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EXPERIMENTAL INVESTIGATION ON PERFORMANCE OF HOLLOW BRICK WITH FLY ASH, CEMENT AND SAND

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Abstract

Cement clay interlocking (CCI) hollow bricks have been used as a construction material in many developed and developing countries. Many emerging and underdeveloped nations have utilised cement clay interlocking (CCI) hollow bricks as building materials. In India, Andhra Pradesh local makers prepare these cement clay interlocking (CCI) hollow bricks by simply mixing clay, cement, and sand in a traditional method, without following strict design criteria or rules. Previous research has demonstrated that the mechanical characteristics of CCI hollow bricks gathered from various locations in detailed manner respect to hand books on Civil Engineering as per Indian Standards. Bricks from one region had compressive strengths that were significantly lower than the other region Indian Community Standards. Various methods were employed in this investigation to enhance the mechanical characteristics of CCI bricks. New mix patterns were created with the use of sand, cement, and fly ash in this research paper.

Keywords:

Compressive strength;
Modulus of Rupture;
Water Absorption;
Mix Design Ratio:
Cement Clay Interlocking;
Strength Parameters.

1 Introduction

Bricks have been utilized as building and construction materials across the world. Clay and shale combinations are typically used as raw materials in conventional clay-based brick manufacture, such as shaping, drying, and high temperature firing. Building walls are primarily constructed using fired clay bricks [1]. The increasing demand for building construction gives rise to the need to identify and address construction related issues. Similar to interlocking bricks are an alternate system to traditional clay bricks that use less mortar to hold the bricks together. The interlocking brick system is a quick and affordable building method that provides outstanding construction solutions. In India, low-rise residential buildings are commonly constructed using cement clay interlocking (CCI) bricks, which are manufactured from clay that is readily available in the market. These interlocking bricks are made locally in little facilities spread across various parts of India. There are currently at least 892 brick factories in India [2]. Most of these plants are found in rural areas, and the people who own them are prosperous farmers or business owners who have worked with other brick plants to gather experience. Many brickmakers in rural areas utilize clay that they have dug up on their property. The distribution of sedimentary and metamorphic rocks in India is rather varied, ranging from mudstone to sandstone and shale, according the country geological map [3]. Numerous investigations have revealed that variations in the amount of clay in bricks affect their mechanical properties [4, 5].

In the central region of India, looked into the mechanical characteristics of native cement clay interlocking (CCI) bricks. The bricks that interlock were gathered from various parts of India. Additionally, it was found that the mechanical characteristics of cement clay interlocking (CCI) bricks are significantly influenced by the mix design ratio and locally accessible materials. Cement clay interlocking (CCI) bricks were found to have a compressive strength ranging from 4.12 MPa to 15.80 MPa. Significant differences were also noted between locations in the parameters of splitting tensile strength, modulus of rupture, and absorption [6]. Numerous researchers have looked into the use of various waste materials such as fly ash, slags, waste from construction and demolition projects, wood sawdust, cotton waste, pulp and

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paper production residues, boron waste, cigarette butts, waste tea, rice husk ash, and crumb rubber as well as other natural materials to change the mechanical properties of traditional clay bricks in the interest of environmental preservation and sustainable development [7].

According to the author's information, a small number of studies have been carried out to improve the mechanical properties of interlocking hollow bricks made in India using waste materials and other naturally occurring materials [8].

The studies on various waste materials and ashes, including fly ash and ceramic debris, have been conducted in India [9, 10]. By altering the mix design ratio of region A (Maharashtra, India), several strategies have been tried in this study to improve the mechanical properties of CCI bricks from the Maharashtra, India (region A). The three components utilized to create the new mix designs, Mix-1, Mix-2, and Mix-3, are sand, cement, and fly ash. The mechanical characteristics of freshly produced CCI hollow bricks, including their compressive strength, modulus of rupture, splitting tensile strength, and water absorption capacity, were compared to previously published research paper of CCI bricks constructed using the traditional method from the central region, which produced less satisfactory mechanical property results [11].

2 Literature Survey

An experimental study on the mechanical characteristics of cement clay interlocking (CCI) bricks gathered from three distinct regions A, B, and C of India, was conducted by John et al. [12]. Each of these three zones possesses a distinct layer of clay, exhibiting a range of mechanical characteristics such as modulus of rupture, splitting tensile strength, compressive strength, and water absorption. It was determined what mechanical qualities included modulus of rupture, absorption, splitting tensile strength, and compressive strength. The findings indicate that distinct mix design ratios are being followed by each location, depending on the accessibility of local resources and expertise. Additionally, it was found that the mechanical characteristics of CCI bricks are significantly influenced by the mix design ratio and locally accessible materials. CCI bricks have a compressive strength ranging from 4.12 MPa to 15.80 Mpa [13]. Overall, it was discovered that the mechanical qualities of the cement clay interlocking bricks gathered from region B were better than those of the bricks gathered from provinces A and C. Furthermore, it was discovered that the bricks gathered from region A did not meet or fulfil the requirements of Indian standards (IS) in terms of compressive strength and water absorption capacity [14].

3 Experimental Program

This study is an extension of earlier research that looked into the mechanical characteristics of CCI bricks made in three separate regions in Andhra Pradesh. Previous research has demonstrated that the mechanical characteristics of CCI hollow that are gathered from various places. In fact, region A's compressive strength was determined to be much below the standard levels advised by Indian Standards [15]. In this study, various methods have been used to alter or add new materials to the mix design ratio of the substandard region (region A) in order to improve the mechanical qualities of CCI bricks. The three components utilised to create the new mix designs, Mix-1, Mix-2, and Mix-3, are sand, cement, and fly ash. In general, sand is used because it is inexpensive and easy to obtain. Additionally, fly ash was utilised in place of cement in order to make CCI bricks, and its efficiency was examined efficiently. One of the coal combustion products (CCPs) produced by coal burning power plants is fly ash, which has significant concentrations of elements that could be hazardous to the environment. Fly ash is a useful supplemental material that can be used in place of cement in the manufacturing of concrete and bricks, according to a significant number of ongoing research projects [16, 17]. Table 1 summarises the typical chemical composition of fly ash and regular Portland cement. The proportion of each of the various compounds is the primary distinction between Portland cement and fly ash. Fly ash is low in lime (CaO) compared to Portland cement. Reactive silicate content is higher in fly ash and lower in Portland cement. By altering the mix design ratio of region A, various strategies have been tried in this study to improve the mechanical properties of CCI bricks from the substandard region (region A). The three components used to create the new mix designs, Mix-1, Mix-2, and Mix-3, are sand, cement, and fly ash. The section that follows goes into more detail about the experimental programme, including the mechanical properties and the process used to manufacture CCI bricks.

Table 1: Chemical Composition of fly ash and cement.

Chemical Compound	Fly Ash	Ordinary Portland Cement
SiO	42.00	18.45
Al2O3	19.55	6.50
Fe2O3	19.89	2.88
CaO	5.45	60.89
MgO	1.14	2.82
SO3	4.32	4.32
Na2O	0.67	0.38
K2O	2.38	1.01

4 Manufacturing of CCI Bricks

In this study, the CCI bricks are produced by varying the proportions of the component materials such as cement, sand, and fly ash of the CCI bricks produced in region A using three distinct mix designs [18]. Three steps involved in the majority of the CCI brick manufacturing process. First, a mechanical grinding machine is used to break down large boulders of clay into finer material. Different component materials, including cement, sand, and fly ash, are mixed in the second step. The cement-clay mixture is finally poured into the aluminum mould and pressed using either manually or hydraulically powered equipment. The CCI bricks made using various mix designs have a nominal size of 250 mm x 125 mm x 100 mm (length x width x height). The following Table 2 displays the component materials by weight along with their nominal weights. Fig. 1 displays the typical CCI bricks produced with the original mix and the newly suggested mixes [19].



a) b)

Fig. 1: a) Typical CCI brick Sample of Region A, b) Typical Mix Hollow Bricks.

Table 2: Details of Mix Components and Nominal Weight of CCI Bricks.

Components	Original Mix	Mix-1	Mix-2	Mix-3
Cement [kg]	165	165	165	330
Sand [kg]	-	165	-	-
Fly ash [kg]	-	-	165	-
Red Clay [kg]	1638	1475	1475	1475
Nominal Weight [g]	4955	5240	5545	5398
Density [g/cm^3]	1.63	1.72	1.83	1.77

5 Mechanical properties of CCI Bricks

Using common testing techniques, the mechanical characteristics of the CCI bricks were determined by looking into their splitting tensile strength, compressive strength, modulus of rupture, and water absorption. The sections that follow provide a description of each test method [20].

5.1 Compressive Strength

The ASTM C1314-14 standard test procedure was applied to determine the compressive strength of the masonry prisms [21]. Three sample specimens for each type of region were subjected to the test procedure using the universal testing machine (UTM). A constant load applied at a speed of 0.5 mm/minute was used during the testing period. Three samples of average compressive strength results were used. Fig. 2 illustrates a typical loading configuration. The following equation was used to calculate the compressive strength [22].

$$\boldsymbol{CS} = \frac{\boldsymbol{P}}{\boldsymbol{A}} \tag{1}$$

where:
CS – Compressive Strength [MPa],
P – Maximum Load [N],
A – Net bearing area of CCI bricks [mm^2].

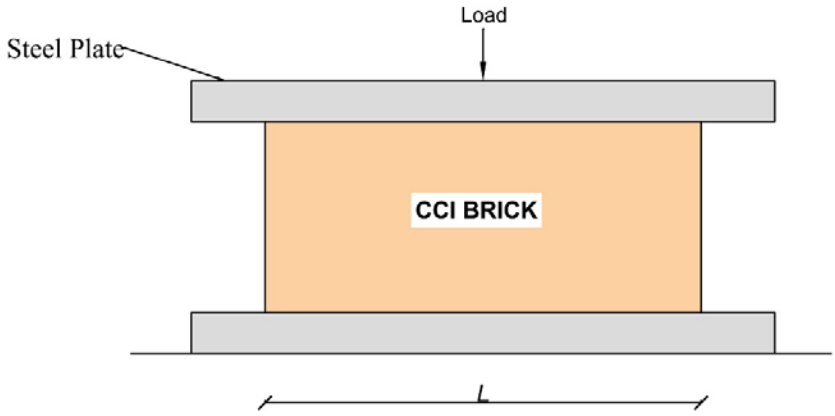

Fig. 2: Loading Setup for Compression Test.

5.2 Modulus of Rupture

A material's modulus of rupture, which is also referred to as its flexural strength, bond strength, or transverse rupture strength, is the form of stress present in the material immediately prior to a flexural test. The modulus of rupture of CCI bricks is examined using the standard test procedure (ASTM C67-03) for brick and structural clay tile sampling and testing [23]. A constant load applied at a speed of 0.5 mm/minute was used during the testing period. Three samples' average modulus of rupture results were used. Fig. 3 depicts a typical loading setup for a compression test. The following expression is used to determine the modulus of rupture is as follows:

$$\boldsymbol{R} = \boldsymbol{3P}\left(\frac{\boldsymbol{L}}{\boldsymbol{2}} - \boldsymbol{x}\right)(\boldsymbol{W} \times \boldsymbol{H^2}) \tag{2}$$

where:
R – Modulus of Rupture [MPa],
L_1 – Distance between the supports [mm],
W – Net width (face to face distance minus voids) at the plane of failure [mm],
H – Depth (bed surface to bed surface distance) at the plane of failure [mm],
x – Average distance from midspan of specimen to plane of failure in the direction of span along centre line of the bed surface subjected to Tension [mm].

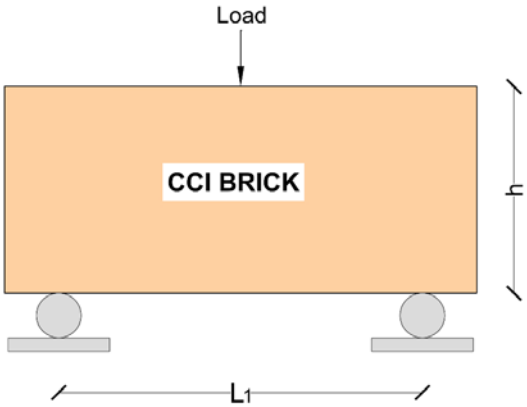

Fig. 3: Loading Setup for Compression Test.

5.3 Split Tensile Strength

The standard test procedure for determining the splitting tensile strength of masonry units (ASTM C1006-07) was applied to samples that were gathered from every region. A constant load applied at a speed of 0.5 mm/minute was used during the testing procedure. Each region's three samples were examined, and the average result served as the standard. Fig. 4 depicts a typical loading configuration for the splitting tensile strength test. Using expression 3, the samples' splitting tensile strength was determined [24].

$$\boldsymbol{T} = \frac{\boldsymbol{2P}}{\boldsymbol{\pi BH}} \tag{3}$$

where:
T – Splitting Tensile Strength [MPa],
P – Ultimate force [N],
B – Split length [mm] (Gross width minus the length of any voids along failure plane of the bearing rods),
H – Distance between rods [mm].

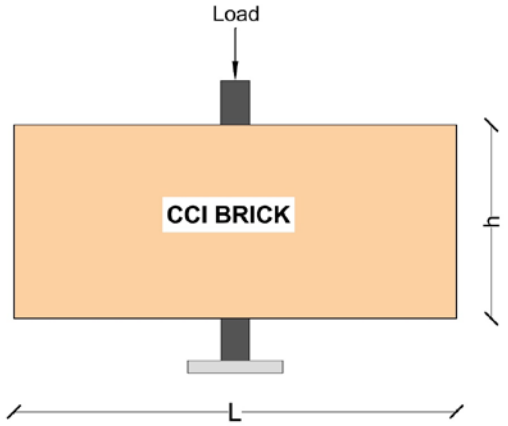

Fig. 4: Loading Setup for Split Tensile Strength Test.

5.4 Water absorption Capacity

The CCI bricks were immersed in water for 24 hours and water absorption capacity (percentage by mass) was determined by using standard sampling and testing procedure of concrete masonry units (ASTM C 140-11). Again, three samples were immersed in water from every region and the average value was taken as a reference value for each region [25]. The absorption capacity of CCI bricks was calculated by using the next expression.

$$\boldsymbol{A} = \left(\frac{\boldsymbol{100}}{\boldsymbol{W_d}}\right)\left(\frac{\boldsymbol{W_s}}{\boldsymbol{W_d}}\right) \tag{4}$$

where:
A – Water absorption capacity [%],
W_s – Specimen weight in saturated condition [kg],
W_d – Oven dry weight of specimen [kg].

6 Results and Discussions

This section discusses the experimental results for newly manufactured bricks, including their compressive strength, modulus of rupture, splitting tensile strength, and water absorption. Tables 3,4,5,6 and 7 and Figs. 5,6,7,8,9,10,11 provide a summary and graphical representation of the experimental results. The following sections go into further detail about the test results and study findings.

Table 3: Test results of mechanical properties of CCI Bricks.

Bricks	Compressive Strength [MPa]	Modulus of Rupture [MPa]	Splitting tensile strength [MPa]	Water absorption [kg/m^3]
M1-1	4.62	1.88	0.11	228.0
M1-2	6.48	0.60	0.15	171.0
M1-3	6.37	1.08	0.16	186.0
Average	5.82	1.18	0.14	195
M2-1	12.37	2.10	0.29	330.5
M2-2	11.78	1.53	0.42	302.8
M2-3	15.32	2.12	0.41	330.7
Average	13.15	1.91	0.37	321.3
M3-1	12.45	1.82	0.48	162.5
M3-2	6.01	2.27	0.43	167.0
M3-3	6.84	2.31	0.35	168.5
Average	8.43	2.13	0.42	166

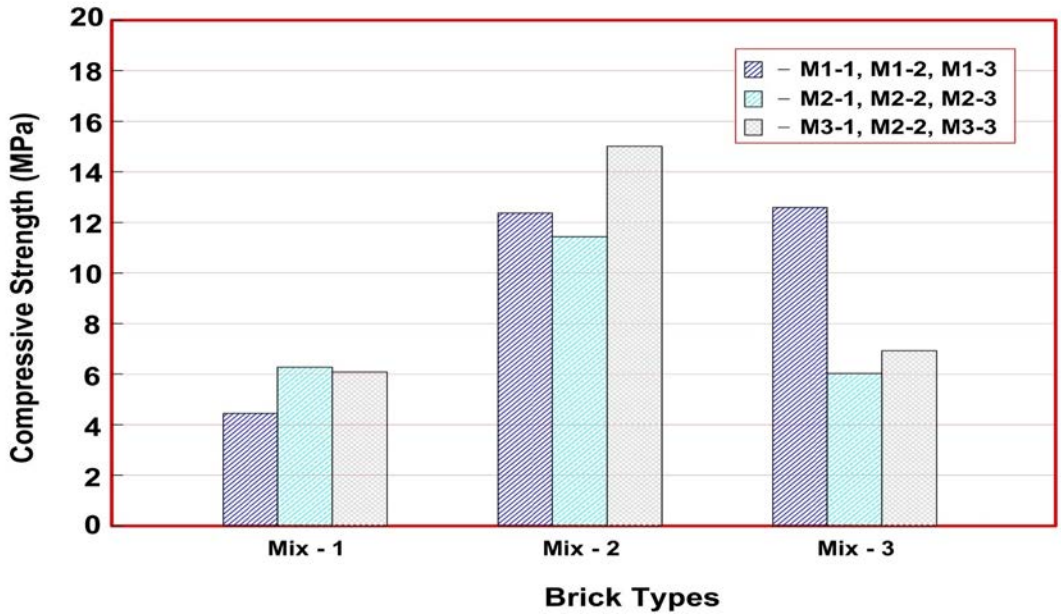

Fig. 5: Comparison of Compressive Strength Values.

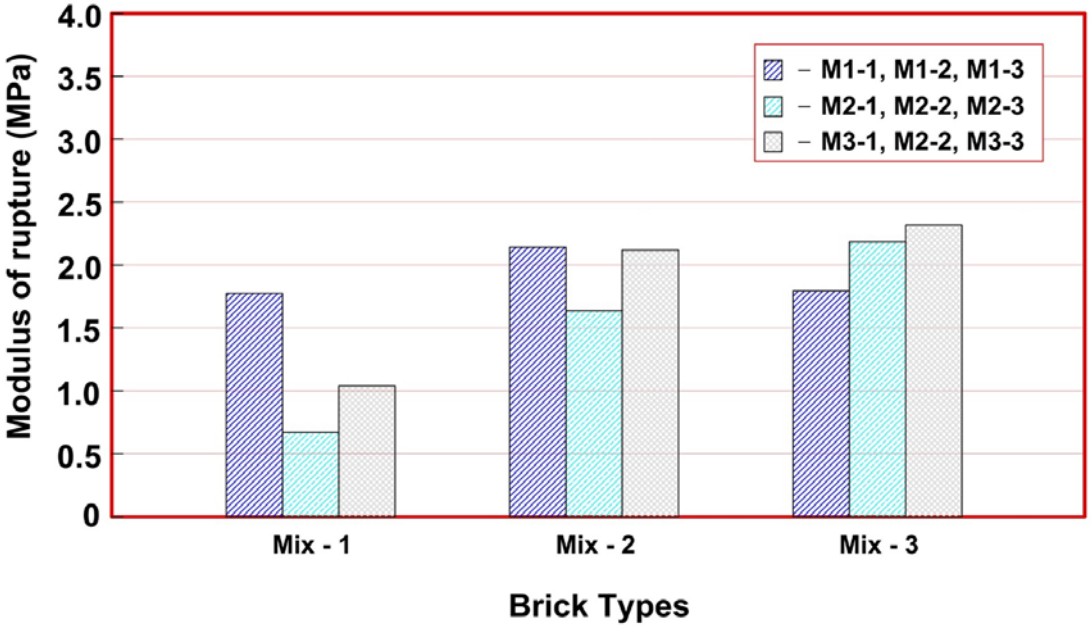

Fig. 6: Comparison of Flexure Test Results.

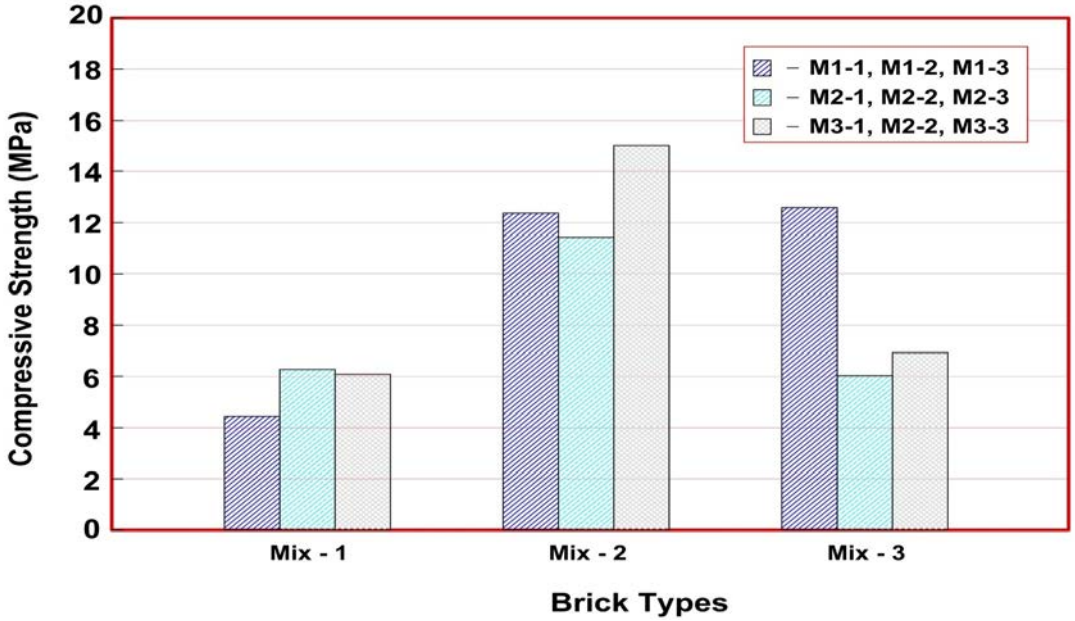

Fig. 7: Comparison of Splitting tensile strength values.

6.1 Compressive Strength

By applying an axial compressive load under static loading, the compressive strength of CCI bricks was ascertained. Table 3 present an overview of the results of the experimental tests. As can be seen, because Mix-2 CCI bricks contain a higher percentage of cement than other mixes, they have the highest recorded compressive strength (13.15 MPa). On the other hand, CCI bricks of mix-1 showed the lowest values of compressive strength (8.43 MPa), while CCI bricks of mix-3 showed a moderate value of 8.43 MPa. According to test results, fly ash contributes less to the compressive strength increase of CCI bricks than cement does. This is primarily because, in comparison to fly ash, cement has a higher amount of lime. Prior research pertaining to the utilization of fly ash in brick production has also revealed that bricks produced with high fly ash content exhibit a reduced compressive strength in contrast to bricks made with either low or high fly ash content [26]. When it comes to cement mortar made with fly ash, a similar pattern has also been noted [27]. It is evident from a comparison of Table 4 with the CCI hollow bricks from Region

A that all three of the recently suggested brick types are highly appropriate for increasing the compressive strength of CCI hollow bricks. The newly manufactured CCI bricks for Mixes 1, 2, and 3 have respective compressive strength results that are 34.10%, 202.99%, and 94.23% higher than the current mix in region A. The compressive strength of Mix-1 CCI bricks is still found to be below Indian community product standard.

Table 4: Comparison of average Compressive Strength Values.

Bricks	Average Compressive Strength [MPa]	Percentage Increases in Average Compressive Strength [MPa]
Region A	4.34	-
Mix-1	5.82	34.10
Mix-2	13.15	202.99
Mix-3	8.43	94.23

6.2 Modulus of Rupture

By putting three brick samples of each mix ratio through a three-point bending loading scheme, the modulus of rupture of CCI bricks was found. Tables 3 and 5 present an overview of the results of the experimental tests. The CCI bricks of Mix-3 exhibit the highest average modulus of rupture, 2.13 MPa, in contrast to their compressive strength. This suggests that using fly ash instead of regular Portland cement can effectively increase the modulus of rupture. Conversely, CCI bricks of mix-1 had the lowest average modulus of rupture (i.e., 1.18 MPa), while CCI bricks of mix-3 had a moderate average modulus of rupture (1.91 MPa). It is evident from comparing test results with region A's CCI bricks Table 5 that all three of the recently suggested mixes significantly improve the modulus of rupture of CCI bricks. The newly manufactured CCI bricks for Mix-1, Mix-2 and Mix-3 have average modulus of rupture that are, respectively, 9.15%, 22.86%, and 29.05% higher than the region A existing mix.

Table 5: Comparison of average Modulus of Rupture Values.

Bricks	Average Modulus Of Rupture [MPa]	Percentage Increases in Average Modulus of Rupture [MPa]
Region A	0.78	-
Mix-1	1.18	9.15
Mix-2	1.91	22.86
Mix-3	2.13	29.05

6.3 Splitting Tensile Strength

Three brick samples of each mix were tested using the single point loading scheme in order to determine the splitting tensile strength of CCI bricks. Tables 3 and 6 present an overview of the results of the experimental tests. High average splitting tensile strength (i.e., 0.42 MPa) was noted for CCI bricks of Mix-3, which is comparable to the compressive strength. CCI bricks from Mix-1 had the lowest splitting tensile strength values, or 0.14 MPa. Conversely, CCI bricks of Mix-3 showed a moderate value of splitting tensile strength, or 0.42 Mpa. The use of cement and fly ash is found to be effective in enhancing the splitting tensile strength of CCI bricks when compared to CCI bricks of region A. The newly produced CCI bricks for mixes 2 and 3 have average splitting tensile strength values that are 5.0% and 6.0% higher, respectively, than the current mix in region A. Table 5 illustrates that the addition of sand results in a lower splitting tensile strength when compared to the original CCI bricks (i.e., CCI bricks from region A).

Table 6: Comparison of Splitting Tensile Strength Values.

Bricks	Average Splitting Tensile Strength [MPa]	Percentage Increases in Average Splitting Tensile Strength [MPa]
Region A	0.21	-
Mix-1	0.14	-
Mix-2	0.37	6.05
Mix-3	0.42	5.50

6.4 Water Absorption Capacity

The immersion method was used to measure the water. All three of the recently suggested mixes are helpful in lowering the water absorption capacity of freshly manufactured CCI bricks. The Mix-1 containing sand has the highest average water absorption capacity (i.e., 10.8%) among freshly manufactured CCI bricks. The CCI bricks with fly ash have the lowest average water absorption capacity value. Fly ash is an extremely useful tool for lowering bricks water absorption capacity, according to a 2002 study by Sunil Kumar on fly ash, lime, and gypsum bricks and hollow blocks for low-cost housing development. The experimental findings of this study, however, differ from those of Charoon 2014 [18], who looked into the possibility that adding more palm ash would also increase the amount of water absorbed. Therefore, it can be concluded from this study that the mechanical properties of CCI bricks are affected differently by different types of fly ash. For CCI bricks of Mix-2, an average absorption capacity of moderate value is noted. It is evident from Table 3 and 7 that using fly ash reduces the water absorption capacity of CCI bricks more effectively than using traditional CCI bricks from region A. The least amount of water absorption capacity has been lost as a result of using sand. When compared to traditional CCI bricks from region A, the use of cement led to a moderate reduction in water absorption capacity.

Table 7: Comparison of Water Absorption Capacity Values.

Bricks	Average Water Absorption [MPa]	Percentage Increases in Average Water Absorption [MPa]
Region A	13.5	-
Mix-1	10.8	23.5
Mix-2	10.7	24.5
Mix-3	8.90	46.5

7 Conclusions

This study uses experiments to examine the effects of fly ash, cement, and sand on the mechanical characteristics of cement-clay interlocking hollow bricks. The water absorption, compressive strength, modulus of rupture, and splitting tensile strength were measured using standard procedures. Using the data from the experiment, the following deductions were made:

- Compared to CCI bricks from region A, all types of newly suggested mix ratios are found to be effective in improving the mechanical properties of CCI bricks.
- When compared to sand and fly ash, cement is found to be the most effective of the recently suggested mixtures for producing CCI bricks.
- The compressive strength of freshly manufactured CCI bricks is significantly higher than that of region A, with an average enhanced compressive strength of 64.3% and a maximum compressive strength of 13.15 MPa.

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