The Impact of Various Soil Proportions Towards the Strength of Interlocking Compressed Earth Brick

Y W Tonduba, A K Mirasa and H Asrah

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

Email: yvonnewill2011@gmail.com

Abstract. An interlocking compressed earth brick (ICEB) is a dry-stacked masonry brick with a similar production process to the Compressed Earth Brick (CEB). ICEB mainly consists of clay soil, sand, ordinary Portland cement (OPC) and water. This paper studies the properties of a combined soil (clay soil and sand), which affects the optimum moisture content (OMC) of the mixture and compressive strength of the produced specimens. There are five types of combined soils with mixture ratios of clay (C) soil to sand (S) of C55:S45, C50:S50, C45:S55, C40:S60, C35:S65 and C30:S70. Every mixture ratio shows a different OMC and varies in its compressive strength. The combination soil ratio of C45:S55, which means 45% of clay soil + 55% of sand, produced the highest compressive strength. The compressive strength increases as the clay content decreases and sand content increases. However, as the clay soil content decreased to lower than 45%, the compressive strength starts to decrease. It is due to the lack of plasticity properties from the clay which are responsible for bonding the material particles.

1. Introduction

The construction of buildings using earth bricks is unavoidable. Earth bricks have become a compulsory construction material in the construction industry. Earth bricks have been mainly produced from the natural resources of clay soil and sand for decades [1]. The difference between fired clay bricks (FCB) and compressed earth bricks (CEB) is the manufacturing method. FCB uses the firing method while CEB uses the compressing method. A compressed earth brick (CEB) is defined as a masonry brick which is small in size and has regular and verified characteristics, that are produced by the static or dynamic compression of earth soil in a humid state followed by immediate de-molding [2]. In terms of sustainability, the high temperature kiln for firing the FCB not only consumes a significant amount of energy, but releases a large quantity of greenhouse gases to the environment [3]. In contrast, CEB offers a sustainable alternative method of production which applies the air-dried method rather than the firing method to achieve the final strength [4]. Interlocking Compressed Earth Bricks (ICEB) are also called mortarless bricks. It is a special form of dry-stack brick construction units. ICEB construction combines the benefits of CEB technology and dry-stack interlocking system masonry.

Raw materials to manufacture ICEB are the same as CEB i.e. clay soil, sand, OPC, and water. OPC is maintained at 10% by weight to produce a sustainable and economical ICEB [5]. There are many factors that influence the quality ICEB such as the i) plasticity index (PI) of soil, ii) the optimum moisture content (OMC) of the mixture, and iii) the composition of clay soil and sand mix ratio [6]. Initially, soil physical testing should be performed to ensure the suitability of clay soil for ICEB
production. There are two types of tests that are commonly carried out which are the Atterberg Limit Test and Grain Size Analysis Test. Atterberg Limits is a soil classification test to determine the soil’s Liquid Limit (LL) and Plastic Limit (PL). LL and PL are the water contents at which the mechanical properties of the soil changes. The Grain Size Analysis Test refers to the analysis of the soils sample’s particle size distribution [7]. The analysis of particle size distribution is used to characterize the soil based on the Unified Soil Classification System (USCS). These two common tests are significant in determining the properties of ICEB. Soil with a low PL or LL, and with a properly graded particle distribution will result in an optimum compressive strength for ICEB [8]. The moisture content of the mixture proportions must be high enough in order to lubricate the soil particles and enable them to move around in such a way as to occupy all the voids during the compaction process. However, an excessively high water content would result in voids full of water and will cause compression difficulties. Proctor compaction test is conducted to determine the OMC for the mixture [9]. This study aims to investigate the optimum clay soil and sand mixture composition which will yield the maximum compressive strength of ICEB.

2. Experimental Program

2.1. Material Preparation
Materials to produce ICEB consist of clay soil, sand as fine aggregates, ordinary Portland cement (OPC) as a stabilizer and water. Clay soil used for this study was collected in the Universiti Malaysia Sabah (UMS) land area. The clay soil to be used must be a subsoil which is the layer under the topsoil on the surface of the ground. Excavated subsoil is normally in wet condition, therefore it needs to be air-dried before being crushed into finer particles. Collected sand was bought from a hardware shop. The source of the sand is from the Tuaran River in Sabah. The sand was washed and few large particles were present. After drying, the sand was sieved under a 4.75-mm sieve to get rid of larger sized particles. Ordinary Portland cement (OPC) used was the Cap Gajah brand distributed by Sabah Cement.

2.2. Methodology
The parameters to find the optimum soil composition for ICEB are i) water content which depends on the optimum moisture content (OMC), and ii) various mix ratios of clay soil and sand. The stabilizer OPC was maintained at 10% by weight and the compaction force for compressing the cube specimens was fixed at 43 kN. Soil properties such as the particle size distribution and PI were used to determine the classification of the soil. Standard ASTM D422 test method was used for the soil particle size analysis. A mechanical sieve analysis apparatus was used to determine the percentage of soil passing sieve No. 200. Standard ASTM D4318 was used in determining the liquid limit (LL), plastic limit (PL), and plasticity index (PI) of the soils, where PI = LL - PL. To determine the OMC of the mixture, the laboratory procedures are stated in standard ASTM D698.

3. Results and Discussion

3.1. Soil Classification
Table 1 shows the soil properties for type A (clay soil) and type B (combination of 50:50 ratio of clay soil to sand). Type A soil has values of LL = 48.00, PL = 24.13 and PI = 23.87, while type B soil has values of LL = 33.54, PL = 19.96 and PI = 13.59. According to the plasticity chart classification as mentioned in standard ASTM D2487, type A soil is classified as CL which is low plasticity clayey soil and type B soil is classified as ML which is low plasticity silty soil. Based on the results, it shows that the combination of clay soil with sand helps to reduce the PI value of the mixture. The best composition of soils for ICEB are those with a low plasticity index. Walker has recommended the soil plasticity index to be between 5 and 15 for cement stabilized soil bricks [10]. Soil with a plasticity index of more than 20 is not suitable for ICEB production as it will cause difficulty in compaction and
molding [11]. Many research has found that soil with a plasticity index below 15 is more suited to use cement as a stabilizer [12][13]. Table 2 presents the grain size results of percentage passing sieve with 75 μm diameter (No. 200). The results show that the combination of clay soil and sand is classified as silty sand type of soil.

Table 1. Properties of soils.

| Soil Properties              | A (Clay only) | B (50:50 of clay soil:sand) |
|-----------------------------|---------------|-----------------------------|
| Liquid Limit (LL)           | 48.00         | 33.54                       |
| Plastic Limit (PL)          | 24.13         | 19.96                       |
| Plastic Index (PI)          | 23.87         | 13.59                       |
| Plasticity Chart Classification | Clayey-Low plasticity (CL) | Silty-Low plasticity (ML) |

Table 2. Classification of soils.

| Mixture of clay soil:sand | Passing sieve no. 200 (%) | USCS Soil Classification |
|----------------------------|----------------------------|--------------------------|
| C100:S0                   | 28.11                      | SC-Clayey sand           |
| C55:S45                   | 18.11                      | SM-Silty sand            |
| C50:S50                   | 17.90                      | SM-Silty sand            |
| C45:S55                   | 15.57                      | SM-Silty sand            |
| C40:S60                   | 15.01                      | SM-Silty sand            |
| C35:S65                   | 13.81                      | SM-Silty sand            |

3.2. Proctor Compaction Test

The optimum moisture content (OMC) of every type of mixture was obtained and the results presented in Figure 1. OMC was determined by conducting the proctor compaction test. The plotted graphs show that the OMC of every mixture is different. The mixture ratio of clay soil and sand at C55:S45 has the lowest OMC and starts to increase as the sand component increases up to C45:S55. The ratios of C40:S60 and C35:S65 show almost the same OMC value. Finding the OMC of the soil mixture is to determine the right amount of water to be added to the dry material in order to mold the bricks and eject them successively as one unit [6]. Water in important in the mixture design for two reasons. The first one is to activate the OPC stabilizer for its hydration process. The second reason is the clay soil requires moisture to reach its plastic state, or the state in which it binds together and becomes moldable. A sufficient amount of moisture needs to be added into the mixture design in order to maximize the final compressive strength of ICEB [4].

3.3. Compressive Strength

The compressive strength was assessed at 7, 14, and 28 days curing ages to investigate the development of strength by aging. The compressive strengths of different mixtures of soil ratios are presented in Figure 2. The graph shows that strength does develop with age. The longer the curing time, the better the strength obtained by the specimens. The strength of the specimen increased with an increase in sand content until the strength reached its highest value. The mixture of clay soil to sand at C45:S55 demonstrated the highest compressive strength. However, compressive strength starts to drop when the sand content increases and clay soil content decreases further. The combination soil ratio of 45% clay soil and 55% sand is seen as the optimal mix proportion of soil to be used in ICEB production. The sand content affects the compressive strength of the ICEB design mixture. The higher the sand content, the higher the strength obtained. Nevertheless, sand content that is too high has an adverse effect towards the strength. This might be due to the low clay content which acts as the bonding agent to bind the particles together and form the required brick shape [14] [15].
Figure 1. Optimum moisture content.

Figure 2. Compressive strength.
4. Conclusions
Prior to the production of ICEB, it is recommended to conduct physical properties testing on the soil to be used in the production. The plasticity index (PI) of a clay soil is 23.87, which is considered a high value for the production of ICEB. Therefore, by combining clay soil with sand helps to reduce the PI of the mixture. The optimum moisture content (OMC) significantly affected the compressive strength of the tested specimen. The right amount of water should be added in the mixture so that all the voids are fully occupied to get the optimum dry density of the specimen after compression. The experimental results reported that the optimum ratio of clay soil to sand was C45:S55 which gave the highest compressive strength.

Acknowledgement
The authors gratefully acknowledge the financial support for this research from Ministry of Higher Education Malaysia research grant (LRGS 0008-2017).

References
[1] Naganathan S Mohamed A Y O and Mustapha K N 2015 Constr. Build. Mater. 96 576–580
[2] Halid A Khatijah S Bakar A and Rahman I A 2013 Int. J. Constr. Technol. Manag. 1 22–27
[3] Zhang L 2013 Constr. Build. Mater. 47 643–655
[4] Sitton J D Zeinali Y Heidarian W H and Story B A 2018 Constr. Build. Mater. 158 124–131
[5] Qu B Stirling B J Jansen D C Bland D W and Laursen P T 2015 Constr. Build. Mater. 83 34–43
[6] Nagaraj H B Rajesh A and Sravan M V 2016 Constr. Build. Mater. 110 135–144
[7] Abdullah A H Nagapan S Antonyova A Rasiah K Yunus R, and Sohu S 2017 MATEC Web Conf. 103 1–8
[8] Kwon H M Le A T and Nguyen N T 2010 KSCE J. Civ. Eng. 6 845–853
[9] Rigassi V 1995 Compressed Earth Blocks : Manual of Production I
[10] Walker P J 1995 Cem. Concr. Compos. 17 301–310
[11] Riza F 2011 Aust. J. Basic Appl. Sci. 5 6–12
[12] Alavéz-Ramirez R Montes-Garcia P Martinez-Reyes J Altamirano-Juárez D C and Gochi-Ponce Y 2012 Constr. Build. Mater. 34 296–305
[13] Yu H Zheng L Yang J and Yang L 2015 Constr. Build. Mater. 77 409–418
[14] Kwon H M and Tuan L A 2013 Appl. Mech. Mater. 284–287 1368–1372
[15] Riza F V Rahman I A Mujahid A and Zaidi A 2010 CSSR 2010 - 2010 Int. Conf. Sci. Soc. Res. Cssr 999–1004