EFFECT OF COMPACTING RATE ON THE STRENGTH PROPERTIES OF SOIL BLOCKS

Conference Paper · August 2015

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Compaction of soil blocks contributes significantly to the strength properties of the blocks. This paper investigates the strength properties of soil blocks produced with different compaction rates. Experiments were conducted to determine the density, compressive strength, splitting tensile strength and erosion properties of soil blocks produced with different rates of compaction speed. The study concludes that although the low rate of compaction achieved better performance characteristics, there is no statistically significant difference between the soil blocks produced with low compaction rate and high compaction rate. However, the study suggests the use of low compaction rate due to its better performance characteristics. The paper contributes to the general body of knowledge in the area of built environment particularly in construction and building materials.

Keywords: compaction rate, compressive strength, density, erosion, soil blocks, tensile strength

INTRODUCTION

One of the factors that affect the strength of earth blocks is compaction. Compaction is the process of mechanically densifying a soil by pressing the soil particles together into a close state of contact so that the entrapped air can be expelled from the soil mass (FM 5-410, 1992). Compaction is an old phenomenon which is called tamping. The tamping used wooden tamper to manually press the earth in a wooden mould to form the blocks. Currently, earth blocks are compacted with compressed earth block machines such as advance earth construction technologies (AECT) compressed earth block machines (AECT, 2009), CINVA-RAM press (Taylor, 2011), BREPAK block making machine (Webb, 1988), among others. These presses are not expensive as they do not require high energy to operate and their maintenance is not complex (Al-Sakkaf, 2009).

The idea of compacting earth is to improve the quality and performance of moulded earth blocks (Guillaud et al., 1995). Soils blocks are often compacted to improve their engineering characteristics, and this can be done in three ways: (a) dynamic compaction, (b) static compaction and (c)

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Danso, H. (2015) Effect of compacting rate on the strength properties of soil blocks *In:* Laryea, S. and Leiringer R. (Eds) *Procs 6th West Africa Built Environment Research (WABER) Conference,* 10-12 August 2015, Accra, Ghana, 387-398.

vibratory compaction for soil blocks improvement (Reddy and Jagadish, 1993). Compressed soil blocks are generally produced by compaction of soil in a hydraulic or electrical block making machine, in which static and control pressure is applied. The strength of compressed earth blocks greatly depends on the compaction energy/pressure (Millogo and Morel, 2012) and the properties of the soil constituent. In recent study by Millogo et al. (2014), the pressure applied in producing the pressed adobe blocks was approximately 2 MPa. In an earlier study on compaction of soil blocks, Lunt (1980) advocated increased forming pressure for more economical block production of 8–16 MPa compared to the usual 1–2 MPa. Another study by Gooding and Thomas (1997) investigated the numerical relation between compaction pressure and cement content, which the range of compaction pressures were from 1 to 10 MPa. In all these studies, the focus was on the compaction pressure.

Since compaction pressure application in producing soil blocks is important to the engineering properties of the blocks, it is imperative to find out if the rate (speed) of applying the compaction pressure could as well affect the strength properties of the blocks. This study therefore, investigates the effect of compaction rate for producing soil blocks on the strength properties of the blocks. Therefore, it is hypothesize that there is significant difference between the soil blocks produced with low compaction rate and high compaction rate.

EXPERIMENTAL METHOD

The experiments were conducted at the civil engineering laboratory of University of Portsmouth. Table 1 reports the characteristics of the soil used for the experimental work. This soil was obtained from Horsea Island, Portsmouth, England. It is defined as low plasticity soil (CL) according to the Unified Soil Classification System (Akbulut, 1999; Kalkan, 2003).

The soil was mixed with water (Figure 1a), weighed and used to fill a steel cylindrical mould. The cylindrical mould was 40 mm in diameter and 125 mm length with a top piston presser of which the mixed soil was compressed to a length of 80 mm with Tinius Olsen (Figure 1b) obtaining as cylindrical specimen of 40 mm by 80 mm (Figure 1c). A number of specimens were produced with compaction rates of 1 mm/min, 5 mm/min, 10 mm/min and 15 mm/min. These compaction rates were selected because they provide a range between a very low speed and a very high speed for compacting soil blocks. The specimens were then dried in an electronic oven at a temperature of 30 ^{O}C (Figure 2). Four different types of tests were conducted which includes density, compressive strength, splitting tensile strength and drip. These test were selected because they provide a wide coverage of testing for engineering properties of soil blocks.

Table 1: Soil characteristics

Properties	Value
Atterberg limits	
Liquid limit (%)	33
Plastic limit (%)	25
Plasticity index	8
Soil classification	
USCS	CL
Compaction	
Maximum dry density (Mg/m^3)	1.83
Optimum moisture content (%)	11.8
Particle size (%)	
Gravel (>2000 µm)	8
Sand (75–2000 µm)	64
Silt (2–75 µm)	16
Clay (<2 µm)	12
Chemical composition (%)	
SiO_2	76.6
TiO_2	0.97
Al_2O_3	10.53
Fe_2O_3	3.24
MnO	0.05
MgO	1.58
CaO	0.37
Na_2O	0.73
K_2O	2.26
P_2O_5	0.16

Figure 1: Cylindrical Specimen preparation process

Figure 2: Drying of specimen

Dry density of the specimens were determined in accordance with BS EN 771-1 (2011). The specimens were further dried at constant temperature of approximately 110 ^{O}C in an oven for 48 hours. After, the dimensions of each specimen were taken and the overall volume computed. The specimens were then weighed and the density of each specimen calculated from Equation 1.

$$p = m/v \qquad (1)$$

Where: ρ is the density; m is the mass (kg); and V is the volume (m^3).

Compressive strength test was conducted in accordance with ASTM C39-96 (1996). The test was made with testing machine (Tinius Olsen) with maximum capacity 50 KN for which three specimens were tested for each compaction rate. Each specimen was placed uprightly on the base plate of the testing machine and carefully centred (Figure 3a). The testing machine applied load at a rate of 0.05 $N/mm^2/s$ until the block failed (Figure 3b). The maximum load at which the specimen failed was recorded and the compressive strength determined from Equation 2.

$$f_c = Pmax/\pi r^2$$

(2)

Where f_c is the compressive strength; *Pmax* is the maximum load sustained by the specimen; and r is the radius of the specimen.

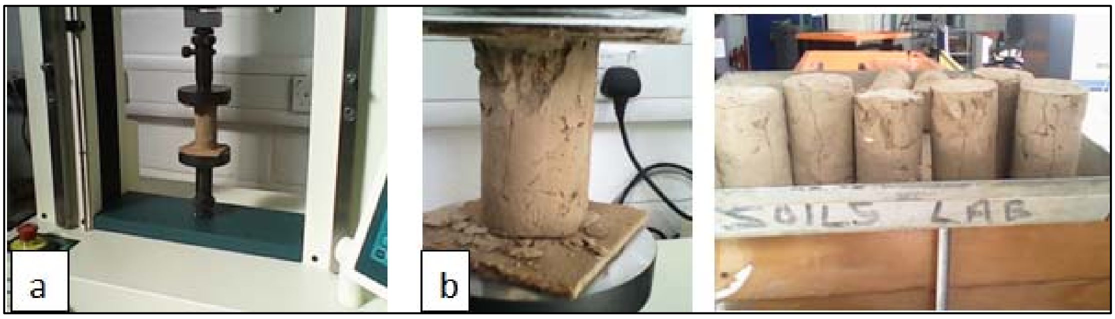

Figure 3: Compressive strength test process

Tensile strength test was conducted in accordance with BS EN 12390-6 (2009). Each specimen was placed longitudenary in the test jig of the Tinius Olsen, for which load was applied till the specimen failed (Figure 4). The maximum load at which the specimen failed was recorded and the slitting tensile strength determined from Equation 3.

$$f_t = 2P/\pi Ld \qquad (3)$$

Where f_t is the splitting tensile strength; P is the maximum load sustained by the specimen; d is the diameter of the specimen and L is the length of the specimen.

Figure 4: Tensile strength test process

Erosion test was performed using Drip (Geelong) method to determine the rate of erodability of the specimen. The test was conducted in accordance with New Zealand Standard (NZS 4298, 1998). The equipment (Figure 5a) was setup with container containing water for which 100 ml mark from the top was noted (Figure 5b). Wettex (J-Cloth) of 16 mm wide (Figure 5b) was placed on the container to soak and transmit the water onto the specimen. The specimens were placed at an angle of 27^{O} at the base and 400 mm vertically away from the J-Cloth, from which water (100ml) was dropped for between 20 minutes and 1 hour. The depth of the pit created on the specimen (Figure 5c) was then measured and the Erodability Index determined.

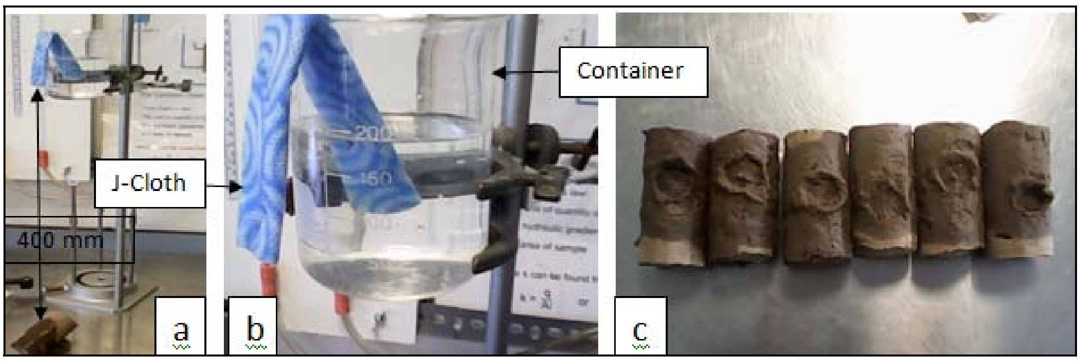

Figure 5: Drip (Geelong method) test process

Table 2: Compaction rate result

Compaction rate (mm/min)	Sample	Dry Density (kg/m³)	Compressive strength (MPa)	Tensile strength (MPa)	Erosion (mm)
1	1	1931	3.10	0.43	6.00
	2	1895	3.50	0.48	7.50
	3	1857	3.20	0.57	5.00
	Mean	1894	3.30	0.49	6.20
	Std Dev	38	0.23	0.07	1.26
5	1	1925	3.70	0.29	8.00
	2	1899	2.70	0.47	6.00
	3	1845	2.60	0.48	7.00
	Mean	1890	3.00	0.41	7.00
	Std Dev	41	0.62	0.11	1.00
10	1	1904	2.40	0.34	7.00
	2	1872	3.20	0.56	9.00
	3	1821	2.70	0.49	6.00
	Mean	1866	2.80	0.46	7.30
	Std Dev	42	0.37	0.11	1.53
15	1	1916	2.50	0.36	8.00
	2	1873	3.10	0.44	7.00
	3	1825	2.70	0.42	9.50
	Mean	1871	2.70	0.41	8.20
	Std Dev	46	0.28	0.14	1.26

RESULTS AND DISCUSSION

Dry Density

Details of the result obtained from the dry density test are presented in Table 2. The results show a closely related average density among the different compaction rates, between 1894 kg/m^3 and 1866 kg/m^3. This was expected due to the equal mass of the mix used for producing each specimen. Similar result was obtained in the study by Chan (2011), which the non-baked specimens did not undergo obvious density change. The density is the relationship between the volume and the mass of the blocks, and therefore shows how compact the blocks are. The dry density is largely a function of the constituent material's characteristics such as moisture content at pressing and the degree of compaction effort applied (Walker, 1995). This implies that the compaction rates may have some influence on the density of the blocks. Although there was slight difference in the density among the compaction rates, the result indicates that the lower rate of compaction achieved the highest density. This implies that the slower the application of compaction load the better the arrangement of the material constituents, making the block denser.

Compressive strength

Figure 6 presents summary of the compressive strength test results. The details of the results can be found in Table 2. The results indicate that the average compressive strength decreased with increase in compaction rates. Implying that the higher the compaction rate the lower the compressive strength of the blocks. The reduction could be attributed to the reduced density of the blocks as the compaction rate increases. This shows a clear relationship between the compressive strength and the density of the soil blocks, which recorded decrease in their values with increased compaction rate. This aligns with Gooding and Thomas (1997) assertion that a given increase in density will result in a greater increase in strength.

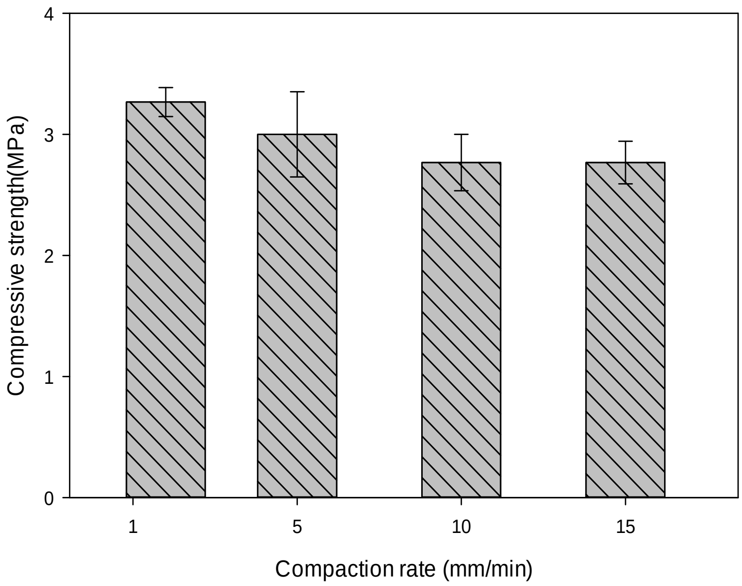

Figure 6: Compressive strength test result

There was about 19% increase in the average compressive strength of the lower (1 mm/min) over the higher (15 mm/min) compaction rate. However, One Way Repeated Measures Analysis of Variance (ANOVA) test result at 95% confidence interval (Table 3) indicates that the differences in the mean values among the different compaction rates are not great enough to exclude the possibility that the difference is due to random sampling variability. There is therefore not a statistically significant difference (p =

0.491) in compressive strength among the different compaction rates of the soil blocks.

Table 3: Summary of test of significant difference (One Way RM ANOVA)

	Compressive strength (MPa)	Tensile strength (MPa)	Erosion (mm)
N	3	3	3
Missing	0	0	0
F	0.907	2.211	0.990
p (Sig.)	0.491	0.188	0.458

Significant at 0.05 (p-value)

Splitting tensile strength

The summary of the splitting tensile strength test result is presented in Figure 7. Details of the results can be found in Table 2. The trend of the result is similar to the compressive strength, however, the 10 mm/min speed recorded an increase in tensile strength over both 5 and 15 mm/min compaction rates. The lower compaction rate recorded the highest strength while the highest compaction recorded the lowest as in the case of compressive strength. This trend can also be linked to the result of the dry density, meaning there is a relationship between the tensile strength and density as well as the compressive strength. This means the lower compaction rate application makes the soil particles arrange very well by eliminating bigger pores in the soil matrix, which contributes to the increase resistance of the material against splitting failure.

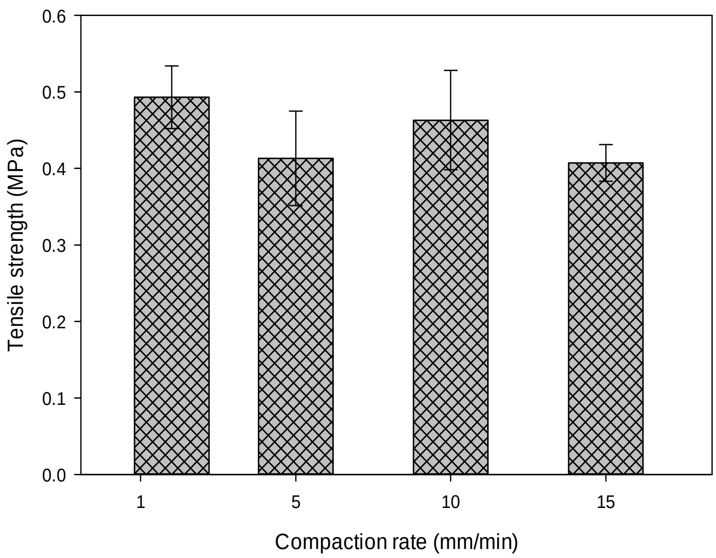

Figure 7: Tensile strength test result

There was about 20% average tensile strength increase of the lower compaction rate over the higher compaction rate. There was similar trend in the compressive strength results. The One Way ANOVA test result (Table 3) indicates that there is not a statistical significant difference ($p = 0.188$) between the compaction rates of the soil blocks.

Erosion test

Summary of the erosion test results are provided in Table 4, while the details can be found in Table 2. It can clearly be seen from the results that the average depth of pit increased with the increase in compaction rates. This shows a relationship with the results of the density test, where density of the blocks reduced with increased compaction rates. This suggests that densification of the blocks affects the rate of the erosion of the soil blocks. The low rate of compaction increased the density of the soil blocks with reduction in the erodability rate. This means that the lower the compaction rate of producing soil blocks the lower the effect of erosion by rain or water on the blocks.

Table 4: Drip Test Results

Compaction rate (mm/min)	Average depth of pit (mm)	Erodability index (E_I)	Rating
1	6.2	3	Erosive
5	7.0	3	Erosive
10	7.3	3	Erosive
15	8.2	3	Erosive

Keys: E_I 1=0 (None-erosive), E_I 2=0<5 (Slightly erosive), E_I 3=>5≤10 (Erosive), E_I 4=>10 (Very erosive)

There is also a relationship between the strength test results and the erosion results. The trend of the test results for compressive strength and drip are similar, as in both cases there were reduction in strength and erosion resistance with increase compaction rate. The results show that the average depth of pit for all the compaction rates were within erodabilty index of 3, which means they were all erosive and therefore failed erosion test (NZS 4298, 1998). However, the low compaction rate performance was better than the higher rates. Conversely, the test of significant difference (Table 3) indicates that there is not a statistically significant difference ($p = 0.458$) among the compaction rates of producing the blocks.

CONCLUSION

The aim of this study was to investigate the effect of compaction rate for producing soil blocks on the engineering properties of the blocks. Based the above findings, the following concluding remarks can be made:

- The lower compaction rate for producing soil blocks obtained a better performance characteristics in terms of physical, mechanical and durability. Thus, 1 min/mm compaction rate recorded the highest density, compressive strength, splitting tensile strength and the erosion resistance of the blocks.
- There was good relationship between the test types. Thus, the compressive strength test result could be associated with the density test result of the blocks. There was also a similar trend in the test results of compressive strength and the tensile strength. Similarly, there was a common trend in the test results of the density and the erosion.
- Test of significance by One Way RM ANOVA at 95% confidence interval for all the test types suggested that there was no a statistically significant difference among the different compaction rates of producing the soil blocks.

The study therefore concludes that although the low rate of compaction achieved better performance characteristics, the hypothesis is rejected, indicating that there is no statistically significant difference between the soil blocks produced with low compaction rate and high compaction rate. This study has demonstrated that there is not much effect on the strength properties of soil blocks produced from low and high compaction rates, but suggests to researchers and practitioners to choose low compaction rate due to its better performance characteristics. Manufacturers of compressed earth block machines may also consider producing machines that do not use high rate of compaction, since it will not improve the strength properties but only consume high energy. Another important factor of making soil blocks is the type of pressure applied, further studies on the use of static and dynamic forces in production of soil blocks are therefore recommended.

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