สมรรถนะของอิฐกลวงที่สร้างจากเถ้าลอย ซีเมนต์และทราย

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บทคัดย่อ

อิฐบล็อกประสานที่ทำจากดินเหนียวซีเมนต์เป็นวัสดุพื้นฐานที่ใช้ในการก่อสร้างและเป็นที่แพร่หลายทั้งในประเทศด้อยและที่กำลังพัฒนา สำหรับในประเทศไทยอิฐบล็อกประสานเหล่านี้ผลิตขึ้นด้วยวิธีอย่างง่ายโดยการผสมดินเหนียว ซีเมนต์และทราย ตามภูมิปัญญาการประดิษฐ์แบบพื้นบ้าน จากงานวิจัยที่ผ่านมาพบว่าสมบัติของอิฐที่ผลิตด้วยกรรมวิธีเหล่านี้ในแต่ละพื้นที่ของประเทศไทยมีการแปรผันเป็นอย่างมาก อิฐในบางพื้นที่ยังให้ค่ากำลังอัดซึ่งต่ำกว่าค่ามาตรฐานผลิตภัณฑ์ชุมชนอิฐบล็อกประสาน (มอก.) อย่างมีนัยสำคัญงานวิจัยนี้จึงมุ่งศึกษาพัฒนาจุดด้อยของอิฐเหล่านั้นด้วยวิธีที่หลากหลาย เช่น การปรับส่วนผสมและนำของเถ้าลอยมาใช้ ซึ่งทำให้ได้สูตรการผสมที่แตกต่างกันถึง 3 สูตรจากผลการทดลองพบว่าด้วยสูตรการผสมใหม่ สามารถผลิตอิฐที่มีกำลังอัดได้สูงกว่าสูตรที่ใช้กันอยู่โดยทั่วไปถึงร้อยละ 68.3 นอกจากนั้นสมบัติอื่นๆ เช่น การดูดซึม และโมดูลัสแตกร้าว ก็ดีขึ้นเช่นกัน

คำสำคัญ : อิฐบล็อกประสานกลวงที่ทำจากซีเมนต์และดินเหนียว / กำลังอัด / โมดูลัสแตกร้าว / ค่าการดูดซึมน้ำ / อัตราส่วนผสม

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Performance of Hollow Brick Made of 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 under-developed and developing countries. In Thailand, these CCI hollow bricks are prepared without designing specifications and guidelines in most of the regions, by simple mixing of clay, cement and sand in a conventional manner by local manufacturers. Previous studies have shown a large variation in the mechanical properties of CCI hollow bricks collected from different regions. The compressive strength of the bricks from one region was even lower than the standard values recommended by the Thai Community Standards. In this study, different techniques were used to improve the mechanical properties of CCI bricks. Sand, cement and fly ash were used to develop new mix designs. Results showed a marked increase in the compressive strength of the newly manufactured CCI bricks (up to 13.20 MPa or 68.3% on average enhanced compressive strength) as compared with the original bricks. Other mechanical properties including the water absorption and modulus of rupture of the newly manufactured CCI hollow bricks also improved.

Keywords : Cement-clay Interlocking (CCI) Hollow Bricks / Compressive Strength / Modulus of Rupture / Water Absorption / Mix Design Ratio

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1. Introduction

Bricks have been widely used as construction and building materials all around the world for a long time. Conventional clay based brick production generally uses mixtures of clays and shale as raw materials, and requires the processes of shaping, drying and firing at high temperature. Fired clay bricks are mainly construction elements used to make walls of buildings [1]. The high demand of construction of buildings gives reason to find ways to fulfill and to solve the problems related to the construction. Interlocking bricks are an alternative system to the conventional clay bricks which is similar to the “LEGO blocks” that use less or minimum mortar to bind the bricks together. Interlocking brick system is a fast and cost-effective construction system which offers good solution in construction. In Thailand, cement-clay interlocking (CCI) bricks made of locally available clay are widely used to construct low rise residential buildings throughout the country. These interlocking bricks are manufactured locally in small factories located in different regions of Thailand. At present, there are at least 700 brick manufacturing plants in Thailand [2]. These plants are located mostly in rural areas and these plants are owned by successful farmers or entrepreneurs who have gained experience through working with other brick plants. Many of the rural brick owners uses clay dug from their own land. According to the geological map of Thailand, the sedimentary and metamorphic rock distribution of Thailand is quite diverse, ranging from mudstone to sandstone and shale [3]. Many studies have reported that change in clay contents cause change in mechanical properties of bricks [4, 5]. Joyklad et al. [6] investigated the mechanical properties of local cement-clay interlocking bricks in the central part of Thailand. The interlocking bricks were collected from different regions of Thailand. Results show that each region is following different mix design ratio based on availability of local materials and knowledge. It was also observed that locally available materials and mix design ratio has a significant effect on the mechanical properties of CCI bricks. The compressive strength of CCI bricks was observed between 4.22 MPa to 16.40 MPa. A large variation in the values of splitting tensile strength, modulus of rupture and absorption were also observed in different regions [6]. For environmental protection and sustainable development, many researchers have studied the utilization of different waste materials (such as including fly ash, slags, construction and demolition waste, wood sawdust, cotton waste, pulp and paper production residues, boron waste, cigarette butts, waste tea, rice husk ash and crumb rubber) and other natural materials to alter the mechanical properties of conventional clay bricks [7-16]. As per author’s information, limited studies have been conducted by using waste materials and other natural available materials to enhance the mechanical properties of interlocking hollow bricks manufactured in Thailand [17, 18]. However, different kinds of waste materials and ashes such as ceramic waste and fly ash have been studied in Thailand [19, 20]. In this study, different techniques have been exercised to improve the mechanical properties of CCI bricks of the substandard region (region A) by changing the mix design ratio of region A. Sand, Cement and Fly ash is used to develop new mix designs Mix-1, Mix-2 and Mix-3, respectively. The results (mechanical properties of newly manufactured CCI hollow bricks such as compressive strength, modulus of rupture, splitting tensile strength and water absorption capacity) were compared with previously published results of region A (Original Mix) CCI bricks with traditional method of construction from the central region with less satisfactory results of mechanical properties. It was found that proposed mix ratios are very effective to enhance the compressive strength and reduce the water absorption of the ICC bricks as compared with original mixes.

2. Summary of Previous Study

Joyklad et al. [6] performed an experimental investigation on the mechanical properties of cement-clay interlocking (CCI) bricks collected from three different regions such as region A, B and C of Thailand. These three regions have their own clay stratum; showing varied results of mechanical properties like compressive strength, splitting tensile strength, modulus of rupture and water absorption. Mechanical properties such as compressive strength, splitting tensile strength, modulus of rupture and absorption were determined. Results show that each region is following different mix design ration based on availability of local materials and knowledge. It was also observed that locally available materials and mix design ratio has a significant effect on the mechanical properties of CCI bricks. The compressive strength of CCI bricks was observed between 4.22 MPa to 16.40 MPa. In general, mechanical properties of cement-clay interlocking bricks collected from region B were found superior than cement-clay interlocking bricks collected from A and C provinces. Further, it was found that compressive strength and water absorption capacity of bricks collected from region A are not meeting or fulfilling the requirements of Thai community product standard 602/2547 [21].

3. Experimental Program

This study is the continuation of previous studies, in which mechanical properties of the CCI bricks manufactured from three different provinces of Thailand were investigated. Previous studies have shown a large variation in the mechanical properties of CCI hollow collected from different regions. Even, the compressive strength of one region (region A) was found much lower than the standard values recommended by Thai community product standard 602/2547 [19]. In this study, different techniques have been exercised to improve the mechanical properties of CCI bricks of the substandard region (region A) by changing and or adding new materials in the mix design ratio of region A. Sand, Cement and Fly ash is used to develop new mix designs Mix-1, Mix-2 and Mix-3, respectively. The use of sand is basically adopted due to the ease in the availability and low cost. Fly ash was also used to replace the cement and to investigate the effectiveness of Fly ash to manufacture CCI bricks. Fly ash is one of the coal combustion products (CCPs) of coal burning power plants and it contains substantial amounts of potentially harmful constituents to the environment. A large number of existing research activities shown that Fly ash is an effective supplementary material to replace cement in the production of concrete and bricks [22, 23]. Typical chemical composition of ordinary Portland cement and fly ash is summarized in the table 1. The major difference between fly ash and Portland cement is the relative quantity of each of the different compounds. Portland cement is rich in lime (CaO) while fly ash is low. Fly ash is high in reactive silicates while Portland cement has smaller amounts. In this study, different techniques have been exercised to improve the mechanical properties of CCI bricks of the substandard region (region A) by changing the mix design ratio of region A. Sand, Cement and Fly ash is used to develop new mix designs Mix-1, Mix-2 and Mix-3, respectively. Further details of experimental program such as manufacturing process of CCI bricks and mechanical properties are discussed in the following section.

Table 1 Chemical composition of fly ash and cement [24]

Chemical Compound	Fly ash	Ordinary Portland Cement
SiO	41.96	18.66
Al_2O_3	19.64	6.56
Fe_2O_3	20.07	3.02
CaO	5.57	61.40
MgO	1.19	2.93
SO_3	4.39	4.39
Na_2O	0.69	0.41
K_2O	2.44	1.03

4. Manufacturing of CCI Bricks

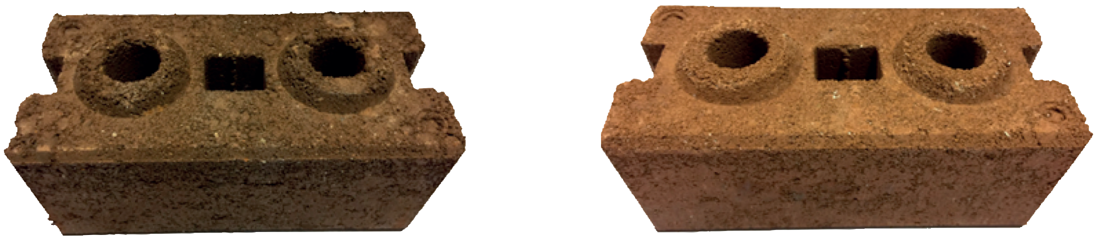
In this study, the CCI bricks are manufactured by changing the ratios of the component materials of CCI bricks of region A by three different mix designs (such as cement, sand and fly-ash). The manufacturing process of CCI bricks is mainly comprised of three steps. In the first step, large boulders of clay are broken down into finer material by using the mechanical grinding machine. In the second step, different component materials such as cement, sand and fly-ash are mixed with clay using a mechanical concrete mixer machine. In the last step, the cement-clay mix is placed into the aluminum molds and pressed either by hydraulically or manually operated machines. The nominal size of the CCI bricks prepared by different mix designs is 250 x 125 x 100 mm (Length x width x height). The component materials by weight and their nominal weights are shown in the following Table 2. The typical CCI bricks manufactured using newly proposed mixes and original mix are shown in the figure 1.

Table 2 Details of Mix Components and nominal weight of CCI Bricks

	Original Mix	Mix-1	Mix-2	Mix-3
Cement (kg)	164.0	164.0	164.0	328.0
Sand (kg)	-	164.0	-	-
Fly Ash (kg)	-	-	164.0	-
Red Clay (kg)	1636.0	1472.0	1472.0	1472.0
Nominal weight (g)	4950.0	5238.0	5541.0	5392.0
Density (g /cm^3)	1.61	1.70	1.80	1.75

a. Typical CCI brick sample of Region A

b. Typical Mix-1 CCI hollow brick



c. Typical Mix-2 CCI hollow bricks

d. Typical Mix-3 CCI hollow bricks

Figure 1 CCI hollow interlocking bricks

5. Mechanical properties of CCI bricks

The mechanical properties of the CCI bricks were determined by using standard test methods to investigate the compressive strength, modulus of rupture, splitting tensile strength and water absorption. Description of each test method is provided in the next sections.

5.1 Compressive Strength

Standard test method for finding the compressive strength of masonry prisms (ASTM C1314-14) was used [25]. The universal testing machine (UTM) was used for carrying out the test method on three sample specimen for each type of region. During the testing period, load at the constant speed of 0.5 mm/minute was applied. The average result of compressive strength of three samples was used. The typical loading setup is shown in figure 2. The compressive strength was determined using the following equation,

$$CS = P/A \tag{1}$$

Where;

CS = Compressive Strength (MPa)

P = Maximum load (N)

A = Net bearing area of CCI bricks (mm^2)

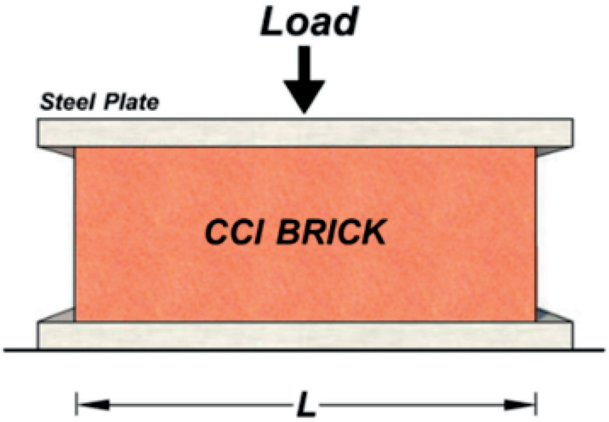


Figure 2 Loading setup for compression test

5.2 Modulus of Rupture

Modulus of rupture (also known as flexural strength, bond strength, or transverse rupture strength) can be defined as, in the material property in the form of stress inside the material just before it yields a flexural test. Standard test procedure for sampling and testing of brick and structural clay tiles (ASTM C67-03) is used for investigating the modulus of rupture of CCI bricks [26]. During the testing period, load at the constant speed of 0.5 mm/minute was applied. The average result of modulus of rupture of three samples was used. Typical loading setup for compression test is shown in the figure 3. The expression used to find the modulus of rupture is as follows;

$$R = 3P(L_1/2 - x)/(W \cdot H^2) \tag{2}$$

Where;

R = Modulus of Rupture (MPa)

L1 = 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 mid-span of specimen to plane of failure in the direction of span along center-line of the bed surface subject to tension (mm)

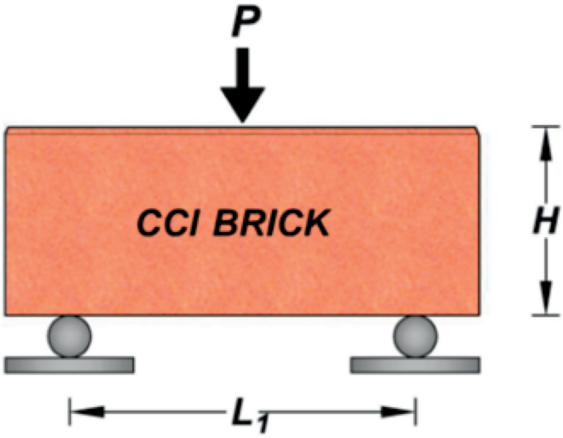


Figure 3 Loading setup for splitting tensile strength test

5.3 Splitting Tensile Strength

Samples collected from each region were tested under standard test method for splitting tensile strength of masonry units (ASTM C1006-07) [27]. During the testing procedure, load at constant speed of 0.5 mm/minute was applied. Three samples from each region were tested and the average value was taken as a reference value. Typical loading setup for the splitting tensile strength test is shown in figure 4. The splitting tensile strength of the samples was calculated by using the expression 3.

$$T = 2P/(\pi BH) \qquad (3)$$

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)

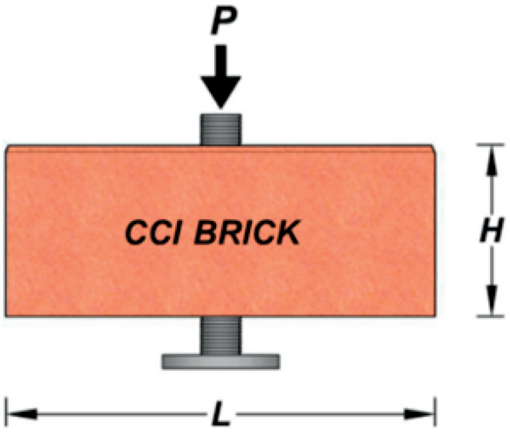


Figure 4 Loading setup for splitting tensile strength test

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 140-11a) [28]. Again, three samples were immersed in water from every region and the average value was taken as a reference value for each region. The absorption capacity of CCI bricks was calculated by using the next expression.

$$A = (100/W_d)(W_s - W_d) \qquad (4)$$

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

The experimental results such as compressive strength, modulus of rupture, splitting tensile strength, and water absorption of newly manufactured bricks are discussed in this section. The experimental results are summarized in the tables 3-7 and graphically shown in the figures 5-11. Test results and findings of this study are further discussed in detail in the following sections.

Table 3 Test results of mechanical properties of CCI hollow bricks

Bricks	Compressive strength (MPa)	Modulus of Rupture (MPa)	Splitting tensile strength (MPa)	Water absorption (kg/m3)
M1-1	4.73	1.90	0.12	229.0
M1-2	6.49	0.62	0.16	172.0
M1-3	6.38	1.10	0.17	184.0
Average	5.87	1.21	0.15	194.6
M2-1	12.32	2.05	0.28	329.0
M2-2	11.88	1.41	0.41	303.0
M2-3	15.39	2.09	0.39	331.0
Average	13.20	1.85	0.45	321.0
M3-1	12.30	1.78	0.49	161.0
M3-2	6.03	2.21	0.41	168.0
M3-3	6.77	2.26	0.34	169.0
Average	8.37	2.08	0.41	166.1

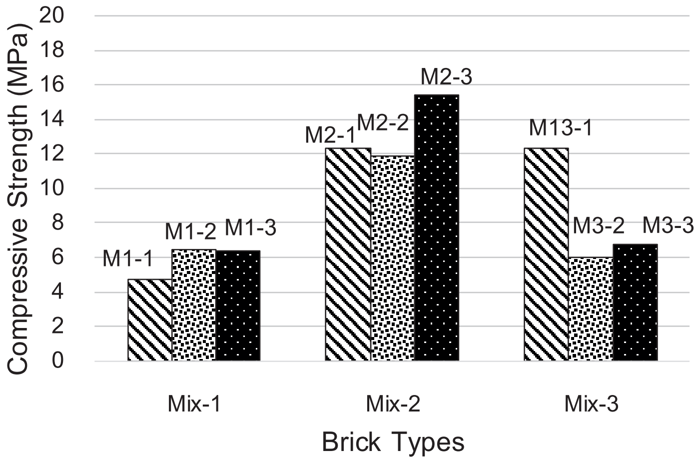


Figure 5 Comparison of compressive strength values

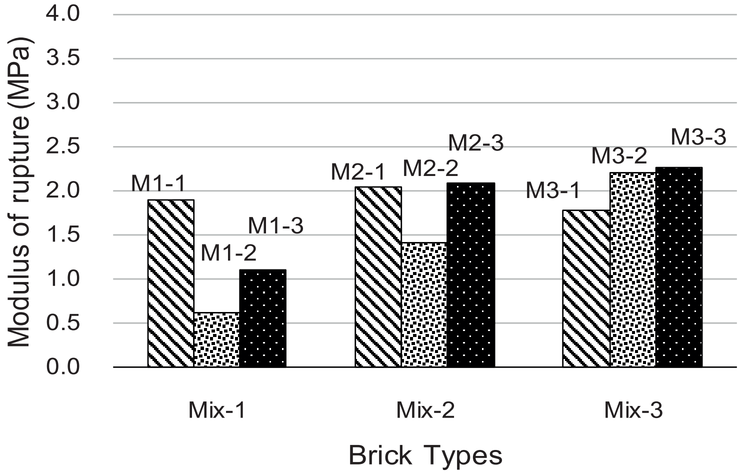


Figure 6 Comparison of flexure test results

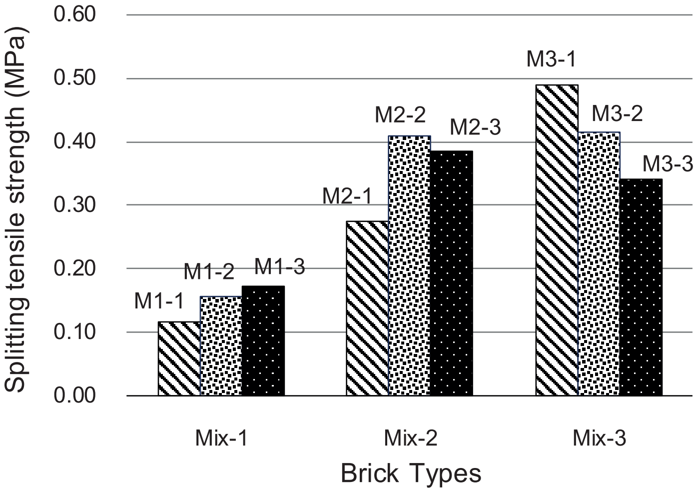


Figure 7 Comparison of splitting tensile strength values

6.1 Compressive Strength

Compressive strength of CCI bricks was determined by applying axial compressive load under static loading. The experimental test results are summarized in tables 3 and 4. The test results are also compared in figures 5 and 8. As it can be seen, the highest compressive strength (i.e., 13.20 MPa) is recorded for CCI bricks of Mix-2 due to the high amount of cement as compared with other mixes. On the other hand, the lowest values of compressive strength (i.e., 8.37 MPa) were observed for CCI bricks of mix-1 and a moderate value of compressive strength (i.e., 8.37 MPa) is recorded for CCI bricks of mix-3. Test resultsindicate that an increase in compressive strength of CCI bricks due to fly ash is lower as compared with cement. This is basically due to the reason that cement contains high amount of lime as compared with fly ash. The previous studies conducted on the use of fly ash to produce bricks have also reported that the compressive strength of those bricks manufactured using high amounts of fly ash is lower as compared with the bricks manufactured using cement and or low amount of fly ash [29]. A Similar trend has also been observed in the case of cement mortar prepared using fly ash [30]. By comparing with CCI bricks of region A (figure 8 and table 4), it can be seen that all three kinds of newly proposed bricks are found very suitable to enhance to the compressive strength of CCI hollow bricks. Compressive strength results of newly manufactured CCI bricks for mix-1, mix-2 and mix-3 are 39%, 213% and 98.30% higher than that of the existing mix of region A, respectively. However, the compressive strength of CCI bricks of mix-1 is still found lower than Thai community product standards.

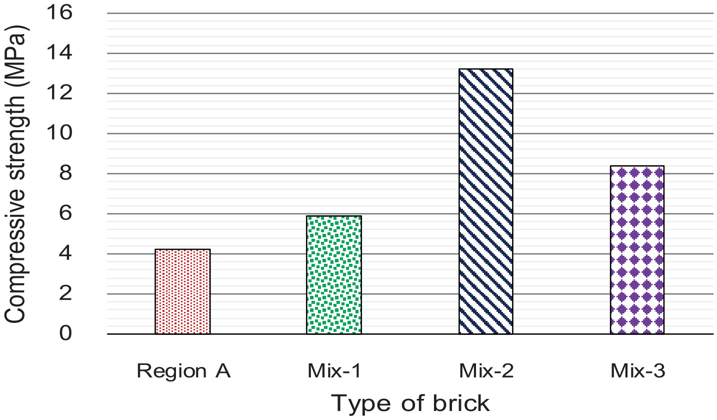


Figure 8 Comparison of average compressive strength values

Table 4 Comparison of average compressive strength values

Bricks	Average compressive strength (MPa)	Percentage increase in average compressive strength
Region A	4.22	-
Mix-1	5.87	39.00
Mix-2	13.20	213.00
Mix-3	8.37	98.30

6.2 Modulus of Rupture

Modulus of rupture of CCI bricks was determined by testing three brick samples of each mix ratio under three-point bending loading scheme. The experimental test results are summarized in tables 3 and 5. A graphical comparison is shown in the figures6 and 9. In contrast to the compressive strength, highest average modulus of rupture (i.e., 2.08 MPa) is observed for CCI bricks of mix-3. This is an indication that use of fly ash is effective to enhance more modulus of rupture as compared with ordinary Portland cement. On the other hand, the lowest average modulus of rupture (i.e., 1.21 MPa) was observed for CCI bricks of mix-1 and a moderate average modulus of rupture (i.e., 1.85 MPa) is recorded for CCI bricks of mix-3. By comparing test results with CCI bricks of region A (figure 9 and table 5), it can be seen that all three newly proposed mixes are very effective in enhancing the modulus ofrupture of CCI bricks. Average modulus of rupture of newly manufactured CCI bricks for mix-1, mix-2 and mix-3 are 8.50%, 23.70% and 29.20% higher than that of the existing mix of region A, respectively.

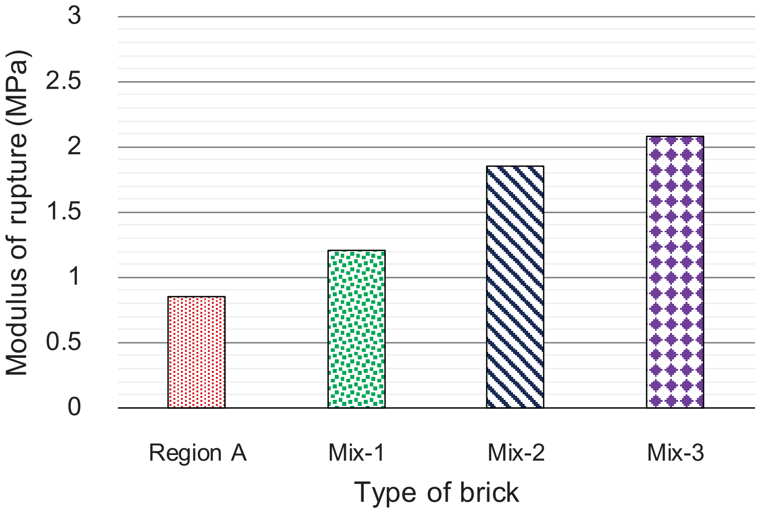


Figure 9 Comparison of average modulus of rupture values

Table 5 Comparison of average modulus of rupture values

Bricks	Average modulus of rupture (MPa)	Percentage increase in average modulus of rupture
Region A	0.85	-
Mix-1	1.21	8.50
Mix-2	1.85	23.70
Mix-3	2.08	29.20

6.3 Splitting tensile strength

Splitting tensile strength of CCI bricks was determined by testing three brick samples of each mix under the single point loading scheme. The experimental test results are summarized in tables 3 and 6. A graphical comparison is shown in the figures 7 and 10. Similar to the compressive strength, high average splitting tensile strength (i.e., 0.45 MPa) was observed for CCI bricks of mix-2. The lowest values of splitting tensile strength (i.e., 0.15 MPa) were recorded for CCI bricks of mix-3. Whereas; a moderate value of splitting tensile strength (i.e., 0.41 MPa) was recorded for CCI bricks of mix-1. By comparing with CCI bricks of region A (figure 10 and table 6), it can be seen that the use of cement and fly ash is found effective to enhance the splitting tensile strength of CCI bricks in comparison with CCI bricks of region A. Average splitting tensile strength values of newly manufactured CCI bricks for mix-2 and mix-3 are 6.0% and 5.0% higher than that of the existing mix of region A, respectively. However, the use of sand is resulted into reduced splitting tensile strength as compared with original CCI bricks (i.e., CCI bricks of region A) as shown in table 5.

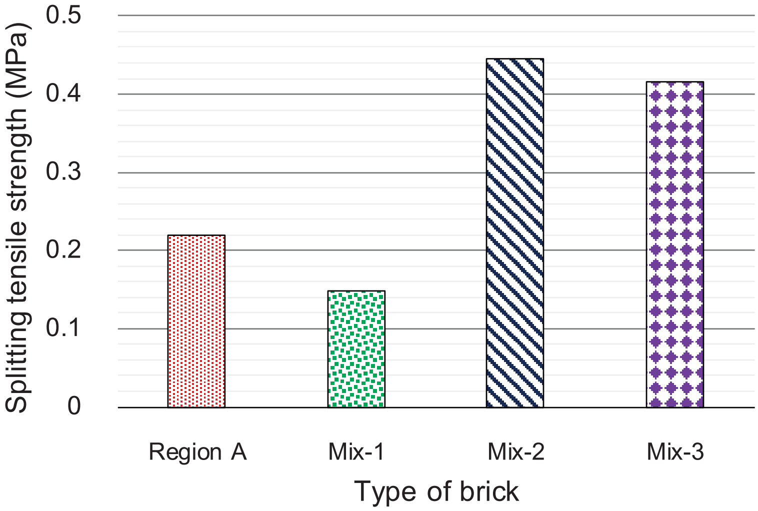


Figure 10 Comparison of average Splitting tensile strength values

Table 6 Comparison of average modulus of rupture values

Bricks	Average Splitting tensile strength (MPa)	Percentage increase in average Splitting tensile strength
Region A	0.22	-
Mix-1	0.15	-
Mix-2	0.45	6.00
Mix-3	0.41	5.00

6.4 Water absorption capacity

Water absorption capacity of CCI bricks was determined by the immersion method. The experimental test results are summarized in tables 3 and 7. A graphical comparison is shown in figure 11. It can be seen (figure11) that all three newly proposed mixes are useful to reduce the water absorption capacity of newly manufactured CCI bricks as compared with traditional CCI bricks of region A. In case of newly manufactured CCI bricks, the highest amount of average water absorption capacity (i.e., 10.6%) is recorded for mix-1 which containing sand.

The lowest value of average water absorption capacity is observed for CCI bricks containing fly ash. A perspective study on fly ash–lime–gypsum bricks and hollow blocks for low cost housing development conducted by Sunil Kumar in 2002 [29] has also reported that use of fly ash is very effective to reduce the water absorption capacity of bricks. However, the experimental results of this study in contrast with Charoon 2014 [18], who investigated that increasing the amount of palm ash also increases water absorption. So, from this study it can be inferred that different types of fly ash have different behavior on mechanical properties of CCI bricks. A moderate value of average absorption capacity is recorded for CCI bricks of mix-2. By comparing with traditional CCI bricks of region A (figure 11 and table 7), it can be seen that the use of fly ash is found more effective to reduce the water absorption capacity of CCI bricks. The use of sand has resulted in least reduction in water absorption capacity. The use of cement was resulted in a moderate amount of reduction in water absorption capacity as compared with traditional CCI bricks of region A.

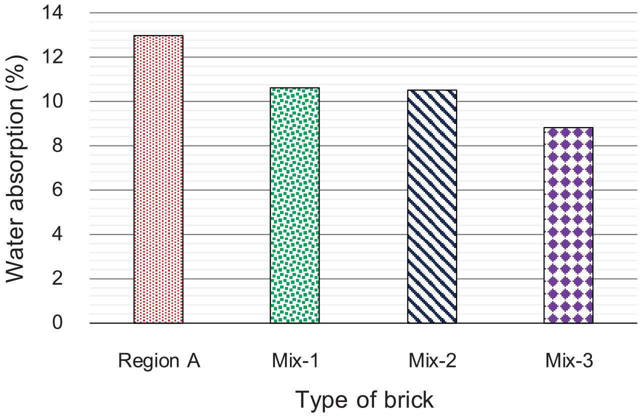


Figure 11 Comparison of average modulus of rupture values

Table 7 Comparison of water absorption capacity

Bricks	Average water absorption capacity (%)	Percentage reduced in average water absorption capacit
Region A	13.0	-
Mix-1	10.6	22.0
Mix-2	10.5	24.0
Mix-3	8.80	47.0

6.5 Failure modes

All CCI bricks showed a quite similar failure mode in each type of test such as compression, flexure and splitting. Under the compression test, the bricks were mainly failed due to the crushing of cement and clay as shown in the figure 12a. An inclined crack in the middle region of CCI bricks was observed in the modulus of rupture test as shown in figure 12b. This is mainly due to the reason that under three-point bending loading scheme, the brick tends to bend after load application. Minor flexural cracks were observed on the tension face of brick prior to the final inclined rupture of the brick. A straight crack line was observed in the middle region of CCI bricks in the splitting tensile strength test as shown in the figure 12c. The straight crack line is indicating the pure compression in the brick during the splitting tensile strength test.

a. Typical failure of brick in compression

b. Typical failure of brick in flexure

c. Typical failure of brick in splitting tensile test

Figure 12 Typical failure modes of tested bricks

7. Conclusions

In this study, the effect of fly ash, cement and sand on mechanical properties of cement-clay interlocking hollow bricks is experimentally investigated. The standard tests were performed to determine the water absorption, compressive strength, modulus of rupture and splitting tensile strength. Based on experimental results; following conclusions were drawn;

1. All kinds of newly proposed mix ratios are found to effective to enhance the mechanical properties of CCI bricks as compared with CCI bricks of region A.
2. Among the newly proposed mixes, use of cement is found most effective to produce CCI bricks as compared with sand and fly ash.
3. Results show a marked increase in the compressive strength of newly manufactured CCI bricks (up to 13.20MPa with 68.3% on average enhanced compressive strength) as compared with region A.

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