Review on interlocking compressed earth brick

E S R Abdullah, A K Mirasa, H Asrah and C H Lim

Faculty of Engineering, Universiti Malaysia Sabah, 88400, Kota Kinabalu, Sabah, Malaysia

Email: eddy.syaizul@ums.edu.my

Abstract. Soil is known as the most cost-effective material in construction since available locally and has been used for centuries. Soil widely used throughout the world in brick production including Malaysia. The used of soil in construction can reduce environmental issues and act as a green building material. In addition, high pressure of compression is used to produce the interlocking bricks and it is at high speed of production compared to conventional method which is firing process that can contribute to the environmental issues. To achieve sustainable development, interlocking compressed earth bricks have been developed which can reduce cost, environmental-friendly, and energy-efficient. This paper aims to review the interlocking compressed earth bricks (ICEB).

1. Introduction

Bricks have been developed using varies methods for centuries. There are several types of brick such as fired clay bricks, concrete bricks, and engineering bricks. The conventional bricks that widely used are fired clay bricks (FCB). The FCB is widely used in construction in Malaysia and worldwide. The FCB can be categorized as polluting construction materials since the production of the bricks involves the firing process which results in the emission of gaseous pollutants and ash into the environment. As the concern of awareness on sustainable development and the environmental issue arises, a new and alternative method has been innovated and developed to improve the green properties of the conventional bricks.

To achieve sustainable development, green building materials which are the Interlocking Compressed Earth Bricks (ICEB). The ICEB is also known as Stabilised Compressed Earth Bricks [10] because of the cement or lime addition into the mixes to stabilize the mixes and to improve the properties of the bricks. The ICEB acts as an alternative and highly potent to replace conventional bricks [22]. The ICEB are bricks made from soil, sand, cement (as a stabilizer) and water. These materials will be compacted using high-pressure hydraulic compaction machine where the volume of two becomes one. Thus the production for the ICEB is environmentally friendly because no firing process involves, reduce waste and maximize value [4], energy-efficient and cost-effective to be compared with the FCB. Besides that, the ICEB helps in speed up the construction process. This is due to the construction using interlocking bricks can be done by dry stacking without any mortar plastering by unskilled workers [2,24] compared to conventional masonry which requires more labor hours, highly skilled and highly paid workers. Overall, the ICEB gives benefits to environment and construction matter and has the potential to become alternative method in building construction, in order to achieve green behavior and sustainable development.

The flow of this paper is as follows, where Section 2 describes the ICEB in general, the type of bricks and advantages of the ICEB. Section 3 describes the materials to be used in the ICEB, mix of the ICEB and stages of the ICEB’s production. Section 4 describes the list of tests that need to be conducted to ensure the quality of the ICEB. Section 5 describes the performance of the ICEB including density, strength and water absorption. The conclusion of this paper has been described in Section 6.
2. ICEB

Malaysian standard categorized bricks as units designed to be laid in a bed of mortar. The conventional bricks that commonly used in building work have no attractive appearance. ASTM defines brick as a solid masonry unit of clay or shale, usually formed into a rectangular prism while in plastic condition and burned or fired in a kiln [5]. In contrast, the ICEB are masonry elements obtained by static or dynamic compression of earth or soil in a humid state before immediate demoulding [13,16,25,26]. The ICEB is different from conventional bricks through its production process. The ICEB gains its strength from the compaction process and content of the stabilizer added into the mixes. Combination of compressed process and interlocking system give more benefits and advantages to the ICEB [24].

The main constituent of the ICEB is soil, where the soil is the oldest building material and seldom being used in construction due to the development of new technology in the construction industry. The most suitable soil for the ICEB is laterite soil and clay soil with mixture ratio 1:8:2 and 1:5:5 (cement:soil:sand) [1].

The production process of the ICEB can be considered as eco-friendly and cost-effective since no firing process and fast production. Even the construction system using the ICEB is also effective in terms of environmental, cost and time compared to the conventional construction method.

The ICEB is mortar-less technology, where the absence of mortar bed laying in between the brick during the construction process. Thus, it is very profitable and effective and also reduces the prerequisites for very particular works [3]. The ICEB is assembled dry and stacked on one another that reduces time to complete a building structure elements such as wall or partition and installation of the ICEB needs no skilled labor for stacking process. Construction using interlocking bricks is two times faster than the conventional method even lesser number of workers [2]. In addition, the construction using interlocking brick with solid block also reduced the total construction cost [15].

2.1. Size and Shape of the ICEB

The size of the ICEB are 300 mm (length) x 125 mm (width) x 100 mm (height). The ICEB have three (3) hollow sections in the middle of the bricks which acts to reduce the weight of the brick, to avoid seepages, to improve insulation, to insert utility pipe such as water pipe or conduit for electrical, to insert vertical steel bar for reinforcement and to pour grout for increasing its stability [21]. The ICEB geometry comes with the tongue and groove where the tongue located at the top surface and groove located at the bottom surface. These features allow the bricks to be stacked and installed easily [14].

Several types of the ICEB such as standard brick, half brick, U brick, curve brick, and pattern brick, where every shape and type of bricks have their own purpose. Standard brick, half brick, and U brick are the common bricks to be used in construction building, where standard brick used for the whole wall structure, half brick are used for the edge and U brick used for lintel or beam. Curve brick and pattern brick are used to give fair finishes.

![Figure 1. Several types of the ICEB (a) half bricks, (b) standard bricks and (c) U-bricks.](image-url)
2.2. Materials of the ICEB

The ICEB is formed by mixing the right portion of materials and then compressed using a high compression hydraulic press machine. High quality and strong bricks produced in a few seconds without any firing process [22].

The composition of the ICEB is soil, sand, cement as a stabilizer and water. Using soil as the main component in the ICEB gives benefits such as high thermal mass value and easily accessible since the soil is locally available. Sand is added and blended with soil and act as an aggregate to improve the properties of the ICEB. The high content of clay in the soil gives a high value of plasticity index, therefore sand is added to reduce it.

A stabilizer is added into the mixture to improve the characteristic of the ICEB. The common stabilizers used in soil bricks are cement and lime. The recommended cement content to be added in the mixture is range 4 to 10% in dry weight of soil and 6 to 12% when the mixture stabilized with lime [24], where the addition above 10% of cement and 12% of lime will cause an increase in the costing of the brick production and increase the emission of carbon dioxide (CO\textsubscript{2}) [24].

Water is needed in the mixture to activate the hydration process of the stabilizer. Water must be in optimum content because insufficient moisture content will affect the hydration process of stabilizer or excessive water content will affect the ICEB during demoulding. The optimum content range of 10 to 20% is needed to make the brick and to demould the brick successfully as one unit [18]. However, optimum moisture content is determined with Proctor test.

2.3. The ICEB Production

To produce the ICEB, there are four (4) major stages which include crushing, mixing, compacting and curing. During soil preparation, the soil must be precisely chosen to get the best result of compressive strength. The extracted soil must be dried before the crushing process. Since soil is naturally available, the size of the soil particles is varying. Therefore, the crushing process needs to be conducted because if the soil does not meet the grading requirements, the quality of the bricks is not guaranteed. After drying, crushed soil then delivered to the mixer to be mixed with other materials such as sand, cement, and water. There are two (2) types of mixing processes in the ICEB production, dry and wet mixing process. The purpose of the dry mixing process is to ensure that the materials are mixed homogeneously. Meanwhile, wet mixing process is to bind the materials and as an activator to the stabilizer. Then, mixture will be compressed in high-pressure compaction where two-volume becoming one. The ICEB is immediately demoulded and cured for 28 days if cement was used as a stabilizer. The bricks were cured after the initial setting until enough strength is gained [4].

![Figure 2](image1.png) ![Figure 2](image2.png) ![Figure 2](image3.png)

**Figure 2.** Types of machinery for the ICEB productions (a) crusher, (b) mixer and (c) high-pressure compaction.
3. The ICEB Quality Tests
The compressive strength, water absorption and physical properties of the ICEB are tested in accordance with the related standard in order to check its quality.

For materials testing, particle size analysis of soil is conducted by the sieve method based on standard ASTM D 422. The specific gravity and water absorption for fine particles are referred to ASTM C 128.

Basically, the bricks samples were prepared and tested based on the standards. For the compressive strength test, past researchers proposed that the ICEB can be tested either grinding or capping (ASTM C 109) the surface of bricks under load. For a single unit of the ICEB testing, the ICEB tested using ASTM C 67, EN 772-1:2000, EN 1052-1:2009 and BS 3921-1985 for the compressive strength test. BS3921:1985 stated the minimum required value for the non-load bearing bricks is 2.8 N/mm$^2$ and for the load-bearing bricks is 5.8 N/mm$^2$ clashing with MS 76:1972 stated that the minimum value is 7 N/mm$^2$.

The ICEB need to be tested for water absorption since water absorption will affect the quality of the bricks especially surface erosion. Several standards that can be followed for determining the water absorption are ASTM 90, MS76:19721, EN 772-7 and BS 3921-1985. The highest maximum value of water absorption is stated by Indian standards which are 20%. Compared to ASTM 90, the maximum allowable for water absorption is 17%.

All these tests were conducted to ensure the quality of the bricks and to fulfill the requirements for producing good quality brick.

4. Performance of the ICEB

4.1. Compressive Strength
Generally, the compressive strength of the ICEB is influenced by two factors which are the degree of compaction and age of the ICEB samples. The ICEB samples were produced by pour clay or laterite soil into the mold and apply desired pressure. Most of the ICEB obtained compressive strength below the predetermined level strength by reason of clay that has high mud content. Thus, the ICEB could not bear the compressive stress applied [1]. The ICEB is tested for compressive strength in two (2) conditions which is dry and wet condition. The wet condition is for the worst scenario and the value of compressive strength will be at the lowest strength values.

The optimum stabilizers as mention in section 2.2. Within the suggested range of percentages, the compressive strength of the ICEB passing the minimum requirement of standards. Although the increasing amount of cement will contribute to high compressive strength, as well as contribute to the high emission of carbon dioxide (CO$_2$) which can lead to air pollution and climate change.

A testing method such as mention in section 3 was used to determine the compressive strength since there are no specific standards testing for ICEB.

4.2. Water Absorption and Moisture Content
It is important to determine the water absorption of the ICEB because it is related to the strength and durability of the bricks. The water absorption is a characteristic of cement and clay content [13]. It is found that the water absorption rate is inversely proportional to the age of the bricks [18]. As the age of the ICEB increases, the ICEB loses its water to surrounding and leads to high water absorption. In order to control the water absorption, moisture content of the ICEB must be overseen. The high water absorption of the ICEB also speed up the deterioration of the materials [17].

To ensure the quality of the ICEB, moisture content of the ICEB must be monitored since the moisture content affects the strength development and durability of the ICEB [26]. When the ICEB having high moisture content, the mortars tend to float on the surface without gaining proper adhesion [23]. Higher moisture content also leads to poor appearance due to the difficulties to be demoulded during production process [13]. Water absorption of the ICEB and temperature of surrounding have a
directly proportional relationship [19]. The high temperature will dry the bricks which can prevent good adhesion and proper hydration of cement during construction [26].

4.3. Density
The density of the ICEB can be determined by dividing the mass of the bricks to its volume. The density of the ICEB is related to the degree of compaction and compressive strength [26]. Increasing value in compressive strength is due to the higher value of density [17]. Compressive strength can be controlled through density [26]. Over the past 20 years, it is proven that strength and density consistently related to each other.

At the age of 28 days with consistent curing process, the ICEB was found increased in density due to the hydration products were produced and filled in the voids within the ICEB microstructure [19]. The calcium silicate hydrate (CSH) formed from hydration process of cement which fills the voids. The ICEB containing ultrafine palm oil fuel ash (POFA) have denser structure due to the production of secondary hydration products compared to the ICEB without addition materials [27].

Most researchers found that the density of the ICEB is within range 1500 – 2000 kg/m³ [21]. The density of ICEB can be determined by using ASTM C 140.

4.4. Energy Efficient, Economical and Environment-Friendly Materials
The ICEB consumed less energy than the FCB about 15 – 20% less [24]. This is due to the usage of less cement and a high amount of soil where the soil is locally available and good thermal insulator. Besides, soil also durable, reusable and recyclable.

As a building material, the ICEB shows good thermal conductivity compared to conventional building materials such as FCB [21]. With low thermal conductivity, the ICEB contributes to energy efficiency, cost reduction in materials, cost reduction in heating and air conditioning in winter and summer and environmental-friendly of a building [26].

The ICEB also consider as environmental-friendly materials since the mixture of the ICEB can be modified by added or replaced materials with agricultural waste or quarry waste such as POFA and quarry dust. The ICEB with addition of POFA and quarry dust shows the improvement of the ICEB properties that satisfied the minimum requirement of standards [17,19].

5. Conclusion
Overall, a review on the Interlocking Compressed Earth Bricks (ICEB) has been done in this paper. The use of the ICEB gives more benefits such as green material building, reduce overall cost construction, fair-faced finishes structure, fast project completion, and easy installation. The ICEB can be used as load or non-load bearing system since the ICEB meets the minimum requirement and specification as mention in standards. Study on the ICEB is still in less of number and there has many possibilities and gap of study need to be conducted in order to explore the ICEB in details.

Acknowledgment
The authors would like to thank the Universiti Malaysia Sabah (UMS) and Kementerian Pendidikan Malaysia for providing the Translational Research Grant (LRGS0008-2017) and finally, acknowledge the research and staffing resources provided by the Faculty of Engineering (Civil Engineering) of the Universiti Malaysia Sabah.

References
[1] Abdullah A H Nagapan S Antonyova A Rasiah K Yunus R and Sohu S 2017 MATEC Web of Conf. 103 1-8
[2] Adedeji Y M D 2008 Pakistan J. Soc. Sci. 5 744-750
[3] Al-Fakih A Mohammed B S Nuruddin F and Nikbakht E 2018 IOP Conf. Series: Earth and Environmental Science 140
[4] Assiamah S Abeka H and Agyeman S 2015 Int. J. Res. in Eng. and Tech. (IJRET) 5 1–10
[5] ASTM C 67 Standard test Methods for Sampling and Testing Brick and Structural Clay Tile
[6] ASTM C 128 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate.
[7] ASTM D 422, 2007, Standard Test Methods for Particle-size Analysis of Soils
[8] Bahar R Benazzoug M and Kenai S 2004 Cement and Conc. Composites 26(7) 811-820
[9] BS 3921:1985 British Standard, Specification for Clay Bricks
[10] Divya S Nithya K Manoj Kumar S and Saravanakumar K 2017 Int. J. Eng. Res. and Modern Edu. 6525 226–234
[11] EN 772-1:2000 Methods of Test for Masonry Units. Part 1: Determination of Compressive Strength
[12] EN 772-7 Methods of Test for Masonry Units Part 7: Determination of Water Absorption of Clay Masonry Damp Proof Course Units by Boiling in Water
[13] Irwan J M Zamer M M and Othman N 2016 MATEC Web of Conf. 7 2–6
[14] Sitton J D Zeinali Y Heidarian W H and Story B A 2018 Cons. and Build. Mater. 158 124-131
[15] Malavika I P Nipuna M Raina T R Sreelakshmi A V and Kripa K M 2017 Int. Res. J. of Eng. and Tech. (IRJET) 4 1224–1229
[16] Miranda T Silva R A Oliveira D V Leitão D Cristelo N Oliveira J and Soares E 2017 Cons. and Build. Mater. 155 65–78
[17] Mirasa A K Besar S N A and Asman N S A 2019 Int. J. Adv. Sci. and Tech. 28 89-96
[18] Nagaraj H B Sravan M V Arun T G and Jagadish K S 2014 Int. J. of Sustainable Built Env. 3 54-61
[19] Nasir M M Asrah H Dullah S and Mirasa A K 2019 Int. Recent Trends in Eng., Sci, and Tech. Conf. 89-96
[20] Nasly M A Zakaria Z Abdullah K 2009 Regional Conf. on Env.and Earth Resources 274–282
[21] Ngian S P and Huei L Y 2015 Structural Eng. and Constr. Conf. 2–6
[22] Oti J E Kinuthia J M and Bai J 2009 Eng. Geo. 107 130-139
[23] Patil S H 2016 Int. J. of Res in Eng. and Tech. 3148 2319–2322
[24] Qu B Stirling B J Jansen D C Bland D W and Laursen P T 2015 Constr. and Build. Mater. 83 34–43
[25] Riza F V Rahman I A Mujahid A and Zaidi A 2010 Int. Conf. on Sci. and Soc. Res. 999-1004
[26] Venkatarama Reddy B V Sudhakar M R Arun Kumar M K 2003 Indian Concrete J 77 903-911
[27] Tonduba Y V et al 2019 J. Phys.: Conf. Ser. 1358 012027