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Performance of Compressed Earth Brick with Sodium Silicate as Alkaline Activator

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Abstract: Nowadays, many building materials including concrete and bricks are utilized in the construction of this structure. A lot of pollution is happening especially air pollution caused by production of the materials. Therefore, an alternative of compressed earth bricks (CEB) is used in constructions because it is eco-friendly. The manufacturing of CEB requires compression method unlike common burnt clay bricks. Regarding this matter, a study of using sodium silicate as alkaline activator in compressed brick is conducted. The main objective of the study is to determine the physical and mechanical properties of the brick as well as determining the optimum content of the alkaline activator. The tests involve to determine the properties are density, water absorption and compressive strength tests. 80 bricks with the size of 250 mm x 125 mm x 100 mm are produced for the tests. The ratio used for the brick mixture is 1: 4: 4 (Ordinary Portland Cement to Sand to Laterite soil) where 0 %, 3 %, 6 %, 9 % and 12 % of sodium silicate are used as alkaline activator. The results for each test are recorded for analysis in accordance to British Standard and ASTM. As for density test, the average results obtained ranges from 1900 kg/m^3 to 2000 kg/m^3 for both curing periods. For water absorption, the ranges obtained for both curing periods are between 10 % to 1 3%. For 7-days and 28-days curing period, only CEB with 0 % sodium silicate (control variable) achieved more than 5 N/mm^2 compressive strength.

Keywords: Compressed Earth Brick, Alkaline Activator, Sodium Silicate

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1. Introduction

In average, non-renewable building materials such as conventional bricks consumed 60% of the basic elements mined from the lithosphere [1]. Brick production also contributes significantly to air pollution. Per kilogramme of brick burnt, a brick kiln emits 70g to 282g of carbon dioxide, 0.001g to 0.29g of black carbon, 0.29g to 5.78g of carbon monoxide, and 0.15g to 1.56g of particulate matter. The values vary based on the type of kiln and the type of fuel used during the fire process [2]. Hence, compressed earth brick is a potential approach for reducing pollution. Compressed Earth brick is environmentally friendly because it is made with a manual compaction machine or a high-pressure hydraulic compression equipment [3]. Since soil cement bricks save energy, they have greater engineering qualities than burnt bricks. This is owing to the high energy consumption of brick combustion, and CEB's use of local soil and labour. Despite being larger than burnt bricks, CEB manufacture uses only 25% to 30% of the burnt brick process. In other words, compared to burned bricks, CEB uses 11 times less energy and emits 13 times less pollution [4].

Compressed earth brick (CEB) as shown in Figure 1 is made up from mixed materials which is Ordinary Portland Cement, soil, sand and with addition of water by compression method. CEB is proven as a sustainable alternative for conventional brick in which CEB uses local material in its production. CEB is also known to have good strength, good insulation, less carbon emission and environmental friendly. In addition, laterite soil is suitable for CEB production because it can be found easily in equatorial climate of Malaysia [5]. The objectives of this study are to determine the density and rate of water absorption of compressed earth brick with sodium silicate as alkaline activator as well as to determine the compressive strength of compressed earth brick with sodium silicate as alkaline activator.

Figure 1: Compressed earth brick

2. Materials and Methods

2.1 Material preparation

The necessary materials which are laterite soil, sand, Ordinary Portland Cement (OPC), sodium silicate (alkaline activator), and a little water are prepared. The ingredients are then mixed together for sample production in accordance with the sodium silicate percentage which are 0% ,3%, 6%, 9% and 12%. After the materials have been combined, they are loaded onto the machine that produces the CEBs. The specimens are then cured for 7 and 28 days, respectively. Following that, tests are performed on the specimens, and data is collected and examined. For each test, the average results of the specimens are also determined. The test results are discussed, and a conclusion is reached in this regard. Before measuring the materials, the dry laterite soil were crushed using the crusher machine shown in Figure 2 and then sieved until the particle size of soil passes 1.18mm sieve [5]. The soil are crushed to obtain a fine texture. Sand, OPC and Sodium Silicate (alkaline activator) used in this study are also prepared individually. The function of sand is to provide plasticity to the bricks so that it can be easily molded. Meanwhile, OPC is used to bind all of the materials. Besides that, water used for mixing and curing are obtained from the laboratory.

Figure 2: Crusher machine

2.2 Production of sample

First and foremost, crushed laterite soil, sand and OPC are measured by volume. Figure 3.8 shows the materials are weighed and ready to be mixed. As for the alkaline activator which is sodium silicate, it is measured as a solution according to the percentage stated (0%, 3 %, 6 %, 9 %, 12 %). Wearing gloves when measuring and handling the solution is needed because the solution can be irritating to skin and also has a risk of damage to the eye. Therefore, the solution is handled with care and precautions as well as avoid from touching the eye area. All of the materials are measured sufficiently according to the ratio 1 : 4 : 4. There are a total of five batches in accordance to the alkaline activator percentage. Each batches produce 12 CEB.

After measuring, crushed laterite soil, sand, OPC and water are placed into the mixer as shown in Figure 3. Then, the mixer is switched on to mix the materials thoroughly. When the materials are well mixed, 3 % of sodium silicate (alkaline activator) are added. The materials are mixed again until thoroughly combined. After the mixing process is completed, the opening at the bottom of the mixer are opened to transfer the mixed materials onto the conveyor as shown in Figure 4. The conveyor transports the materials towards the hopper of the compression machine so that CEBs can be formed. Afterward, the materials are loaded into the hopper of the compression machine as shown in Figure 5. The machine will continue to process the molding and compressing of the materials into blocks of CEB. The dimension of the specimens are as stated which is 250 mm x 125 mm x 100 mm. Onto the last step of sample production, the specimens are moved to the curing area as shown in Figure 6. The specimens are left to cured for 7 and 28 days to achieve the optimum strength. Apart from that, all of the steps in the sample production are repeated with the remaining alkaline activator percentage (3 %, 6 %, 9 %, 12 %). When the curing process is completed for each period, the specimens are ready for the the physical and mechanical testing.

Figure 3: Mixer machine

Figure 4: Conveyor and mixer machine

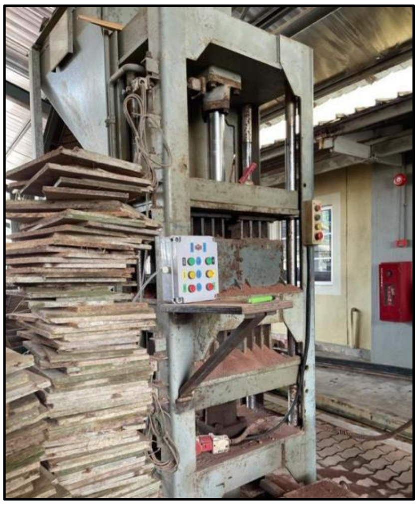

Figure 5: Compression machine

Figure 6: Curing area

Table 1 shows the amount of specimens used for each test according to the percentage and curing period. In this study, a total of 60 CEBs are produced for the testing and is cured for 7 and 28 days.

Table 1: Summary of specimens

Testing day	**7th**					**28th**				
AA (%) / **Test**	0	3	6	9	12	0	3	6	9	12
Water absorption	4	4	4	4	4	4	4	4	4	4
Density and Compressive strength	4	4	4	4	4	4	4	4	4	4
Total	8	8	8	8	8	8	8	8	8	8
	40					40				
	80									

The size of the specimens are 250 mm x 125 mm x 100 mm. The percentage of sodium silicate as alkaline activator used is 3 %, 6 %, 9 %, 12 % and 15 % from water content (not exceeding 15 % from 1 : 4 :4 ratio). The percentage were chosen based on literature review. The physical tests conducted are density and water absorption along with compressive strength as mechanical test. All experiments conducted are in accordance to Standards BS 3921:1985 and ASTM 6140.

2.3 Density Test

Density of bricks varies depending on the clay composition.To obtain density of each CEB, To calculate the density of brick, the general formula of density is used:

$$\rho = \frac{m}{v} \text{Eq.1}$$

Where:

ρ = Density (kg/m^3)

m = $Mass$ (kg)

v = $Volume$ (m^3)

2.4 Water Absorption Test

This test is conducted to determine the water absorption of brick according to the BS EN: 771-1. Lower water absorption implies that the bricks are of higher quality and more resistant to weathering, especially when exposed to rain and sunlight (Nagapan *et al.*, 2017). Water absorption of bricks rely on the clay composition as well as the temperature and duration of firing process. The percentage of water absorption are calculated by using the equation (3.2).

$$\text{Percentage of water absorption, \%} = \frac{\text{Mwb} - \text{Mdb}}{\text{Mdb}} \qquad \text{Eq.2}$$

Where:

M_{wb} = Mass of wet brick (kg)

M_{db} = Mass of dried brick (kg)

Firstly, the specimens are weighed using weighing scale to determine the mass. Then, specimens are immersed in water bath (Figure 7) for half an hour. After that, the wet specimens are weighed and the percentage of water absorption is calculated by using the equation 2. As a precaution, when the specimens are being immersed in the water, the specimens should be fully submerged. Apart from that, to calculate the absorbed water accurately, the specimens should be taken out of the water and held in the air until the water drips stop.

Figure 7: Water bath used to immerse specimens

2.5 Compression test

Compressive strength of CEB increases with decreasing porosity in which it is influenced by the chemical composition and curing process. Compressive strength of brick is restricted by brittle fracture as well as sensitive to flaws associated to large particles, fissures formed during shaping and shrinkage crack. In this test, the equipment needed are vernier caliper, steel ruler, balance (6 kg x 0.1 g) and compressive machine (ELE Compact-1500). This test is conducted to determine the compressive strength of a brick according to BS 3921-1985. First thing first, the dimension of the specimens is measured by using steel ruler and vernier caliper. Then, the surface area and the volume of the specimens are calculated. Onto the next step, the specimens are weighed in order to determine the mass. After that, the specimens are put into the compression machine (Figure 8) and the controller was twisted until the specimens achieve failure. Then, the maximum load applied are recorded and the average compressive strength of the specimens are calculated using equation 3.

$$\text{CS} = \frac{\text{Force}}{\text{Area}} \qquad \text{Eq.3}$$

Where:

CS = Compressive strength (N/mm^2)

Force and area involve in the Eq.3 can be interpret as follows:

$$\text{Force, } F = ma$$

Where:

m = Mass of the object (kg)

a = Acceleration (m/s^2)

$$\text{Area} = (\text{Length x width}) - \prod r_1^2 - \prod r_2^2 \qquad (3.5)$$

Where:

r_1 = Radius of big hole

r_2 = Radius of small hole

Apart from that, to ensure there is no injury while performing the test, the person incharge must stand far from the machine to avoid flying debris if any. Beforehand, to avoid any uneven compressive force distribution causing cracks at below average load, the surface of the brick must be even. Regarding that matter, the production process needed to be precise to avoid failure contributing factor. Besides that, the remaining debris on the surface of the testing machine should be cleaned so that it will not interfere with future test.

Figure 8: Compression machine

3. Results and Discussion

3.1 Density

To obtain the density, the mass of CEB is needed to divide by its volume. Therefore, the mass for each CEB and the dimension for volume calculation is measured. The length, height and width are 250 mm, 100 mm and 125 mm respectively. In addition, the diameter of two different holes of CEB is 70 mm and 30 mm. Hence, the volume is 0.002 m^3 for all CEB.

For 7-Days, the mass of CEB for all variable ranges between 4.2 kg to 4.7 kg. The smallest mass obtained is 4.201 kg which contains 12 % of sodium silicate while the biggest mass obtained is 4.710 kg containing 3 % sodium silicate. In addition, the average mass of the CEB is 4.490 kg. As for density of CEB, the density ranges from 1900 kg/m^3 to 2100 kg/m3 approximately. The lowest density obtained is 1897.5 kg/m^3 with 12 % of sodium silicate while the highest density obtained is 2127.4 kg/m^3 containing 3% sodium silicate. However, CEB with 0 % sodium silicate have the highest average density which is 2093.4 kg/m3 while CEB with 12 % of sodium silicate has the lowest density which is 1978.1 kg/m^3. Besides that, the density of CEB with 3 %, 6 % and 9 % sodium silicate has the average density of 2045.1 kg/m^3, 2035.2 kg/m^3 and 1989.9 kg/m^3 respectively. With that, it can be said that the density obtained for these CEB comply with the standard ASTM 6140 which states that the range of density for a brick is between 1500kg/m^3 to 2000kg/m^3.

For 28-Days, the mass of CEB for all variable ranges between 4.2 kg to 4.7 kg. The smallest mass obtained is 4.207 kg which contains 12 % of sodium silicate while the biggest mass obtained is 4.692 kg containing 0 % sodium silicate. In addition, the average mass of the CEB is 4.461 kg. As for density of CEB, the density ranges from 1900 kg/m^3 to 2000 kg/m^3 approximately. The lowest density obtained is 1900.2 kg/m^3 with 12 % of sodium silicate while the highest density obtained is 2119.3 kg/m^3 with no sodium silicate content. In line with that, CEB with 0 % sodium silicate have the highest average density which is 2066.9 kg/m^3 while CEB with 12 % of sodium silicate has the lowest density which is 1976.8 kg/m^3. Besides that, the density of CEB with 3 %, 6 % and 9 % sodium silicate has the average density of 2032.5 kg/m3, 2022.2 kg/m^3 and 1977.0 kg/m^3 respectively. With that, it can be said that the density obtained for these CEB comply with the standard ASTM 6140 which states that the range of density for a brick is between 1500 kg/m^3 to 2000 kg/m^3.

Based on Figure 9, both graphs have the same pattern which is decreasing. This can be concluded that the density decreases because the mass decreases. The mass of CEB decreases because the cement content for CEB is reduced as the sodium silicate content increases. Overall data for 28-Days also shows a slight difference with 7-Days. Each density data for 28-Days is slightly lower than 7-Days. This may be due to the amount of moisture content decreases as the curing time increases.

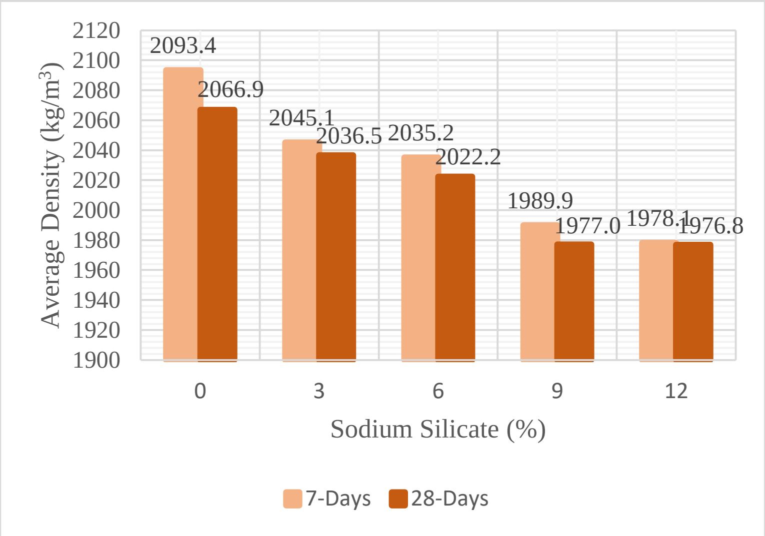

Figure 9: Density of CEB for 7-Days and 28-Days

3.2 Water absorption

To obtain the rate of water absorption, the difference between mass of dried brick and wet brick needed to be divided by the mass of dried brick. The result is then multiply by 100 % to obtain the rate of water absorption in percentage. Besides that, CEB during water absorption test can be seen in Figure 10.

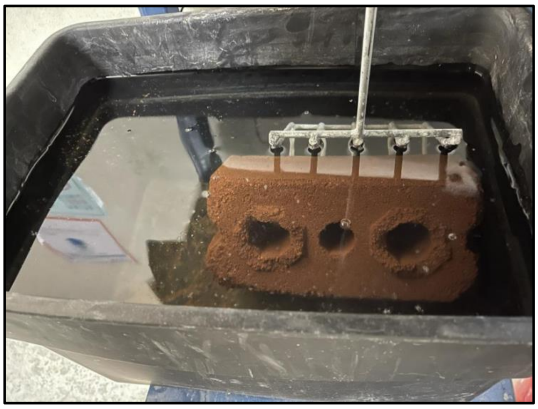

Figure 10: CEB during Water Absorption Test

For 7-Days, the mass of dried CEB for all variable ranges between 4.5 kg to 4.9 kg while the mass of CEB after submerged in water ranges from 5.1 kg to 5.6 kg. On the other hand, the mass of water absorbed by the CEB ranges between 0.4 kg to 0.7 kg. The CEB that absorbed water the most is one of the CEB that contains 3 % sodium silicate. The CEB that absorbed water the least is the CEB containing 9 % sodium silicate. Apart from that, the average water absorbed by the CEB is approximately 0.62 kg. As for the rate of water absorption, it ranges from 9 % to 15 % for each CEB. The CEB with 9 % sodium silicate has the lowest rate which is 9 % while the CEB with 3 % sodium silicate has the highest rate which is 15 %. However, the CEB that has the lowest average rate of water absorption is CEB containing 9 % sodium silicate which is 11 %. Meanwhile, the CEB that contains 3 % sodium silicate has the highest average rate of water absorption which is 14 %. Besides that, the rate of water absorption of CEB with 0 % and 6% sodium silicate has the same value which is 13 %.

Meanwhile, CEB with 12 % sodium silicate obtained 12 % for rate of water absorption. Thus, it can be said that these ranges of water absorption rate for the CEB cured for 7 days comply the standard BS EN: 771-1 which states that the allowable percentage is 15 %. BS EN: 771-1 also states that the percentage should be not more than 17 %.

For 28-Days, the mass of dried CEB for all variable ranges between 4.6 kg to 5.1 kg while the mass of CEB after submerged in water ranges from 5.2 kg to 6.0 kg. On the other hand, the mass of water absorbed by the CEB ranges between 0.4 kg to 0.7 kg. The CEB that absorbed water the most is one of the CEB that contains 0 % sodium silicate which is 0.761 kg. The CEB that absorbed water the least is the CEB containing 9 % sodium silicate which is 0.395 kg. Apart from that, the average water absorbed by the CEB is approximately 0.57 kg. As for the rate of water absorption, it ranges from 7 % to 15 % for each CEB. The CEB with 0 % sodium silicate has the lowest rate which is 7 % while the CEB with 6 % sodium silicate has the highest rate which is 15 %. However, the CEB that has the lowest average rate of water absorption is CEB containing 9 % sodium silicate which is 10%. Meanwhile, the CEB that contains 6 % sodium silicate has the highest average rate of water absorption which is 13 %. Besides that, the rate of water absorption of CEB with 3 % and 12 % sodium silicate has the same value which is 11 %. Meanwhile, CEB with 0 % sodium silicate obtained 12 % for rate of water absorption. Thus, it can be said that these ranges of water absorption rate for the CEB cured for 28 days comply the standard BS EN: 771-1 which states that the allowable percentage is 15 %. BS EN: 771-1 also states that the percentage should be not more than 17 %.

Based on Figure 3, both graph have the same pattern which is about constant. This can be conclude that the rate of water absorption varies when different percentage of sodium silicate is added. Overall data for 7-Days also shows a slight difference with 28-Days. Each data for 7-Days is slightly higher than 28-Days. However, the rate of water absorption of CEB for 7-Days and 28-Days are the same which is 13 %.

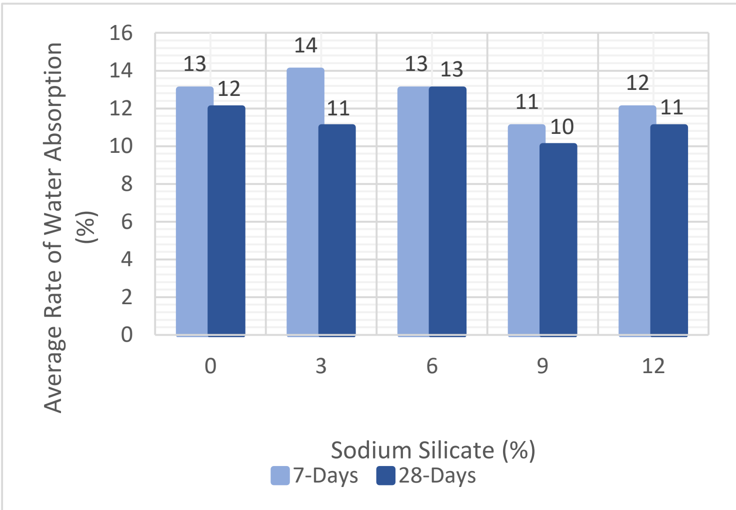

Figure 11: Rate of Water Absorption of CEB for 7-Days and 28-Days

3.3 Compression

To obtain the compressive strength, the load applied during compressive strength test is needed to divide by the area of top surface of CEB. Therefore, the value of load applied by the compression machine The length and width of CEB are 250 mm and 100 mm respectively. Besides that, the radius of two different holes of CEB is 35 mm and 15 mm. Hence, the surface area is 16000 mm^2 for all CEB. Besides that, CEB during compressive strength test can be seen in Figure 12 and CEB after compressive strength test can be seen in Figure 13.

Figure 12: CEB during compressive strength test

Figure 13: CEB after compressive strength test

For 7-Days, the load applied on all CEB during compressive strength test ranges between 60000 N to 200000 N. The smallest load applied is 60700 N which is applied on CEB containing 3 % sodium silicate. Meanwhile, the biggest load applied is 200600 N which is applied on CEB with no sodium silicate content. Thus, the lowest compressive strength obtained is 3.79 N/mm^2 while the highest compressive strength of CEB tested is 12.54 N/mm^2. On the other hand, CEB with 0 % sodium silicate also has the highest average compressive strength which is 11.71 N/mm^2. Meanwhile, CEB with 12 % sodium silicate has the lowest compressive strength which is 4.43 N/mm^2. Besides that, the compressive strength for CEB which contains 3 %, 6 % and 9 % sodium silicate are 4.28 N/mm^2, 5.13 N/mm^2 and 5.35 N/mm^2 respectively. Regarding this matter, CEB with sodium silicate content are classified as non-load bearing brick according to BS 3921:1985 which only requires 2.8 N/mm2. Meanwhile, CEB with no sodium silicate content can be classified as load bearing brick with the requirement of 5.8 N/mm2 based on BS 3921:1985.

For 28-Days, the load applied on all CEB during compressive strength test ranges between 63000 N to 203000 N. The smallest load applied is 63700 N which is applied on CEB containing 12 % sodium silicate. Meanwhile, the biggest load applied is 203700 N which is applied on CEB with no sodium silicate content. Thus, the lowest compressive strength obtained is 3.98 N/mm^2 while the highest compressive strength of CEB tested is 12.73 N/mm^2. On the other hand, CEB with 0 % sodium silicate also has the highest average compressive strength which is 11.96 N/mm^2. Meanwhile, CEB with 12 % sodium silicate has the lowest average compressive strength which is 4.33 N/mm^2. Besides that, the average compressive strength for CEB which contains 3 %, 6 % and 9 % sodium silicate are 4.90 N/mm^2, 5.44 N/mm^2 and 4.33 N/mm^2 respectively. Regarding this matter, CEB with no sodium silicate content can be classified as load bearing brick with the requirement of 5.8 N/mm^2 based on BS 3921:1985. Meanwhile, CEB with sodium silicate content are classified as non-load bearing brick according to BS 3921:1985 which only requires 2.8 N/mm^2.

Based on Figure 14, both graph is quite similar to each other. There is only a slight difference between the data for 7-Days and 28-Days. However, the graph pattern remains the same. In contrast to that, the result of low compressive strength is due to the presence of sodium silicate.

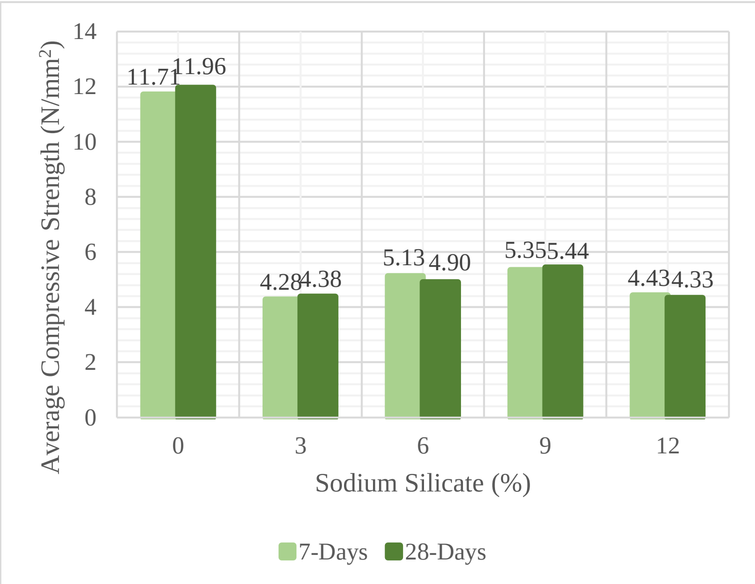

Figure 14: Compressive Strength of CEB for 7-Days and 28-Days

4. Conclusion

To summarize everything that has been stated before, compressed earth brick is a great substitution for common brick. The production of compressed earth brick are able to reduce the pollution causes by the firing process of common brick. It is because the production of earth brick only requires air curing process. Throughout this research, the production of sample as well as testing procedure follows the standard provided. It can be concluded that the objectives are achieved in which the density, rate of water absorption and compressive strength for the CEB are obtained. The three stated testing results comply the standard for a brick. However, regarding compressive strength, the results obtained are not as expected because overall result for bricks with sodium silicate are much lower than control variable brick.

Therefore, it can be conclude that sodium silicate does not contribute in increasing the strength of CEB but rather has the revere effect. This similar situation can also be compared to experiment conducted by Lone *et al* (2015) on the effects of sodium silicate towards properties of concrete. The use of sodium silicate should only be used in certain circumstances because it contributes to loss of strength of concrete in later ages (Lone *et al.*, 2015). Apart from that, according to BS 3921:1985, for the compressed earth brick with 0 % sodium silicate (control variable), it is classified as load bearing brick. Load-bearing brick requires laying the masonry unit one at a time as a layer. The masonry units are bonded together by mortar, which gives the entire structure strength and stability. A load bearing structure's most distinguishing feature is that each wall serves as a load bearing member. As for the other compressed earth brick which contain 3 % to 12% sodium silicate, they are classified as non-load bearing brick. Non-load bearing brick refers to the fact that such elements are not required to support vertical loads. Wind, earthquake, unintentional or nominal lateral stresses can all cause lateral loads to such elements.

5. Recommendation

Recommendations are important in order to provide improvement towards future research. In this case, the application of sodium silicate in compressed earth brick should be reviewed in terms of the percentage. Thus, the recommendations are as follow:

1. To study the relationship between sodium silicate and cement as well as the effects towards each other.

2. To study the acceptable percentage of sodium silicate in compressed earth brick as well as to determine the optimum percentage of sodium silicate that can be used in the production of compressed earth brick.

3. To study the suitability curing process (wet or dry curing process) for compressed earth brick containing sodium silicate.

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