. It should be noted that all the stresses and strains discussed in this paper are engineering stresses and strains.

2. Methodology

This section presents the details about the materials used and the procedures adopted and adapted for specimen preparation as well as the two types of tests that were conducted during this research.

2.1. Materials used

The main materials used for this research were adobe and steel wire mesh. Adobe was composed of caly, silt, sand, kenaf fibres (hibiscus cannabinus), and water. Table 1 presents the proportion of each constituent used for the preparation of adobe mixture. Since the present research focused only on the effects of steel wire mesh, therefore, no attempt was made to improve the raw strength of adobe. The kenaf fibres, shown in Fig. 1 were added merely to avoid excessive cracking due to shrinkage. The length of the kenaf fibres ranged from 5 to 10 cm. The same adobe mix was used for the preparation of all the specimens.

The wire mesh used for the reinforcement was the welded type and had a square opening with a wire diameter of 1.042 mm (BWG 19) and an opening size of 12.7 mm × 12.7 mm. The sample wire mesh reinforcements prepared for the specimens are shown in Fig. 2. The ends of the wire mesh were overlapped about 40 mm, or three opening sizes. The mesh was made of mild steel material with a tensile strength of approximately 275 MPa.

2.2. Mixing procedure

The adobe mix was prepared using a concrete mixer. The clay, silt, and sand; which were obtained earlier through sieving process, were dry-mixed first in the appropriate portions to make sure a homogenous mix was obtained. The kenaf fibers were then added to this mix gradually. Once the dry mix was ready, water was added gradually until a homogenous paste was obtained. Potable water was used for mixing and the volume of water was approximately 20% of the volume of the dry mix.

Table 1
Details of the constituents of adobe mixture used.

S. No.	Name of Constituent	Key Property	Proportion in the Mix (by Volume)
1	Clay	Particle size <0.2 mm	25%
2	Silt	Particle size 0.2–0.6 mm	20%
3	Sand	Particle size 0.6–2 mm	53%
4	Kenaf Fibres	Length 2–6 mm	2%