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Comparison of Compressive and Tensile Strength of Baked Clay with Those of Normal Concrete

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Abstract

Due to high cost of aggregates, cement and steel in plain regions of Pakistan, low income people are unable to get their houses constructed using Reinforced Cement Concrete (RCC). In this study, potential of baked clay as an economical material of building construction is investigated in order to replace normal concrete. For this purpose, compressive strength and tensile strength of baked clay fired at 1000˚C were determined. The results show that the compressive strength and tensile strength of baked clay are about 65%, and 80% more than those of corresponding values of normal concrete, respectively. This implies that by utilizing reinforced baked clay instead of RCC, saving of cement aggregates and reinforcing steel could be achieved.

Keywords

Baked Clay, Tensile Strength, Compressive Strength, Modulus of Rupture, Normal Concrete, Compaction

1. Introduction

Provision of houses to low income people is a challenging task in Pakistan since its independence in 1947. This is due to increase in cost of traditional materials of building construction such as cement, aggregates and steel. It is, therefore, responsibility of engineering community to investigate possible use of local and low cost materials of building construction so that the people could be able to get their houses constructed at an affordable cost. The indigenous and low cost materials of construction include wood, clay and stone. Among these materials,

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clay is abundantly and economically available in plains of Pakistan [1]-[3].

Baked clay bricks were found from the excavations of buildings constructed about 10,000 years ago in Mesopotamia [4]-[7]. Since then people learned various techniques for construction of different elements of a building such as footings, walls, columns, slabs, arches and domes [8]. The later civilizations of Indus valley, Babylonia, Jericho, and Turkey etc. also used baked clay bricks for the construction of their buildings and monuments such as Ishtar gate (in Babylonia), Ziggurats of Mesopotamia, and Moen-Jo-Daro, in Sindh, Pakistan. Even today about 30% of the world population still live in buildings constructed with un-baked or baked clay bricks [9]-[11].

Compressive and tensile strength of a construction material are important to study for the design of basic structural elements. These structural elements include beams, slabs, columns and footings. Among these elements, beams and columns are subjected to both compressive and tensile stresses and are called flexural structural members. Hence, such structural members are designed to carry both compressive as well tensile stresses simultaneously [12] [13]. The ratio of tensile to compressive strength of a construction material is important to study for designing the flexural members. Various codes formulated for reinforced concrete structures suggest that all the tensile stresses are designed to be carried by reinforcing material such as steel only and no part of tensile stresses is to be taken by concrete [14] [15]. The ratio of tensile to compressive strength of concrete is about 10%. Since for baked clay, no such study is reported in the literature. Therefore, it is necessary to investigate the ratio of tensile to compressive strength of baked clay in order to be able to decide its suitability as a construction material to replace reinforced cement concrete.

The compressive strength of baked clay can be improved by compaction and firing [16]-[20]. Average compressive strength of baked clay as high as 30 MPa can be obtained by firing at 1100˚C [19]. Whereas, the design cube crushing strength of normal concrete is 20 MPa [21]. This shows that on proper compaction and baking of clay, higher compressive strength can be obtained as compared to that of normal concrete.

Baked clay is a low cost, heat resistant, long lasting and environmental friendly material of construction [22] [23]. Baked clay can be post-reinforced and could be used as beams, columns, slabs, and footings. Reinforced Cement Concrete (RCC) structures can economically be replaced with Reinforced Baked Clay (RBC). This is because in RBC local clay is utilized as major material of construction and no any aggregates are needed. In addition to this, RBC structures can be designed and constructed to last for thousands of years when reinforced with non-corrosive materials like Fiber Reinforced Polymer (FRP).

2. Materials and Methods

2.1. Clay and Pit Sand Mixture for Casting of Beams

Clay was quarried at a depth of one meter in the vicinity of Nawabshah city (Pakistan). The soil is classified as clayey according to ASTM D3282-15 [24]. The clay was dried in an oven at 105˚C for 24 hours, and then it was crushed into a fine powder using Pulverizer. Pit sand collected from the sand dunes was dried similarly and sieved through ASTM Sieve No. 50 (0.3 mm mesh opening size) in order to separate debris and roots of plants from it. Clay was mixed with 40% of pit sand. The clay and pit sand mixture was mixed with 22% of water in a pan mixer for fifteen minutes. This much amount of water was required for workability in order to cast and compact the beams easily.

2.2. Casting and Baking of Clay Beams

Clay beams were cast and compacted in the steel mould of the Mechanized System (**Figure 1**). The clay beams could be cast and compacted up to a pressure of 8 MPa using the Mechanized System [25] as shown in **Figure 2**. During the process of casting, the clay beams were covered with a propylene fabric sheet and were compressed in drained condition at a pressure of 6 MPa. The mould is capable of casting the clay beams of size 150 mm × 300 mm × 1980 mm. From now on, the beams are referred to as laboratory size beams. The clay in the mould was placed in five layers of equal thickness. Each layer was manually tamped, and a slight spray of water was applied before putting the next layer. The beams were dried in shade (**Figure 3**). The dried clay beams were baked at a temperature of 1000˚C in a commercial Hoffman's kiln.

3. Testing Procedure

Cubes of 150 mm [26] were sawed (**Figure 4**) from the baked clay beams and tested in Forney Universal Testing

Figure 1. Mould for casting clay beams.

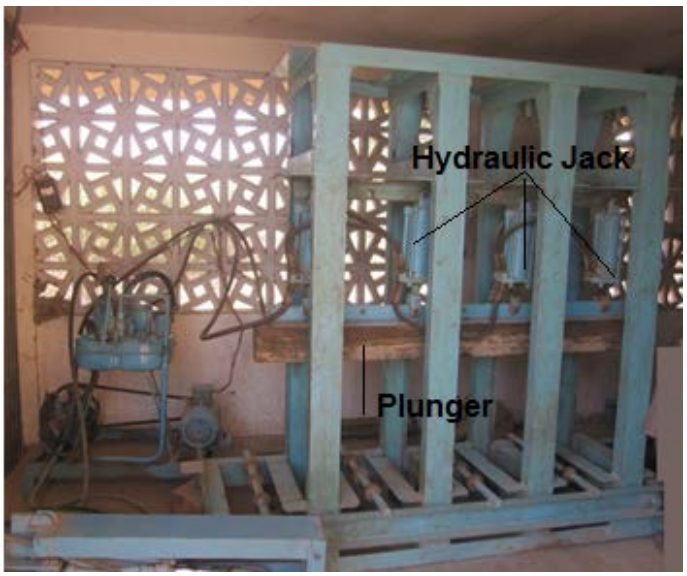

Figure 2. Mechanized system for casting and compacting clay beams.

Machine (**Figure 5**), to determine compressive strength. In order to determine tensile strength in terms of modulus of rupture, the beams of size 150 mm × 300 mm × 900 mm [27] were cut from the baked clay laboratory size beams. These beams were tested using Simple Beam with Center-Point Loading [28] in Torsee's Universal Beam Testing Machine (**Figure 6**). In this test, the effective length of the beam was 850 mm, with a single point load at mid span. The modulus of rupture of baked clay was determined by using the standard relation as follows [29].

Figure 3. Clay beam dried in shade.

Figure 4. 150 mm size cubes sawed from baked clay beams.

Figure 5. Baked clay beams being tested in universal testing machine.

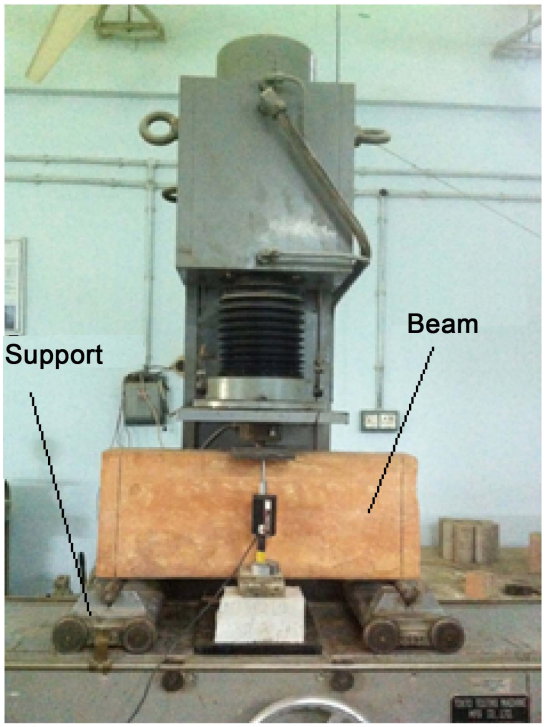

Figure 6. Plain baked clay beam being tested for flexural tensile strength in Torsee's universal beam testing machine.

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

where R is the modulus of rupture in MPa; P is the maximum applied load in N; L is the span length in mm; b and d are the average width and depth of the specimen in mm, respectively.

Empirical formula for modulus of rupture, f_r of concrete given by ACI committee 318-11 [29] is as follows:

$$f_r = 7.5\sqrt{f_c} \quad (2)$$

where f_c is the standard compressive strength of a cylinder in psi.

4. Results and Discussion

4.1. Compressive Strength of Baked Clay

Average compressive strength of the 150 mm cubes that were cut from the baked clay beams was found to be 33 MPa. It is to be noted that the cube crushing strength of the normal concrete is 20 MPa. This implies that the baked clay, investigated in this study, gave about 65% more compressive strength than that of the normal concrete.

4.2. Flexural Tensile Strength of Baked Clay

Six plain baked clay beam specimens having size of 150 mm × 300 mm × 900 mm were tested in flexure with a point load applied at the mid span. The results of the load at failure and calculated modulus of rupture are presented in **Table 1**. Average value of modulus of rupture of baked clay was calculated to be 5.5 MPa. According to ACI code (cf. Equation (2)), the modulus of rupture of concrete having cube crushing strength of 20 MPa is calculated as 3 MPa. This indicates that the modulus of rupture of baked clay is about 80% more than that of normal concrete. The magnitude of the modulus of rupture gives tensile resistance of a material. The tensile strength of baked clay was found to be about 16% of its compressive strength. Whereas, the tensile strength of

Table 1. Load at failure and modulus of plain baked clay beams.

S. No.	Load at failure (kN)	Modulus of rupture (MPa)
1	51.3	4.8
2	63.5	6.0
3	67.5	6.3
4	50.1	4.7
5	53.3	5.0
6	63.0	5.9

concrete is about 10% of its compressive strength. This shows that for same cube crushing strength, baked clay is stronger in tension as compared to normal concrete. This suggests that less amount of tensile reinforcement may be required in baked clay beams compared to that of reinforced concrete beams. Thus a twofold saving in terms of cost of materials of construction, and steel can be achieved by using baked clay beams instead of concrete beams.

5. Conclusions

In this study, the compressive strength and tensile strength of baked clay fired at 1000˚C were determined and compared with those of normal concrete. The following conclusions were drawn:

1) Average compressive strength of the baked clay cubes was found to be 33 MPa which is about 65% more than that of normal concrete.

2) Tensile strength of plain baked clay beams, in terms of modulus of rupture, was found to be 5.5 MPa. The value of the tensile strength of the baked clay was about 80% more than that of normal concrete.

3) The results suggest that saving, in terms of cost of construction materials can be achieved by utilizing reinforced baked clay as an alternative to reinforced cement concrete.

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