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The Formulation of Non-Fired Bricks with Na-Based as Stabilisers and Sand as Additive

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Abstract: Carbon Dioxide (CO_2) emission to environment was one of the problem that has been a headache to every country due to the effect that was release to the environment. CO_2 effect air pollution because of the emission of greenhouse gasses and other pollutants which came from fired bricks. This is because, fired bricks at high temperature can emit the CO_2. Thus, to solve this problem the studies of non-fired bricks has been done. The combination of laterite, sodium silicate, sodium hydroxide, water, and sand were the substance that being used for making non-fired bricks in this studied. Both of the substance which is sodium hydroxide and sodium silicate were alkali activators. It was the alkaline solution that acts as an activator in the geopolymerization process to give an effect on the non-fired bricks. The geopolymer can increase the strength, durability and workability of non-fired bricks. The effect of mix proportions of various ratio of Na_2SiO_4/NaOH (0.9,1.1,1.3,1.5,1.8) on mechanical properties of bricks were investigate. The result showed that the last mix proportion which was 1.8 was the best ratio related to our research between laterite soil (LS) bricks and laterite soil-sand (LSS) bricks. The method that has been used to determine this result was came from water absorption and compressive strength tests. The result shown, the compressive strength for both bricks for Na_2SiO_4/NaOH ratio of 1.8 were 11.5% and 12.3% respectively. This is due to the presence of sodium silicate in the solution which had more than sodium hydroxide, thus it lead to silica gel that can increase the compressive strength of the bricks. The laterite soil- sand (LSS) bricks was higher than laterite soil (LS) brick was prior to the addition of sand in the bricks. Thus, based on Malaysian standard these bricks can be used at partition wall and loadbearing bricks class 1.

Keywords: Non-Fired Bricks, Compressive Strength, Water Absorption

1. Introduction

Bricks has been the oldest material that been discovered and it was made by hardening the dried mud in the sun. Non-fired bricks were a new type of bricks that were rising in construction industry to

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develop the industry to a new level. The manufacturing of fired bricks had problems and it was due to the emission of CO_2 to the environment which happened when bricks was fired at high temperature. The effect of CO_2 to an environment was, it could produce air pollution and embodied energy, thus it gives a negative impact [1]. Thus, the manufacturing of non-fired was made which can help to counter the impact of fired bricks to the environment. In addition, the non-fired bricks also were produces to achieved the Sustainable Development Goals (SDG) based on the objective of SDG which was climate change and sustainable consumption and production.

Furthermore, the formulation of non-fired bricks was made with the combination of laterite soil, alkali solution which was sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) with an addition of water and sand. Alkali activator materials was owned by geopolymers. Geopolymer was used in non-fired bricks because geopolymers have a wide variety of characteristics such as high comprehensive strength, low shrinkage and low thermal resistance [2]. Alkali solution act as stabilisers in these studied and based on previous study, the increasing value of sodium silicate in alkaline solution leads to more silica gel which increased the compressive strength of the bricks [3]. Furthermore, the geopolymerization occurs when sodium hydroxide and sodium silicate was mixed with laterite soil, water and sand which acts as a binder.

Moreover, NaOH alone cannot boost the compression strength thus, the use of Na_2SiO_3 can affect the workability, setting time and compression strength of the activated mixture. Researchers found that smaller effects have been found on NaOH compared to the content of the Na_2SiO_3. The ratio of $NaOH/Na_2SiO_3$ can also affect the weight of the bricks with the increasing number of days. The weight was increased because of the exposure due to the absorption and exposed liquid. Furthermore, the addition of sand in this study was due to its ability to prevent bricks from cracking, shrinking, and also can help to increase the bulk and strength of the bricks. Sand reduce shrinkage that occur in drying because sand particle opposed the shrinkage movement.

In addition, temperature for fired bricks usually was range between 800-1100°C but for this study the temperature of non-fired bricks was 50°C and 200°C. Non-fired brick was choosing to cure at 50°C for 48 hours while 200°C for 24 hours. According to the Zhang et. al., the curing of 48 hours at 50°C can increase the compressive strength of bricks but after 48 hours, there were no further improvement. [4] This was because in the first 48 hours, Si and Al ions was dissolve to the alkaline solution. Si and Al ions formulate aluminosilicate gel thus resulting to the improvement of high strength in bricks. Furthermore, Zhang et. al., also reported, the sample without elevated temperature possessed the lowest compressive strength and temperature that elevate from 50°C can increase the compressive strength. Thus, the used of 200°C temperature in bricks for another 24 hours give a positive impact to the bricks. It used only 24 hours because after 24 hours, the temperature of 200°C can experience a decrease in ultimate compressive strength. But, in 24 hours, 200°C temperature can give a very good value of compressive strength.

Moreover, the standard requirement needed by non-fired bricks to achieve the strength of bricks followed the specification of British Standard and Malaysian Standard. [5]. Table 1.1 and Table 2.3 shows the British Standard and Malaysian Standard for water absorption and compressive strength. The water absorption and compressive strength test were performed to determine the characteristics of non-fired bricks. The characteristic that needs to be found were durability, workability and strength of bricks. Water absorption test can determine the durability of the bricks such as the quality and behavior of the bricks while the compressive strength can determine the value of the load that bricks can withstand when facing failure in the form of cracks and fissures.

Table 1.1: Classification of brick for British Standard

Class	Compression strength (N/mm^2)	Water absorption (%)

Engineering A	70	4.5
Engineering B	50	7.0
Damp-proof course 1	5	4.5
Damp-proof course 2	5	7.0
All others	5	No limits

Table 1.2: Classification of brick for Malaysian Standard

Designation	class	Average compressive strength (N/mm^2)	Average water absorption (%)
Engineering brick	A	69.0	4.5
	B	48.5	7.0
Loadbearing brick	15	103.0	No specific requirements
	10	69.0	
	7	48.5	
	5	34.5	
	4	27.5	
	3	20.5	
	2	14.0	
	1	7.0	
	Partition	1.4	
Non-loadbearing brick	Internal wall	5.2	
Bricks for damp-proof course	DPC	As required	4.5

Lastly, the problem that had cause to manufacture non-fired bricks was firing the bricks at high temperature has been found to give a bad impact on the environment due to emission of GHG but, non-fired bricks can tackle this problem thus the development of this study was required. Non-fired bricks produce strength of bricks from the alkaline activator which was Na_2SiO_3 and NaOH that act as a binder, thus the bricks were not required to be fired at high temperature to produce strength. In addition, water absorption and compressive strength tests were performed in the process of making non-fired bricks to test the characteristics of the bricks. But, the lack of studies of non-fired bricks characteristic was found. Thus, the manufacturing process of bricks was important to determine the characteristic of bricks. Furthermore, the objectives of studied was to determine the compression strength and water absorption characteristics of non-fired bricks samples and also to formulate the best ratio of materials mixture for non-fired bricks production as field application considerations.

2. Methodology

The materials and methods section are describing all the necessary information that was required to obtain the results of this study. Below shows the mixing ratio used for this study.

Table 3.1: Mixing ratio for LS bricks

No.	Clay (g)	Na_2SiO_3(g)	NaOH(g)	Water(g)	Na_2SiO_3 / NaOH
1.	1500	97.5	105	225	0.9
2.	1500	105	97.5	225	1.1
3.	1500	112.5	90	225	1.3
4.	1500	127.5	82.5	225	1.5
5.	1500	135	75	225	1.8

Table 3.2: Mixing ratio for LSS bricks

No.	Clay (g)	Na_2SiO_3(g)	NaOH(g)	Water(g)	Na_2SiO_3 / NaOH	Sand(g)
1.	1387.5	97.5	105	225	0.9	112.5
2.	1387.5	105	97.5	225	1.1	112.5
4.	1387.5	112.5	90	225	1.3	112.5
3.	1387.5	127.5	82.5	225	1.5	112.5
5.	1387.5	135	75	225	1.8	112.5

3.1 Materials

This soil has been obtained from industry which is RCS Company which was used after the soil was dried. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) were both from May Chemical Sdn. Bhd. in Rawang, Selangor. Quartz sand used in this study is natural white sand which has been sieve to size 2mm. The sand is provided by university which is UTHM in Pagoh, Johor.

3.2 Methods

3.2.1 Procedure of bricks sample

Firstly, the dried clay was weighed and put into a bowl of water and NaOH, Na_2Si0_3, additional water and sand was also weighted according to the ratio design. After that, NaOH, Na_2SiO_3 solution and additional water was mixed for 3 – 4 minutes' maximum. The mixing solution then was poured into a dry clay in mixer bowl and was mixed thoroughly for 3-5 minutes. The 2.9 kg fresh mixture then was weighed and the steel mould in the dimensions of 215 mm of length, 96 mm in width and 65 mm in height was filled with the fresh mixture. The mould must be firm enough to withstand the pressing. To make it easier to demould, the mould was greased.

Next, the hydraulic press was used to compress the bricks at pressure of 3 MPa for 60 – 80 seconds and then, the whole mould is moving away from hydraulic press to demoulded and trimmed to half-size bricks and the weighted of brick was recorded. After the bricks was trimmed, the dimension of bricks was obtained. The bricks were then placed in 50^{o}C oven for 48 hours after it was shaped. Lastly, the bricks were move to 200^{o}C oven for another 24 hours after 50^{o}C curing wasdone. The bricks then were cool for 12 hours at room temperature.

3.2.2 Water absorption

Water absorption test is the test where it can determine the moisture content of the bricks as percentage of the dry weight. The strength of bricks can be reduced due to insufficient water for the hydraulic reaction thus it fails to bond the mortar and water. In addition, the strength and durability of bricks can change if bricks absorb more water. Next, the procedure of water absorption was provided by Malaysia Standard, MS 76: 1972. The process of water absorption was done by drying the sample at 105^{o}C for one night. Then, the sample was taken out and weighed and recorded as W1 for every brick using electronic balance. The sample then was immersed in cold water using curing tank with temperature of 15-20^{o}C for 24 hours. After that, the sample was removed from water and the sample was wiped using cloth. Lastly, the bricks were weighed using electronic balance as W2 for every sample

$$\text{Water absorption} = \frac{W2-W1}{W1}\ X\ 100 \qquad eq\ 1$$

3.2.3 Compressive strength test

Compressive strength test is the test where the load was applied on the bricks using a Universal testing machine (UTM). The test is done to determine the measurement of the maximum amount of load that the bricks can bear before crush. The excellent result of the test can be determined if the value of the strength is not below minimum strength of compressive strength which is 20%. The test is done according to procedure provided by Malaysia Standard, MS 76: 1972.

The bricks are placed on the universal testing machine between plated with the plywood placed under and above the bricks. The thickness of the plywood is approximately 3mm thick to ensure the specimen uniform bearing was not capped. The requirement that had to pay attention to during the test was, the plywood must be placed more than the dimensions of brick in 5mm to 15mm and then the clean plywood is used in every test. The speed neededfor the test is 0.4 - 0.5 mPa according to industry and the sample is applied without shackles. The rate of the load was maintained until it failed and the maximum load was recorded.

$$\text{Compressive strength} = \frac{\textit{maximum load}}{\textit{average load}} \qquad Eq.\ 2$$

3. Results and Discussion

The results and discussion present the data and analysis of the test done to obtain the characteristics of non-fired bricks. There were two bricks that was being discuss in this chapter which laterite soil (LS) brick and laterite soil-sand (LSS) bricks. The test that being discuss was water absorption and compressive strength test.

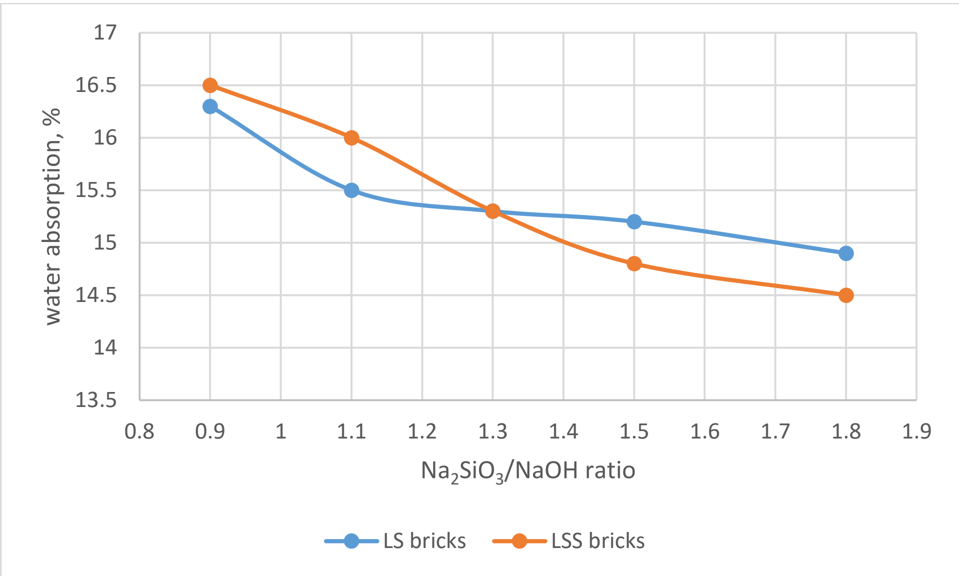

Figure 4.1: Graph of water absorption against $Na_2SiO_3/NaOH$ ratio

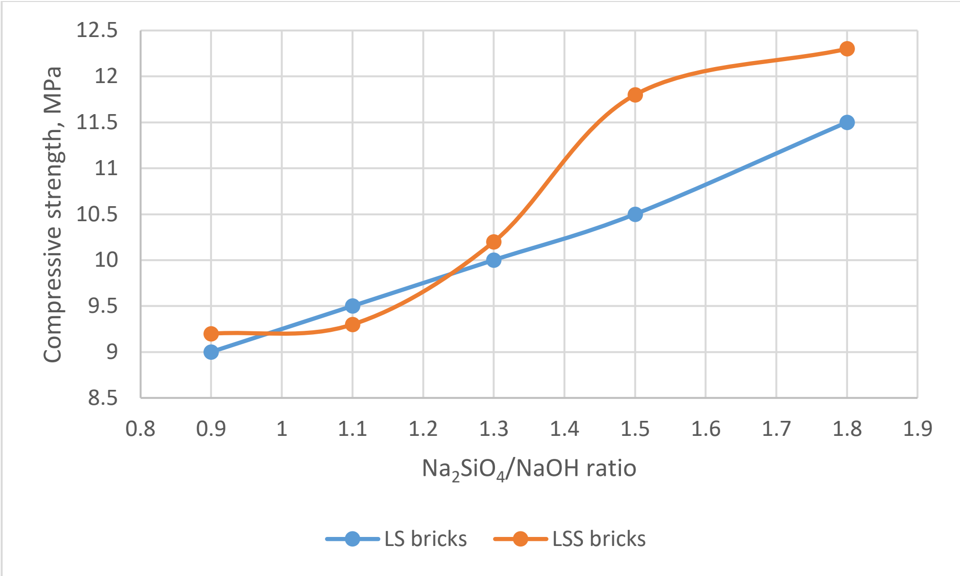

Figure 4.2: Graph of compressive strength against Na_2SiO_3/NaOH ratio for LS bricks

The graph in Figure 4.1 and 4.2 shown the result of water absorption and compressive strength against Na_2SiO_3/NaOH ratio for LS and LLS bricks. The best mix ratio for this studied was 1.8 because it had the lowest value of water absorption and highest value of compression strength. Thus, the result of 1.8 ratio shows the water absorption value for LS and LLS bricks was 14.9% and 14.5% respectively While, the value of compressive strength value of LS and LLS bricks was 11.5MPa and 12.3MPa respectively. Based on the graph, the result shown the decreasing value of water absorption must be affected due to the increasing of compressive strength of bricks. Based on the previous studies, this was because the higher the strength of bricks, the lower the water can penetrate into the bricks. This was related to the porosity of particle as water was absorbed by pores in the bricks which means that the strength was higher when less pores was connected which indicated the strength of bricks. [6]

In addition, the ratio of NaOH/Na_2SiO_3 also play a role in the cause of the rise of value for non-fired bricks. The ratio of 1.8 had more Na_2SiO_3 and NaOH/Na_2SiO_3 ratio was the alkali activator that help to achieve the high compressive strength of bricks in the presence of geopolymer. Based on the previous study, geopolymerization occurs when the sodium ions act as an alkaline activator which later produce the aluminosilicate gel that acts as the binder. In addition, if the ratio of sodium silicate was more than sodium hydroxide, it can lead to more silicate gel which increase the compressive strength of the bricks. This was reason why the increasing of ratio can increase the compressive strength of the bricks. But, the compressive strength of bricks can be reduced at some point because of the excessive alkali content which retards the geopolymerization process.

Furthermore, Figure 4.2 also shown the value of compressive strength for LS bricks was higher than LSS bricks which was 11.5 MPa and 12.3 MPa respectively. The compressive strength for was found to be increased for LLS bricks because it contained 7.5% sand addition. According to the Nagaraj H.B., this was because any gradation of sand could show a significant in influence of strength of laterite soil-sand mixture. This can be explained as sand was one of the silica materials. Silica sand can improve the compressive strength of pure geopolymer paste. This because sand enhance the composite's porosity and minimise cracking due to the presence of silica in sand. Furthermore, the small increasing in compressive strength can be contribute to the small value of sand that was added in the mixing. Thus, value of sand can be increase to get the higher compressive strength.

Moreover, the result obtained for water absorption and compressive strength shown the negative correlation between both data. A decrease in water absorption was accompanied by a corresponding increase in graph. This shown the materials was durable due to the value of water that absorb into the bricks. This was the reason the bricks were increased in terms of compressive strength. Other than that, in LS and LSS bricks, compressive strength was also affected due to the presence of leakage during compression process. Leakage happened because of the void that presence during compression process between base and mould. Figure 4.4 shown the materials leakage at mould of bricks. Thus, some of the value of compressive strength was loss due to the presence of leakage.

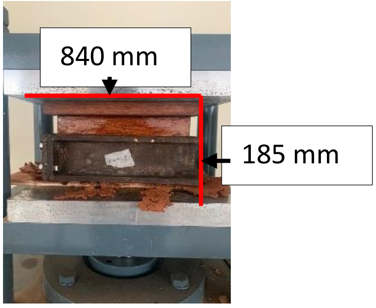

Figure 4.3: Leakage of materials

Next, Figure 4.3 shows the result of water absorption for controlled sample of LS and LLS bricks. The picture captured the condition of bricks after 24 hours. The difference condition of bricks between before and after it was place in the box was obvious which cause by the pressure of water. After 24 hours was done, the condition of bricks can be considered as porous since the bricks was crumbled after it was taken out from water. While, Table 4.1 shown the result of compressive strength for LS bricks and LSS bricks. The value of compressive strength for both bricks was 3.6 MPa.

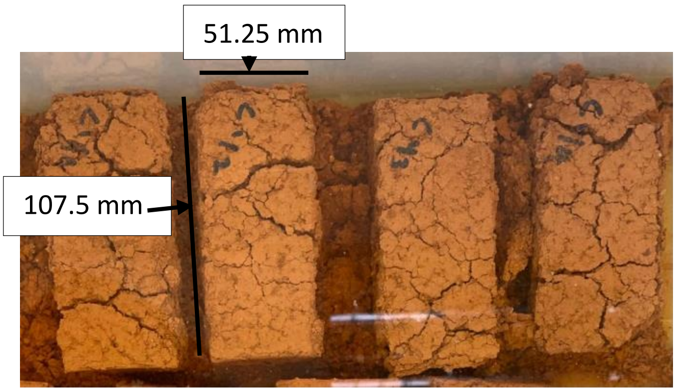

Figure 4.4: Water absorption test for LS bricks control samples

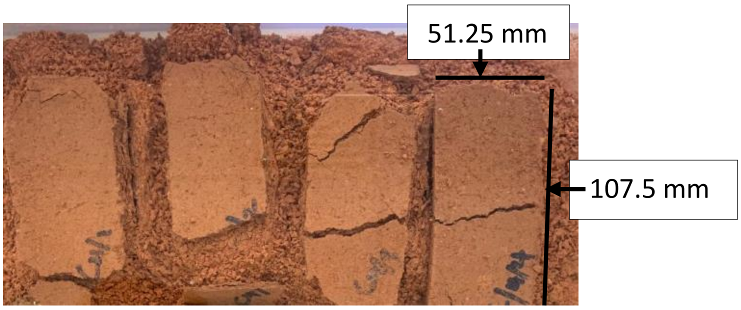

Figure 4.5: Water absorption test for LLS bricks control samples

Table 4.1 Compressive strength of controlled sample

Type of soil	Sample no.	Length (mm)	Width (mm)	Area (mm)	Force (kN)	Compressive strength (MN/m^2)	Average compressive strength (MN/m^2)

LS	1	105.3	49.7	5233.41	20.314	3.7	3.6
	2	105.5	54.4	5739.20	68.998	3.6	
	3	104.9	51.5	5402.35	66.119	3.7	
LSS	1	109.2	50.7	5536.44	19.242	3.5	3.6
	2	106.5	50.5	5378.25	19.078	3.5	
	3	97.1	51.4	4990.94	21.569	3.9	

Next, Figure 4.3 shows the result of water absorption for controlled sample of LS and LLS bricks. The picture captured the condition of bricks after 24 hours. The difference condition of bricks between before and after it was place in the box was obvious which cause by the pressure of water. After 24 hours was done, the condition of bricks can be considered as porous since the bricks was crumbled after it was taken out from water. While, Table 4.1 shown the result of compressive strength for LS bricks and LSS bricks. The value of compressive strength for both bricks was 3.6 MPa.

Based on table above, the value of compressive strength for controlled sample LS bricks and LSS bricks was less than value of bricks with stabilisers. This can be explained as stabilisers acts as binder that connect the materials together. The overall average of value of compressive strength was lower than 5 MPa and it cannot meet the standard requirement of strength for the bricks. Thus, it cannot be used in construction industry. In addition, the effect of this strength also can be seen based on water absorption test which the presence of severe crack was formed on the bricks in 24 hours. Thus, the bricks had to add stabilisers which was acts as a binder to make sure the compressive strength of the bricks can be increase and achieve the standard requirement strength for Malaysian and British Standard.

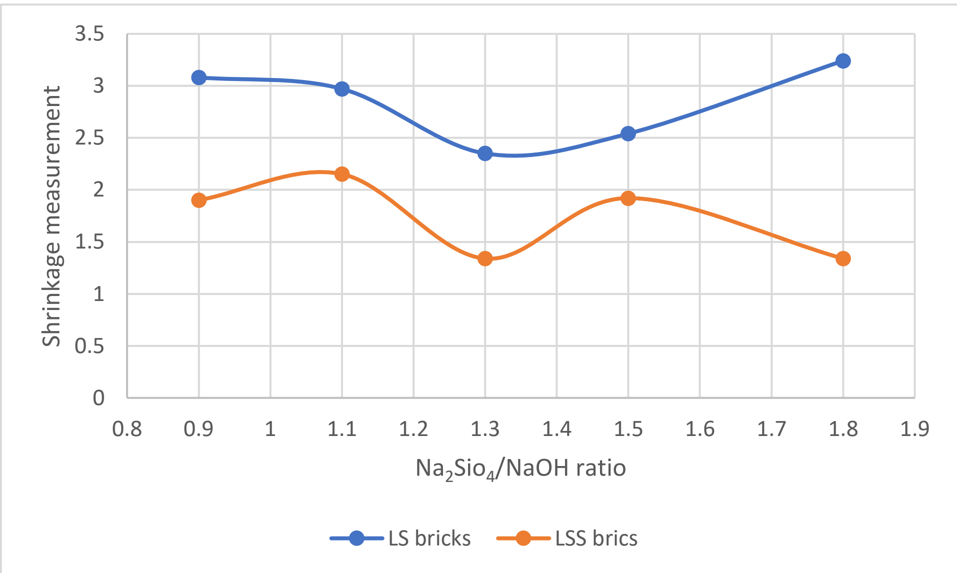

Figure 4.5: Graph of shrinkage measurement

Figure 4.4 shown the data of shrinkage measurement for LS bricks and LSS bricks. The highest value of shrinkage measurement in LS data was at ratio 1.8 which was 3.24% while in LSS brick is at ratio 1.1 which was 2.15%. Shrinkage happened when the heating process were occurred thus it change the microstructure of bricks. The value of LSS lower than LS bricks due to the existence of sand in the bricks. Based on previous study, the addition of sand prevented the bricks from shrinking. This was because sand particle opposed the shrinkage movement. This result shown the advantage of sand addition in the bricks for non-fired bricks. In addition, the value of shrinkage measurement for LSS bricks followed the standard of dimension tolerance which is ±2%. This was a good advantage for the LLS bricks as it can increase the grade of the bricks.

4. Conclusion

The value of compressive strength for LSS bricks was much higher than LS bricks. The value of compressive strength and water absorption in LSS bricks was 12.5 MPa and 16.5% while LS brick is 11.5MPa and 16.3% respectively. This was because the presence of sand in LSS bricks tied the joint of the materials together when it filled the porosity. The best ratio for this studied was 1.8 ratio based on the value of compressive strength. In addition, based on the standard of Malaysian, the bricks can be made into loadbearing bricks which was for partition wall and class 1 bricks, while for nonloadbearing bricks it can be made into internal wall. This was a good result for the production of non-fired bricks which it also can benefit the company. This was because, the LS bricks and LLS bricks had a possibility and potential to be develop for Malaysian Market and it could be used as an innovation for the company. Lastly, these had been recommended to be continued to studies until the optimum value of ratio can obtained and it also was recommended to increase the percentage of sand in the bricks to get the highest value of compression strength for the bricks.

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