Mechanical Properties of Local Cement-Clay Interlocking Bricks in Central Part of Thailand

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ABSTRACT

This paper presents the findings of an experimental investigation performed on cement-clay interlocking (CCI) hollow bricks made using cement and clay, by conventional method. In Thailand, these CCI bricks are made in different regions by using locally available clay and there is no standard mix design to prepare bricks. Therefore, CCI brick samples were collected from different three regions of Thailand to study the influence of locally available clay and mix design ratio on the mechanical properties of CCI bricks. Mechanical properties such as compressive strength, splitting tensile strength, modulus of rupture and water absorption were determined. 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 for different regions. This study indicates that there is an urgent need to establish and enforce standard guidelines for codes for CCI brick manufacturing process in Thailand.

Keyword: Compressive strength, tensile strength, water absorption capacity, interlocking bricks

1. Introduction

In many developing countries especially in the rural, natural compacted soil has good insulation and fire-resistant properties [1]. It is, however, vulnerable to weather especially during rainy season and soil material can expand and loose cohesiveness, particularly with cement plaster. There is an initiative to produce bricks by using natural soil bricks because they have been identified as low-cost material. The technology uses the available soil on site, which can be stabilized with a small amount of cement or/and lime depending on the characteristics of the soil so as to improve the engineering properties of the produced bricks. Soil can be improved and used as a building material for various types of structures by adding substances known as stabilizers, and the product is called stabilized soil [2]. A properly stabilized, consolidated, well-graded soil that is adequately moisturized, mixed, and cured will provide a strong, stable, waterproof and long-lasting building bricks. Regarding soil, Walker [3] assessed the influence of soil characteristics and cement content on the physical properties of stabilized soil blocks. Both saturated strength and durability of cement stabilized soil blocks were improved by increasing cement and impaired by clay content. He concluded that the most ideal soils for cement soil block production should have plasticity index between 5 and 15. Soils with a plasticity index above 20–25 are not suited to cement stabilization using manual presses, due to problems with excessive drying shrinkage, inadequate durability and low compressive strength. Reddy [4] studied the use of steam curing process and showed that it can lead to quick production of stabilized soil blocks. Venkatarama and Gupta [5] studied the various characteristics of soil-cement blocks using highly sandy soils. The results indicate that there is 2.5 times increase in strength for doubling of cement content from 6%. Saturated water content of the blocks is not sensitive to cement content, whereas rate of moisture absorption greatly depends on the cement content. Pore size decreases with increase in cement content of block, whereas surface porosity is independent of the cement content. Stabilized soil cement blocks have been used for load bearing masonry structures in many parts of the world like India. More details on stabilized soil block technology can be found in other studies [6-9]. Mortar is used in normal brick construction in order to create continuous structural form and to bind together the individual units in brickwork. In normal bricks, mortar and bricks provides the high strength in brickwork system. Many studies have been done in perfecting the performance of the brickwork [10-12]. The higher demand of construction of buildings gives reason to find ways to fulfill and to solve the problems related to the construction. Interlocking bricks is an alternative system which is similar to the "LEGO blocks" that use less or minimum mortar to bind the bricks together. Interlocking bricks was introduced to reduce the use of manpower, hence fulfill the requirement of Industrialized Building System (IBS). 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 [13]. These plants are located mostly in rural areas and these plants are owned by successful farmers or entrepreneurs who have gained experience through working in other brick plants. Many of the rural brick owners use 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 sand stone and shale [14]. Many studies have reported that change in clay contents cause change in mechanical properties of bricks [15-16]. In addition, there are no standard guidelines or reference codes in practice to prepare CCI bricks.

Therefore, each CCI manufacturing plant is using different mix designs. These mix designs are developed based on the availability of local materials and knowledge. For example, some plants use only cement and clay to produce CCI bricks whereas some plants also add stone duct or sand to along with cement and clay to produce CCI bricks. The change in mix design proportions directly effects the mechanical properties of CCI bricks such as compressive strength, tensile strength and water absorption.

As per author's information there are limited research studies on the mechanical properties of clay-cement interlocking bricks manufactured in different regions of Thailand. Hence there is a need to hasten the effort to determine the effect of locally available materials and mix design ratios on the mechanical properties of clay-cement interlocking bricks. To achieve this goal, an experimental program was planned to determine the mechanical properties such as compressive strength, splitting tensile strength, and modulus of rupture and water absorption. CCI brick samples were collected from different three regions of Thailand to investigate the influence of locally available clay and mix design ratio on the mechanical properties of CCI bricks.

2. Experimental Program

This paper presents an experimental investigation on the mechanical properties of cement-clay interlocking (CCI) bricks manufactured by small factories in different regions of Thailand. The main objective of this study is to investigate the effect of locally available materials and different mix rations on the mechanical properties of CCI bricks such as compressive strength, splitting tensile strength, modulus of rupture and water absorption. Further details of experimental program are discussed in the following sections.

2.1. Cement-Clay Interlocking Bricks

In this study, CCI bricks were collected from different provinces or regions i.e., region A, region B and region C of Thailand to investigate the effect of locally available materials and mix design ratio on the mechanical properties of clay brick blocks. According to the geological map of Thailand, the soil stratum of Thailand is comprised of different types of sedimentary and metamorphic rocks as shown in figure 1 [16]. In this study, each region was selected to represent different types of sedimentary and metamorphic rock thus different kinds of locally available materials. The names of regions or provinces are not given in this paper to avoid any conflict. A short description about sedimentary and metamorphic rocks of each region is also provided in Table 1. The mix design ratio followed by each plant is also shown in the table 2. The CCI brick samples were collected from brick manufacturing plants located in each region and nominal size of CCI brick samples are given in Table 3.

Table 1

Soil stratum details [16]

Region type	Soil Stratum type
Region A	Siltstone, sandstone, claystone and congiomerate
Region B	Mudstone, limestone, sandstone, claystone and congiomerate
Region C	Semi-consolidated and consolidated rocks Limestone, dolomitic limestone, chert and dolomite Mudstone, siltstone, sandstone, and limestone

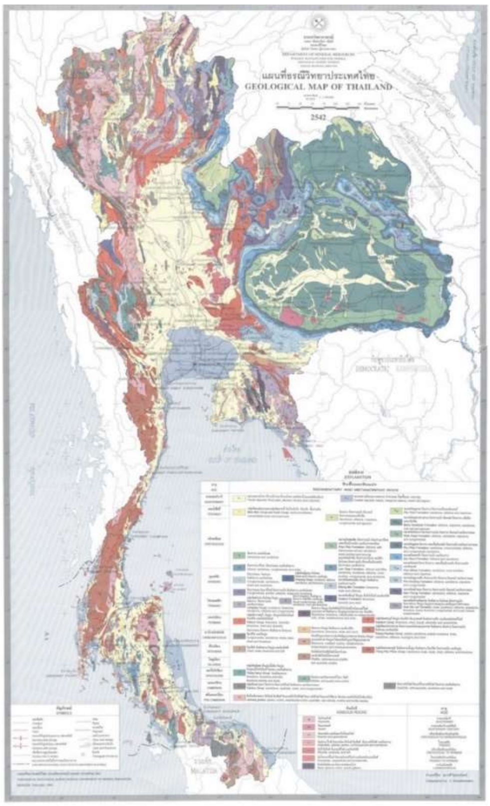

Figure 1 Geological Map of Thailand [16]

Table 2

Mix components of different regions to prepare CCI bricks

Mix components (kg/m^3)	Region A	Region B	Region C
Cement	164.0	660.0	534.0
Sand	-	570.0	380.0
Stone dust	-	380.0	126.0
Red clay	1636.0	190.0	760.0

3. Manufacturing of bricks

In this study, the cement clay interlocking bricks were collected from different region of Thailand. These CCI bricks are usually made using locally available materials such as clay, sand and stone dust along with the cement as a binding agent to enhance the strength and durability of CCI bricks. The manufacturing process of CCI bricks is essentially comprised of three steps. In the first step, the large size clay boulders are broken into fine pieces by using mechanical grinding machine. In the second step, the fine-grained clay is mixed with cement and water using mechanical concrete mixer. In the final step, the cement-clay mix is placed into the aluminum molds and pressed either by hydraulically or manually operated machines. The typical samples of CCI bricks collected from different regions are shown in the figures 2-4. The nominal dimensions of CCI bricks are shown in figure 5 and summarized in table 3.

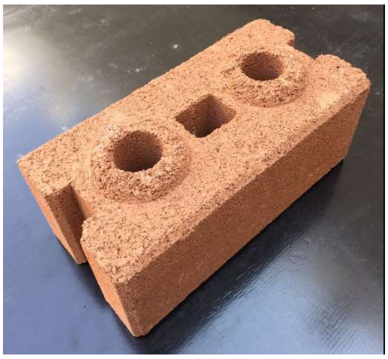

Figure 2 CCI brick sample (Region A)

Figure 3 CCI brick sample (Region B)

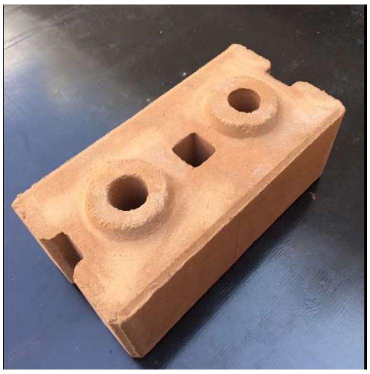

Figure 4 CCI brick sample (Region C)

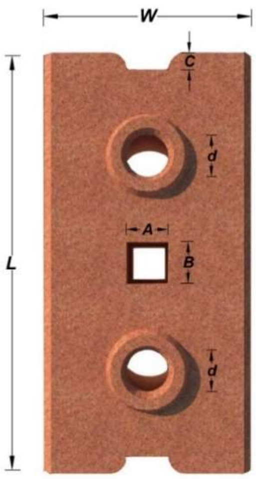

Figure 5 Typical detailing of CCI brick

Table 3

Detailing of CCI bricks

Dimensions (mm)	Region A	Region B	Region C
L	250	200	250
L1	200	150	200
W	125	100	125
H	100	100	100
d	35	20	30
A x B	20 x 20	30 x 25	25 x 25
C x D	10 x 20	10 x 25	10 x 25
Bearing Area (BA) (cm^2)	285	181	287
Weight (kg)	4.95	3.02	5.01

4. **Mechanical properties of CCI bricks**

The mechanical properties of cement-clay interlocking (CCI) bricks such as compressive strength, modulus of rupture, splitting tensile strength and water absorption were investigated by performing standard tests on CCI bricks. A detailed description about test methods is provided in the following sections.

4.1. Compressive Strength

The compressive strength of CCI bricks was determined following standard test method for compressive strength of masonry prisms (ASTM C1314-14) [17]. As the interlocking bricks contain frogs and projections. The net loaded area is more than 35% of the bed face, the frogs and projections were removed by cutting. The ICC bricks were tested in universal testing machine (UTM). The load was applied at constant speed 0.5 mm/minute. Three samples of bricks were tested for each type and average results were used. The compressive strength was determined *using equation 1. A typical load setup is shown in the figure 6.*

$$CS = P/A \qquad (1)$$

Where;

CS = Compressive Strength (MPa)

P = Maximum load (N)

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

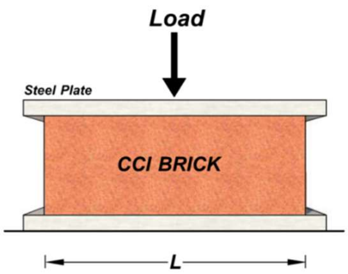

Figure 6 Loading setup for compression test

4.2. Modulus of Rupture

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. In this study the flexural strength of CCI bricks was determined following standard test methods for sampling and testing brick and structural clay tile (ASTM C67-03) [18]. The load was applied at constant speed 0.5 mm/minute. Three samples of bricks were tested for each type and average results were used. The modulus of rupture was calculated using expression 2. A typical loading setup for flexure strength is shown in the figure 7.

$$R = (3P/WH^2)(L_1/2-x) \qquad (2)$$

Where, R is modulus of rupture (MPa), L_1 is the distance between the supports (mm), W is the net width (face to face distance minus voids) of the specimen at the plane of failure (mm), H is the depth (bed surface to bed surface distance) of the specimen at the plane of failure (mm), and x is the average distance from the mid-span of the specimen to the plane of failure measured in the direction of the span along the centre-line of the bed surface subjected to tension (mm).

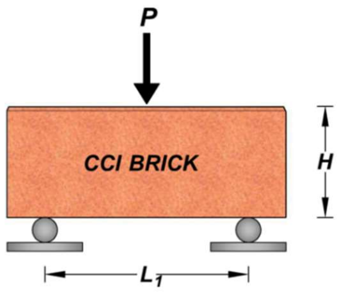

Figure 7 Loading setup for flexural strength test

4.3. Splitting tensile strength

In this study, the splitting tensile strength of CCI bricks was determined by essentially following standard test method for splitting tensile strength of masonry units (ASTM C1006-07) [19]. The load was applied at constant speed 0.5 mm/minute. Three samples of bricks were tested for each type and average results were used. A typical loading setup for flexure strength is shown in the figure 8.

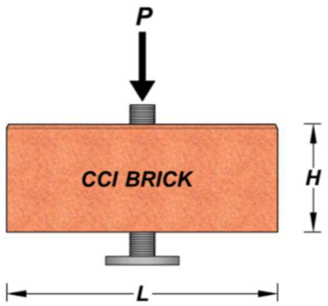

Figure 8 Loading setup for splitting tensile strength test

The splitting tensile strength was calculated using the following expression.

$$T = 2P/(\square L_2 \cdot H) \qquad (3)$$

Where, T is splitting tensile strength (MPa), P is the ultimate force (N), L_2 is the split length, in. (mm), gross length minus the length of any voids along the failure plane of the bearing rods and H is the distance between rods (mm).

4.4. Water absorption capacity

Water absorption capacity (percentage by mass) after 24 hours immersion in water of CCI bricks was essentially determined following the standard test methods for sampling and testing concrete masonry units and related units (ASTM C140-11a) [20]. A typical setup for brick immersion is shown in the figure 9.


Figure 9 Immersion of CCI bricks in water

The absorption capacity of the CCI bricks was calculated by using following expression.

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

Where, A is absorption capacity in percentage (%), W_s is saturated weight of specimen, (kg) and W_d is oven-dry weight of specimen, (kg).

5. Results and Discussion

In this study, CCI bricks were collected from different provinces or regions i.e., region A, region B and region C of Thailand to investigate the effect of locally available materials and mix design ratio the mechanical properties of clay brick blocks. The experimental results are summarized in the tables 4-7 and graphically shown in the figures 10-13. Test results and findings of this study are further discussed in detail in the following sections.

5.1. Compressive Strength of CCI bricks

Compressive strength of CCI bricks were determined by applying axial compressive load under static loading. The experimental test results are summarized in table 4 and compared in figure 10. As it can be seen, the highest compressive strength is recorded for CCI bricks collected from region B due to the highest amount of cement and clay contents compared with others. On the other hand, the lowest values of compressive strength were observed for CCI bricks collected from region A. This is associated with the factor that CCI bricks of region A contains a lowest amount of cement as compared with other regions. The compressive test results of CCI bricks collected from region C shows moderate values compared with regions A and B. According to the Thai community product standard 602/2547, the lowest compressive strength of clay bricks is 7.0 MPa [21]. By comparing with Thai community product standard, average compressive strength of region A bricks is found lower than standard recommendations, however compressive strength of region B and C is found higher than recommended values.

Table 4

Test results of compressive strength

Bricks	Compressive strength (MPa)
1A	5.23
2A	2.84
3A	4.59
Average	4.22
1B	18.52
2B	14.78
3B	16.08
Average	16.46
1C	7.41
2C	11.60
3C	8.48
Average	9.16

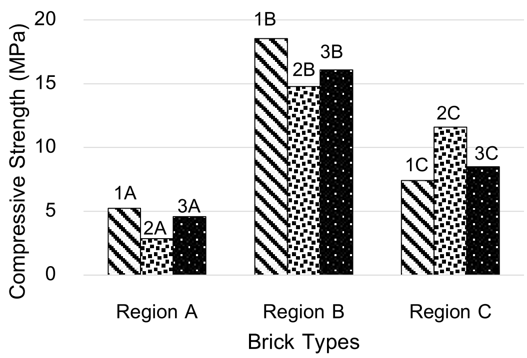

Figure 10 Compressive strength test results

5.2. Modulus of Rupture

Modulus of rupture of CCI bricks were determined by testing three brick samples of each regions under three-point bending loading scheme. The experimental test results are summarized in table 5 and graphical comparison is shown in the figure 11. In contrast to the compressive strength, highest average modulus of rupture (i.e., 1.94 MPa) is observed for CCI bricks collected from region C. The modulus of rupture of region C bricks is found slightly higher than the region B (only 7%) which may be associated with higher amount of red clay in region C bricks as compared with region B. Modulus of rupture (sometimes referred to as bending strength), is a measure of a brick's strength before rupture. Since red clay is cementitious material and a higher amount of red clay may cause large bending of the bricks prior to the rupture of bricks thus resulted into higher modulus of rupture of brick. The lowest values of modulus of rupture is recorded for CCI bricks of region A. The CCI bricks collected from region B showed a moderate value of modulus of rupture as shown in the figure 11.

Table 5

Modulus of rupture

Bricks	Modulus of Rupture (MPa)
1A	0.77
2A	0.72
3A	1.06
Average	0.85
1B	1.73
2B	1.98
3B	1.67
Average	1.80
1C	2.06
2C	1.56
3C	2.20
Average	1.94

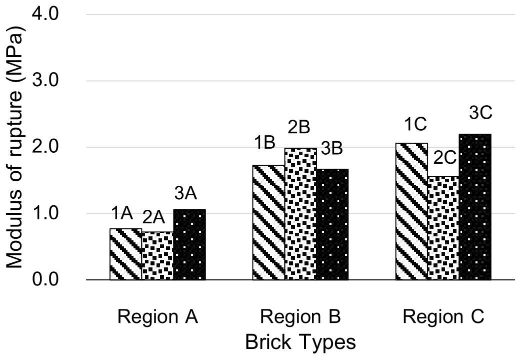

Figure 11 Flexure test results

5.3. Splitting tensile strength

Splitting tensile strength of CCI bricks were determined by testing three brick samples of each regions under single point loading scheme. The experimental test results are summarized in table 6 and graphical comparison is shown in the figure 12. Similar to the compressive strength, highest average splitting tensile strength (i.e., 0.29 MPa) is observed for CCI bricks collected from region B. The lowest values of splitting tensile strength is recorded for CCI bricks of region C. The CCI bricks collected from region A showed a moderate value of modulus of rupture.

Table 6

Splitting tensile strength

Bricks	Splitting tensile strength (MPa)
1A	0.25
2A	0.18
3A	0.22
Average	0.22
1B	0.24
2B	0.32
3B	0.31
Average	0.29
1C	0.23
2C	0.25
3C	0.20
Average	0.23

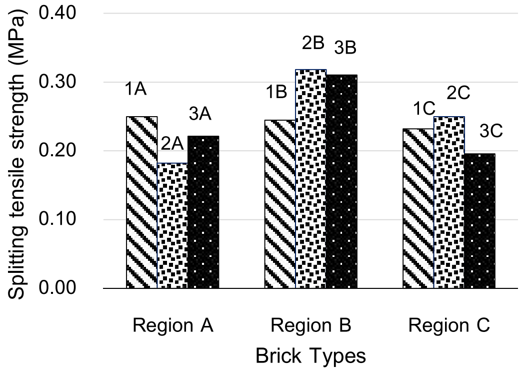

Figure 12 Splitting tensile strength results

5.4. Water absorption capacity

Water absorption capacity of CCI bricks were determined by immersion method. In this method three brick samples of each regions were immersed in water for 24 hours to determine saturated weight. The experimental test results are summarized in table 7 and shown graphically in figure 13. The highest average amount (i.e., 13.0%) of water absorption was observed for CCI bricks of region A. This is indicating that region A bricks are not well compacted (lowest compressive strength is also verifying this assumption) thus having large voids inside due to the absence of sand particles. Large air voids in CCI brick tends to absorb more water. Consequently, CCI bricks collected from region B and C showed quite close values of average absorption capacity of 10. 0% and 10. 1% , respectively. The lower water absorption can be associated with well compaction due to the presence sand as shown in table 2. According to the Thai community product standard 602/2547 [24], the maximum water absorption capacity of bricks is 288 kg/m^3. By comparing with Thai community product standard 602/2547, water absorption capacity of all collected bricks is lower than recommended values, however water absorption capacity of region A brick is relatively close to the standard values.

Table 7
Water absorption test results

Bricks	Water absorption (%)	Water absorption (kg/m^3)
1A	15.15	265.0
2A	14.50	253.0
3A	9.340	160.0
Average	13.00	226.0
1B	9.830	167.0
2B	10.39	171.0
3B	9.840	164.0
Average	10.00	167.0
1C	10.02	174.0
2C	10.34	179.0
3C	10.07	178.0
Average	10.10	177.0

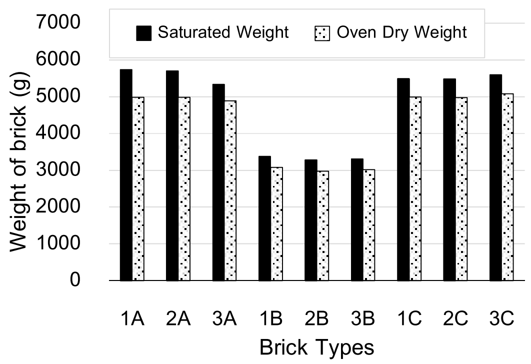

Figure 13 Comparison of absorption test results

5.5. 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 14. An inclined crack in the middle region of CCI bricks were observed in the modulus of rupture test as shown in figure 15. 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 at 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 16. The strain crack line is indicating the pure compression in the brick during splitting tensile strength test.

Figure 14 Typical failure of brick in compression

Figure 15 Typical failure of brick in flexure

Figure 16 Typical failure of brick in splitting tensile test

6. Conclusions

This study reported an experimental investigation on the mechanical properties of cement-clay interlocking (CCI) bricks collected from different provinces or regions of Thailand located over different geological stratum. 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. Experimental results indicate that use of locally available materials and mix design ratio has a significant effect on the mechanical properties of CCI bricks.
2. In general, mechanical properties of cement-clay interlocking bricks collected from region B are found superior than cement-clay interlocking bricks collected from A and C provinces. Only modulus of rupture of region B brick is found slightly lower than region C.
3. Further studies should examine more precise mechanical properties of cement- clay interlocking brick blocks considering uniform mix design ratios along with uniform properties of individual mix contents.
4. There is an urgent need to establish and enforce standard guidelines for codes for CCI brick manufacturing process in Thailand.

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