Development and Behaviour of Interlocking Compressed Earth Bricks in Universiti Malaysia Sabah, Malaysia

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Abstract. Conventional bricks such as Fired Clay Bricks (FCB) contribute to environmental issues due to the production process. Previous study has shown that interlocking bricks have potential as alternative way for sustainable development. The Interlocking Compressed Earth Bricks (ICEB) is a sustainable construction material which all the main constituents locally available and stabilize with Ordinary Portland Cement (OPC). Thus, this study focuses on determination of proper mix design for the ICEB in line with that to reduce the contribution to environmental issues. Six (6) different of cement contents were investigated, which 0\% to 10\% by incremental of 2\%. All the ICEB samples were tested for water absorption and compressive strength at the ages 7, 14 and 28 days. The ICEB with 10\% of cement contents show the highest compressive strength which have exceeded the minimum required stated in BS3921:1985 (5 N/mm\(^2\)) however the water absorption exceeds the allowable limit of 15\% based on MS 76:1972. This study may contribute and act as manual for mix design of the ICEB.

1. Introduction

In order to achieve sustainable development, greener technology and construction materials were produced. The conventional method or materials are not efficient to used nowadays, yet still applicable and practical. The conventional construction materials such as fired clay bricks (FCB) give good result in term of engineering properties but slightly endow to environmental issue such as air pollution and contribute to the global warming by releasing the gases and ashes into the environment from the firing process. Thus, more intention to boost and evolve the conventional became more sustainable. The ICEB were produce as improvise the conventional construction materials.

The ICEB provide advantages in term of environmental and construction matter. This is due to the production process of the ICEB are environment-friendly where only compression method either manual or mechanical is engaged [9]. Thus, no hazard or dangerous gaseous or ashes is emitted. In terms of construction and environment perspective, the ICEB reduce the waste and maximize value, energy efficient and cost effective compared to the conventional bricks [7,12]. Due to the unique design of the ICEB, the installation became more easier by stacking the ICEB without any plastering and can be done by unskilled workers [7]. Without plastering, reduce amount of cement is good for low carbon dioxide release which can lead to lower energy and carbon footprint [2].

Due to the insufficient of knowledge and guidelines, this study was conducted and investigated to produce the ICEB with the best quality. The study proportion of the cement is varied to obtain the optimum content which contribute to the low-cost materials and meets the minimum requirement for load bearing bricks and. Data of this study can be used as a guideline in the production of the ICEB in Sabah.

2. Overview of Interlocking Compressed Earth Brick

2.1. Materials

In order to produce ICEB, three main raw materials needed are clay soil, sand and ordinary Portland cement (OPC). The specific gravity for cement, soil and sand are 3.05, 2.31 and 2.68. For the water absorption soil and sand are 2.75\% and 2.67\%. These materials were tested to determine their
properties. Table 1 and Table 2 show the chemical composition of the materials and properties of the soil. The soil has the highest SiO$_2$ compared to other materials. With proper amount of silica, a good brick can be produced because silica will improve the durability of the bricks [15]. Sand is added into the mixes by reason of clay soil gives high value of plasticity index, thus sand added to reduce the value. In order to bring the most suitable soil for the ICEB with mixture ratio 1:8:2 (cement:soil:sand), 25% of sand is added into the mixes. The addition of the OPC into the mixes are to improve the characteristic of the ICEB. The OPC also acts as soil stabilizer [7,9]. Six proportions of OPC were tested in this study which from 0, 2, 4, 6, 8 and 10%. Water content for the ICEB used in this study is 12%. Increase the water content disrupt the demoulding process as the stickiness of the soil is high due to the amount of water.

![Figure 1. The main materials in the ICEB (a) cement, (b) soil and (c) sand.](image)

The addition of stabilizer can improve the strength and erosion resistance property of the brick. Different stabilizer used other that OPC are fly ash, coir, lime and chemical (NaOH and NaSiO$_3$) [4].

**Table 1**: Chemical compositions for cement, soil and sand.

| Materials | SiO$_2$, % | Al$_2$O$_3$, % | MgO, % | TiO$_2$, % | P$_2$O$_5$, % | SO$_3$, % | CaO, % | Fe$_2$O$_3$, % | K$_2$O, % |
|-----------|------------|----------------|--------|------------|--------------|-----------|--------|----------------|-----------|
| Cement    | 14.53      | 20.57          | 0.66   | 0.10       | 0.29         | 3.66      | 73.42  | 3.26           | 0.38      |
| Soil      | 62.52      | 11.78          | 3.40   | 1.00       | 0.54         | -         | 0.14   | 9.87           | 4.26      |
| Sand      | 62.97      | 3.47           | 0.52   | 0.78       | 0.85         | -         | 5.18   | 8.50           | 5.46      |

**Table 2**: Properties of soils.

| Properties       | Soils |
|------------------|-------|
| Liquid Limit, %  | 47    |
| Plastic Limit, % | 26.75 |
| Plastic Index, % | 20.25 |
| Specific gravity | 2.31  |
| Water absorption, % | 2.75 |

2.2. Production of Interlocking Compressed Earth Brick

The ICEB samples were produced at the Universiti Malaysia Sabah. There are four stages involved in production of the ICEB: (1) Crushing, (2) Mixing, (3) Compacting and (4) Curing. For the crushing stages, the soil must be precisely chosen to get the best performance in term of compressive strength.
The soil collected then dried before the crushing process. Crushing process is needed to ensure that the size of the soil meet the grading requirement. Then the soil will be conveyed to the mixer for mixing process. There are two mixing process involve such as dry and wet mixing process where dry mixing to ensure that the mixture is homogenously and uniformly mixed while the wet mixing is to activate the stabilizer. Beside that to bind the all the materials. In order to get the mixture to be blended homogenously, weight suggested in one session mixing is between 50 – 60 kg. During adding water, the moisture content of the mixture needs to be checked over time to keep the liquid and plastic limit. The mixture then conveyed to compressor where the mixture will be compressed to become the ICEB. The mixture was compressed under 3000 psi to 4000 psi and immediately demould. After the demoulding process, the ICEB allow to dry for 24 hours before curing for the initial setting completed. Curing process will be continued for 28 days so that the stabilizer can undergoes fully hydration process. The method of curing should be taken into account because the ICEB is very brittle at the early stage and the surface of the ICEB easily get eroded by water. Thus, the suitable method is by spraying or sprinkling the ICEB [5,6].

The ICEB are place and store under the shed area in order to prevent the crack and shrinkage due to the rapid loss of water [4]. The cured ICEB will be tested on day 7, 14 and 28 for the properties of the ICEB. During the production of the ICEB no firing process involve. Thus, the ICEB can be considered as environmental-friendly and cost effective since the production is faster than conventional method [1]. For the production process, it is important to take consideration on these matter a) condition of machines, b) moisture content of mixture and c) type of soil and stabilizer.

2.3 Shape and Size
The ICEB have a unique design on the shape since the ICEB consist of tongue and groove which contribute and allow mutual connection also known as the interlocking system. The tongue located at the top while the groove at the bottom surface of the ICEB that allow the bricks to be stacked and installed efficiently [14]. Due to the unique design of the ICEB, period of assembling and stacking process in making wall or partition can be reduced [1]. Since the ICEB produced from compaction method, thus three hollow section in the middle of the ICEB which contribute to the reduction of weight, avoid seepages, to insert utility pipe such as water
pipe and conduit for electrical, to insert vertical steel bar for reinforcement and to pour grout for increasing its stability [7,8].

The size of the standard ICEB are 100 mm in height, 125 mm in width and 300 mm in length which still the range size of clay brick defines by BS 3921:1985 where a masonry unit not exceeding 337.5 mm in length, 112.5 mm in height and 225 mm in thickness. The length of the ICEB is more than that conventional FCB. Due to this difference, construction that use ICEB as construction materials is faster because the number of bricks needed for the construction is less due to the extra length of the ICEB [4].

The ICEB comes with three main types such as standard bricks for wall structure, half bricks for fill in the edge or corner of the wall structure and U-brick acts as lintel or beam as supporting element of the wall structure. Another function for U-bricks are to lay horizontal steel bar for reinforcement as a link and grout to increase the structure stability [16].

![Figure 4. Three types of ICEB (a) standard brick, (b) U-brick and (c) Half brick](image)

Since the ICEB is made from high compression method, thus the weight of the ICEB is high compare to the FCB. Due to this, the ICEB is suits for the internal and external wall since the ICEB can be considered as load bearing bricks.

3. Quality Testing

3.1. Compressive Strength

The compressive strength of the ICEB were determined by tested using Universal Testing Machine 300kN with a loading rate 4 N/mm² in accordance to the requirement of ASTM C67. The ICEB were capped top and bottom so that the bricks are flatten surface. The ICEB will be compressed at the age of 7, 14 and 28 day. Recorded values of compressive strength will be classified according to the requirements of BS 3921. The value of the compressive strength is important as a mark to compare to
The compressive strength of the ICEB is affected by several parameters such as soil types, stabilizer content and compression value applied [13]. The compressive strength of the ICEB can be calculated as follow:

\[
\text{Compressive strength (MPa)} = \frac{\text{Load applied (N)}}{\text{Area of the specimens (mm2)}}
\]  

(1)

**Figure 6.** The ICEB undergoes compression test.

3.2. Density
The density of the ICEB is determined through standard procedure from ASTM C 140. In this study, the compression value is fixed and the amount of OPC in the mixture contribute to the changes on the density of the ICEB. Higher density value indicate that the ICEB is more compact and denser. The density of ICEB can be determined by using equation as follow:

\[
\text{Density, kg/m}^3 = \frac{\text{Weight of the ICEB (in kg)}}{\text{Volume of the ICEB (in m}^3)}
\]  

(2)

3.3. Water Absorption and Moisture Content
Since the ICEB is made of soil consist of sand and clay, thus the water absorption and moisture content need to be monitored. The optimum moisture content of the ICEB is obtained from Proctor Compaction Test. One of the parameters related to the strength and durability of earth blocks is water absorption and water absorption is a characteristic for clay and cement content [3]. As the age of the bricks increase, the water absorption rate is decrease [10]. Water absorption of the ICEB are affected by several parameters such as clay content and cement content [13]. Water absorption can be calculated using equation as follow:

\[
\text{Absorption, %} = \frac{\text{(wet mass – dry mass)}}{\text{dry mass}} \times 100
\]  

(3)

4. Results and Discussions
4.1. Initial Rate Absorption
With the increasing of the cement, the initial rate absorption (IRA) was increasing too. This is due to water demands by the cement for hydration process. The lowest IRA recorded was 0.8 kg/(m2×min) for control brick and the highest IRA is 3.04 kg/(m2×min) for bricks with 10% cement additions. Clay bricks with range of IRA between 0.35 to 3.60 kg/(m2×min) shows the bricks quickly absorb water when contact with moist area [11]. Thus, in order to keep the quality, the ICEB need to be wetted before construction. This is because dry bricks will contribute to the decreasing of the bond strength [11]. In addition, bricks with high IRA will disturb the hydration process of mortar if ICEB is not wet by absorbing the moisture from the mortar. However, wetting the ICEB without proper monitoring will lead to the efflorescence.
4.2. Compressive Strength

In practical, the value of the compressive strength for the ICEB in 7th day competes the minimum value in British Standards requirement 2.8 MPa for pre cast concrete and 5.8MPa for load bearing FCB. Thus, the lowest compressive value recorded is control ICEB and can be considered as non-load bearing bricks since passing the minimum requirement BS 3921. As the age of the ICEB increases, the highest compressive strength value recorded is ICEB with addition of 10% of cement which passing the load bearing minimum requirement for BS 3921 of 5.2 MPa for load bearing FCB. As the value of compression is fixed during the compression stage, thus the addition of cement is contribute the changes in compressive strength trend of the ICEB. The addition of cement as stabilizer leads to the increasing of compressive strength. Other parameter that related to compressive strength are compaction force during manufacturing [7,13].

4.3. Density

The ICEB dense are influenced by the compression value applied during the compression stage. High value of compression value contributes to the high density [13]. In addition, the increasing of cement in the mixture contribute to lower air voids. This is due to the larger surface area of the cement. From figure 9 shows that the density of the ICEB increase with the increasing of OPC taken on day 28. Later age, the density of ICEB is increased [6]. The density of the ICEB increase because the curing process is dragged. The lower air voids due to the hydration products which filling the gap.
4.4. Water Absorption

Figure 10 shows the water absorption of the ICEB decreasing as the addition of the cement at the age of day 28. As the density increased, the air voids are filled thus the absorption of the water is decreased. The water absorption is decreased due to the improvement on the microstructure of the ICEB where more hydration products formed. Based on the figure 10, the water absorption of the ICEB exceed the allowable limit 15% based on MS 76:1972. As discussed in 4.1. in order to keep the quality of the ICEB, the ICEB need to be wetted before application or construction.

5. Conclusion

This study conducted in order to increase the knowledge on ICEB and may contribute to ICEB standard for design and production. The following conclusion can be drawn based on the results:

- Highest Initial Rate Absorption recorded is 3.04 kg/(m²xmin) for 10% addition of cement (10C). Thus, watering needed for the brick at the site before construction start to avoid the bricks absorb moist from the mortar that can cause lose bonding between the mortar and bricks.
- Addition of cement into the mixture contribute to the increasing of compressive strength, initial of rate absorption and density but lower the water absorption value.
- 10% cement addition shows the compressive strength at 7 day passing the minimum requirement for load bearing brick as stated in BS3921.
The water absorption of ICEB exceeds the allowable limits based on MS 76:1972 but can be improved by wetting the ICEB before construction.

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