The Effect of Moisture Content and Curing on the Properties of the Interlocking Compressed Brick

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Abstract. The moisture content and curing condition affect the compressive strength of the interlocking compressed brick (ICB). Higher strength of ICB can only be achieved when the moisture content is at the optimum level and under proper curing method. However, the moisture content of soil is varied and difficult to be identified. In addition, there is no standard of curing method was established for ICB. Therefore, this study investigates the effect of moisture content and types of curing on the compressive strength and water absorption of the ICB samples. Two (2) different moisture contents were investigated, which are the 11% and 18%. All ICB samples were cured under three (3) different curing conditions and tested for the compressive strength, water absorption and density tests. The findings showed that all ICB samples containing 18% of moisture exceeded the minimum requirement of compressive strength (7 N/mm²) based on MS76:1972. Meanwhile, ICB cured under Curing B condition has shown the highest compressive strength and lower water absorption. This indicates that sufficient moisture and proper curing method can produce good ICB brick for use in the building construction.

1. Introduction

The emission of toxic elements from the manufacture of conventional clay bricks lead to the air pollution problem. To overcome this problem, a greener brick which is known as interlocking compression brick (ICB) has been produced through the compression method. With no burning process, this ICB brick is an energy efficient product and therefore, gives no harm to the environment. The raw materials for ICB production are mainly of sand, cement and clay soil. By controlling these raw materials, strength of the ICB can be designed to suit its application in the construction. Other factors such as moisture content and curing type also play important factor in affecting strength of the ICB brick. However, the moisture content of soils is varied and is difficult to be controlled. Improper control of moisture content during the production process will affect the properties of the ICB brick produced. Lower moisture content decreases the compressive strength of the ICB [1], but if too high moisture added to the mix, it will cause difficulties in the ICB production, especially during the demoulding process. Hence, the moisture content must be kept optimum. Most researches suggested the optimum moisture content of the ICB mixture must be within 10 – 13% [2].

On the other hand, the curing process done on the ICB is to overcome excess evaporation which normally results in loss of water, a situation that may disturb the hydration process of cement, with the consequences of reduced strength, durability and cracks arising from early rapid drying and shrinkage [3]. In addition, the ICB needs to be cured in a sufficient period of time to avoid reduction in the compressive strength [4]. Insufficient moisture content and improper curing method will produce low strength ICB. However, there is very limited information has been published which related to the
moisture and curing effect on the properties of the ICB. In addition, there is still no proper guidelines in the production of ICB in construction. As a result, the properties of ICB produced at the production plant is varied. In order to produce good ICB, the effect of moisture and curing on the ICB must be monitored and controlled during the production process. Hence, this study investigates the effect of moisture content and curing on the properties of the ICB produced at the ICB Teaching Factory in Universiti Malaysia Sabah (UMS), Malaysia. Findings of this research can be used as reference in the production of good strength ICB brick for use in the low-cost housing construction in Sabah.

2. Materials and Methods

2.1 Materials, methods and mix design
The materials used to produce the ICB were sand, ordinary Portland cement (OPC), and clay soil. The clay soil was obtained from the UMS area. The properties of the clay soil are shown in table 1. To determine the optimum moisture content (OMC), the Proctor test was performed. The optimum moisture content referring to the moisture of the ICB mixture at which a given soil type will become most dense and achieve its maximum dry density. This test was performed on the soil, and combination of clay soil, cement, and sand (ICB mixture). The soil sample was compacted in a mould for 27 blows using rammer which dropped from height of 300 mm above the soil. The density of the compacted soil was then determined, and after demoulding, the moisture content was measured. This process was repeated for different moisture content. The graph of dry density against moisture content was then plotted. The mix design ratio of the ICB is shown in table 2.

2.2 ICB production
All ICB samples were produced at the ICB Teaching Factory, UMS under three (3) main stages; (1) Preparation, (2) Mixing, and (3) Moulding (figure 1 – figure 5). In the preparation stage, the soil was first dried and then crushed using the crushing machine. Other materials, such as sand, cement and water were weighed based on the mix ratio shown in table 2. After that, the raw materials were fed into the mixer for the mixing process. The raw materials were first mixed in dry condition, then water was gradually added to the mixture until it was homogeneous and uniform in colour. The wet mixture was then conveyed to the compressor for moulding process. The compression force to produce the ICB brick is 43 MPa. After compression, the fresh ICB samples were carefully removed from the compression mould and placed at a temporary area for 24 hours.

![Figure 1. Drying of clay soil.](image1)

![Figure 2. Mixing of ICB raw materials.](image2)

![Figure 3. Moulding process.](image3)

![Figure 4. Placement of ICB at a](image4)

![Figure 5. Hardened ICB](image5)
temporary area after moulding. sample.

| Properties                | Clay soil |
|---------------------------|-----------|
| Liquid Limit (%)          | 44        |
| Plastic Limit (%)         | 25        |
| Plasticity Index          | 19        |

| Curing | Mix Ratio Cement: Sand: Soil | Water (%) |
|--------|-----------------------------|-----------|
| ICB11  | 1: 2: 2.66                   | 11        |
| ICB18  | 1: 2: 2.66                   | 18        |

2.3 Curing
After 1-day production, the hardened ICB samples were placed at an open area under the roof enclosure for curing process. The ICB samples were arranged to have at least 5 cm gap between each other. The curing process was performed using different methods as stated in table 3.

| Curing | Description                                                                 |
|--------|-----------------------------------------------------------------------------|
| A      | Sprinkling with water in the morning and evening for 28 days.               |
| B      | Sprinkling with water in the morning and evening for 7 days, and thereafter cover with tarpaulin until day 28. |
| C      | Complete cover with tarpaulin for 28 days.                                  |

2.4 Testing on the ICB
All ICB samples were tested to determine its density, compressive strength, and water absorption at 14-day and 28-day curing. The density test was carried out based on ASTM C20. In this test, the dimension and weight of each brick were measured. The density of ICB was calculated by dividing the mass of ICB (in kg) to its volume (m³).

Testing of the ICB samples was performed in accordance to ASTM C109. The ICB was capped at both sides (top and bottom) using metal plate (figure 6) to create a flat surface during testing. The loading rate of the test was 5 (N/mm²)/s. The crushing load force corresponding to the failure load for each brick was then recorded. The compressive strength was obtained by dividing the maximum crushing force (N) with the sectional area (mm²) of the ICB.

Water absorption was conducted to determine the amount of water absorbed within 24 hours. In this test, the ICB sample was first dried in the oven for 24 hours. The oven dried ICB was then immersed in the water for 24 hours. Water absorption of the ICB was calculated using Eq.1.
Absorption = 100 x (wet mass – dry mass) / dry mass  

3. Results and discussions

3.1 Optimum moisture content

The Proctor Compaction test was performed to determine the amount of water required to obtain the maximum density of soil. The optimum moisture contents of soil and the ICB mixture (combination of soil, sand and cement) are shown in figure 9 and figure 10, respectively. From figure 9, the optimum moisture content for the soil is 18%. At this value, the maximum dry density is 1689 kg/m³. Meanwhile, the combination of cement, sand and the clay soil (ICB mixture) required much lower moisture content to produce maximum dry density (1785 kg/m³), which is 11% (figure 10). This indicates that the air voids inside the ICB mixture after compaction was lower than the clay soil.

![Figure 9](image1.png)  
**Figure 9.** The optimum moisture content for soil.

![Figure 10](image2.png)  
**Figure 10.** The optimum moisture content for ICB mixture.

3.2 Density of the interlocking compressed brick

The densities of the ICB18 and ICB11 were determined at 14-day and 28-day age of testing. The results are shown in figure 11 and figure 12. Figure 12 depicts that all ICB samples show higher density as the curing age increases to 28 days. The use of OPC cement as stabilizer promotes to the formation of the calcium silicate hydrate (CSH) within the ICB samples [5]. This process is also known as hydration. As the age of curing increases, more hydration products were produced and filled in the voids within the ICB microstructure. Hence, at later age (28 day), the ICB was denser and the density increased.

From figure 11 and figure 12, it is clearly seen that the highest density is given by the ICB18 samples, especially for ICB18 which cured under the Curing B. Since ICB18 has more water than the ICB11, the amount of water to take part in the chemical reaction with the cement was sufficient to produce more hydration products. In addition, Curing B prolonged the hydration process since it prevented the evaporation of water after curing for 7 days. The hydration product not only gives good bonding between the ICB particles, but it is also able to fill in voids within the microstructure and make the brick more pack and denser.

![Figure 11](image3.png)  
**Figure 11.** The density of ICB18 and ICB11 at different curing conditions.

![Figure 12](image4.png)  
**Figure 12.** The density of ICB18 and ICB11 at different curing conditions.

3.3 The effect of moisture content on the compressive strength of the interlocking compressed brick

The results of compressive strength are shown in figure 13 and figure 14. Regardless of the curing condition, all ICB samples containing 18% (ICB18) and 11% (ICB11) of moisture content showed higher compressive strength when the curing duration increased from 14 days to 28 days. The development of strength against the age of testing is due to the formation of hydration product, which increases the bonding of sand and soil within the ICB [6].

As aforementioned in section 1, the optimum moisture content suggested from the previous researcher were in the range of 10 – 13%. However, in this research, it was found that all ICB18 samples have shown higher compressive strength compared to ICB11 at all ages and curing conditions (figure 13 and figure 14). For example, ICB18 samples cured under Curing A, Curing B, and Curing C have higher compressive strength, which are 11% – 27% higher than the ICB11 at 28 days curing.
This is supported by the results obtained in Section 3.2 (figure 11 and figure 12), where ICB18 samples have the highest densities, which indicates that the samples have high compressibility and denser than ICB11. With sufficient amount of water, the development of ICB strength improves due to high degree of hydration. Hence, the bonding between the sand and soil was also improved, resulting in the increase of the compressive strength.

On the contrary, higher moisture content causes the ICB18 brick to have poor appearance. During the production process, it was observed that all ICB18 brick samples were difficult to be moulded compared to ICB11. After moulding, the surface of ICB18 tends to have rough and crumble surface (figure 7). Meanwhile, ICB11 has shown a smooth surface and good in terms of aesthetic value. Nevertheless, at 28 days testing, all ICB11 and ICB18 bricks have exceeded the minimum requirement stated in BS3921:1985 (5 N/mm²) [7]. The ICB18 can also be used as load-bearing brick with strength satisfying the minimum requirement in MS76:1972 (7 N/mm²) [8].

![Figure 11. The densities of ICBs at different moistures and curing conditions for 14 days testing age.](image1)

![Figure 12. The densities of ICBs at different moistures and curing conditions for 28 days testing age.](image2)

3.4 The effect of curing types on the compressive strength of the interlocking compressed brick

Figure 13 and figure 14 show the compressive strength of ICB18 and ICB11, respectively under three (3) different curing conditions for 14 days and 28 days. It was noticed that the compressive strength of both ICB18 and ICB11 showed similar trend when cured under Curing A, Curing B and Curing C. At 14-days curing, both ICB18 and ICB11 showed higher compressive strength after been cured under the Curing C method (complete cover with tarpaulin) (figure 8). This is followed by ICB cured in Curing B (sprinkling with water in the morning and afternoon for 7 days and covered with tarpaulin until 28 days) and Curing A (sprinkling with water in the morning and afternoon for 28 days). The same result was also reported by [7] where the compressive strength was higher when brick was completely covered with the tarpaulin. Complete covering the ICBs with the tarpaulin causes less evaporation of the bricks, therefore the hydration process was able to proceed. However, as the curing duration increases, the moisture reduced as most of the water has been used for the hydration process. Hence, at 28 days curing, the rate of hydration of ICB under Curing C was reduced due to insufficient water for the chemical reaction to occur.

Interestingly, at 28 days curing, the ICB18 cured under Curing B has shown higher compressive strength with 11.8% and 15% higher than Curing A and Curing C, respectively. Similarly, ICB11 also showed similar trend. Sprinkling of water for 7 days is important since it promotes development of strength through the hydration process at early age. The method of covering ICB after 7 days sprinkled with water controlled the evaporation rate, hence there was still enough water for hydration to proceed after the brick hardened. For Curing A, the compressive strength was slightly higher than Curing C but still lower than Curing B. Even though ICBs were continuously sprinkled with water for 28 days, the evaporation of moisture from the brick can still occur. In addition, rate of evaporation depends on the temperature of the surrounding. Therefore, with improper control of water evaporation, the hydration process might be disturbed and slower down the strength development process.
3.5 Water absorption of the Interlocking Compressed Brick

The results of the water absorption of ICB18 and ICB11 are shown in figure 15 and figure 16, respectively. As expected, all ICB bricks have shown lower water absorption at 28 day compared to 14 days of curing. Formation of the hydration products, which filled pores within the brick has led to the improvement of the ICB’s microstructure.

It was also observed that all ICB18 bricks cured under Curing A, Curing B, and Curing C have lower water absorption compared to ICB11. This is understandable since both density and compressive strength of ICB18 samples showed better performance compared to ICB11. Higher density is an indication that the microstructure is more compact and denser. As a result, the compressive strength increased, and the water absorption reduced.

Comparing between types of curing in both figure 15 and figure 16, samples cured under Curing B have shown the lowest water absorption. This result was also aligned with the compressive strength and density results, where all ICB samples cured using Curing B method have shown higher compressive strength and higher density. Since density, compressive strength and water absorption has proportional relationship, therefore it is obvious that with high density and compressive strength, the water absorption will be reduced. Higher density reduces pore volume of the ICB due to formation of CSH, which filled in voids within the brick.

Figure 13. The compressive strength of ICBs at different moisture and curing conditions for 14 days testing age.

Figure 14. The compressive strength of ICBs at different moisture and curing conditions for 28 days testing age.

Figure 15. The water absorption of ICBs at different moisture and curing conditions for 14 days testing age.

Figure 16. The water absorption of ICBs at different moisture and curing conditions for 28 days testing age.
4. Conclusions

- The optimum water content for the ICB production is 18%. With this amount, the ICB has better properties compared to ICB containing 11% water content. However, the mouldability of ICB18 was more difficult than ICB11.
- ICB18 has higher density and compressive strength compared to ICB11. A sufficient amount of water promotes better hydration. The hydration products produced were able to fill in the voids within and make the ICB more compact and denser.
- ICB18 has low water absorption compared to ICB11. High density of ICB18 indicates that the voids within the brick is low due to its high compressibility. With lower voids, the water absorption is reduced.
- ICB cured under Curing B has high density, compressive strength and low water absorption compared to other curing methods.
- The method used in Curing B is more suitable for the ICB production. Sprinkling the ICB with water for 7 days and covering it with the tarpaulin until 28 can control the water evaporation. This ensures that the hydration process can proceed for the strength development of the ICB.
- All ICB11 and ICB18 exceeded the minimum requirement stated in BS3921:1985 (5 N/mm²). The ICB18 can also be used as load-bearing brick with strength satisfying the minimum requirement in MS76:1972 (7 N/mm²).

5. References

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