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Palm Oil Fuel Ash (POFA) and Ground Granulated Blast-furnace Slag (GGBS) Lightweight Concrete Block

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Lightweight concrete has density in the range of 400 kg/m3-1900kg/m3. The application of lightweight concrete in this country including the lightweight concrete block. However, the use of the concrete lead to the increasing demand of the cement, carbon emission and finally causing the environmental problem. Hence, there are many researchers find the alternative on reducing the use of cement as the main material of the concrete. Malaysia as the country that increased the economy by the agricultural field and industrial country produce a lot of waste as Palm Oil Fuel Ash (POFA) and Ground Granulated Blast-furnace Slag (GGBS). However, the agricultural waste and the industrial waste has the pozzolanic characteristics as the replacement cement materials. Hence, the research has conducted to determine the percentages chemical composition of the POFA and GGBS compared to the cement, the compressive strength of the lightweight concrete block and the properties of the block assembling. The testing has been conducted to achieve the objectives are XRF Test, Compressive Strength, Density, Water Absorption, and Prism Test. The testing was conducted on the sample with the size of 250mm x 125mm x 100mm. The density result of the block stated that the density of blocks less than 1900kg/m3. The percentage of water absorption is less than 20% also affected the compressive strength result to be in the range of 6.9 MPa-17.3 MPa and show the block can be used as the non-structural wall through the cracking failure and prism compressive strength. Hence, GGBS and POFA are effective as the cement replacement materials in terms of density, water absorption and compressive strength.

Keywords: POFA; GGBS; lightweight concrete block; XRF Test; Compressive Strength; Density; Water Absorption; Prism Test

I. INTRODUCTION

The lightweight concrete is used widely in the construction industry. There are many structures in this country using concrete in order to gain more stability within a longer period. Generally, concrete has a higher fire resistances ability than wood and steel. The cost of the construction by using concrete seem to be lower than using the steel because the using of steel need to be covered by two fire resistances plane which more costing than using the concrete. However, the using of concrete is heavy to the workers in Malaysia. Hence, there are new development research that introduces the lightweight concrete in order to increase the workability of concrete.

The research on the effectiveness of waste materials as the Palm Oil Fuel Ash (POFA) and Ground Granulated Blast-furnace Slag (GGBS) is expected to be the replacement of cement in the construction field due to the use of more cement will lead to the higher Carbon emission. The new method is used to manage this type of waste material in order to encourage of the green technology development in this country by reducing the cost to dispose the agricultural waste material.

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The objectives of the study are to determine the chemical composition percentage of POFA and GGBS compared to the cement besides to determine the compressive strength of Lightweight Concrete Block and find the properties of block assembling by using Prism Test. The engineering properties in terms of density, water absorption, compressive strength and cracking failure would present the effectiveness of POFA and GGBS in Lightweight Concrete Block.

The foam concrete is the concrete that classified as the lightweight concrete block (Ramamurthy *et al.,* 2009). The air-voids are entrapped in mortar by suitable foaming agent will reduced the density of the concrete. The practical range densities of lightweight concrete is between 1350 kg/m^3 and 1900 kg/m^3 (Hospital *et al.,* 2016). The application of lightweight concrete can be classified in Table 1 (Wibowo, 2017).

Table 1. The division of lightweight concrete according to usage and requirements (Wibowo, 2017)

Author	Type of Lightweight Concrete	Weight per volume (kg/m^3)	Compressive strength (MPa)
Neville and Brooks (1987)	Lightweight concrete retaining heat (Insulating Concrete)	<800	0.7 to 7
	Lightweight concrete for masonry (Concrete Masonry)	500-800	7-14
	Lightweight concrete structures (Structural Lightweight Concrete)	1400-1800	>17
Dobrowolski (1998)	Concrete with Low Density (Low-density Concrete)	240-800	0.35 to 6.9
	Medium-strength lightweight concrete (Moderate-strength Lightweight Concretes)	800-1440	6.9 to 17.3
	Lightweight concrete structure	1440-1900	>17.3
SNI 03-3449-2002	Lightweight concrete for very light structures	<800	-
	Lightweight concrete for lightweight structures	800-1400	6.89 to 17.24
	Structural Lightweight Concrete	1400-1860	17.24 to 41.36

The Palm Oil Fuel Ash is a product about 5%, by weight of waste material of the palm oil after through the extraction process in the form of biomass fuel to boil water for generates steam for electricity and the extraction process in palm oil mill which is consist of palm oil fibres, shells and empty fruit brunches. The total amount of fresh bunches processes by over four hundred palm oil mills are approximately 87.5 million tonnes. Approximated 61.1 million tons of solid waste by-products in the form of fibres, kernels and empty bunches are produced, which is about 70% of fresh fruit bunches processed (Thomas, 1991). The properties of POFA that can react with calcium hydroxide (Ca (OH)2) due to content silica oxide through the hydration process which is deteriorated to concrete and the pozzolanic reactions and produce more calcium silica hydrate (C-S-H) which is a gel compound as well as reducing the amount of calcium hydroxide (Muthusamy *et al.,* 2014). The supplier of POFA from different palm oil mill resulting to different percentages of chemical properties. The chemical of different POFA used in research works as Table 2.

Table 2. Chemical composition percentage of POFA (Awalludin *et. al.,* 2015; Tangchirapat *et. al.,* 2009; Eldagal, 2008)

Chemical Composition	Awal (%)	Tangchirapat (%)	Eldagal (%)
Silicon Dioxide (SiO_2)	43.60	57.71	48.99
Aluminium Oxide (Al_2O_3)	11.50	4.56	3.78
Ferric Oxide (Fe_2O_3)	4.70	3.30	4.89
Calcium Oxide (CaO)	8.40	6.55	11.69

A research has been conducted by replacing 10%, 20%,30%40% and 50% of POFA by weight of Portland Pozzolan Cement. The results summarised the potential use of the POFA in foamed concrete production. Despite a decline in the strength of concrete with the addition of POFA, the loss of concrete compressive strength by adding 50% POFA is only about 30-40% compared to that control specimen (Muthusamy *et al.,* 2014). The compressive strength is consistently decreased by increasing POFA content in the concrete mix. The percentage of reduction in compressive strength due to the addition of POFA in foamed concrete compared to the normal foamed concrete without POFA as shown in Figure 1.

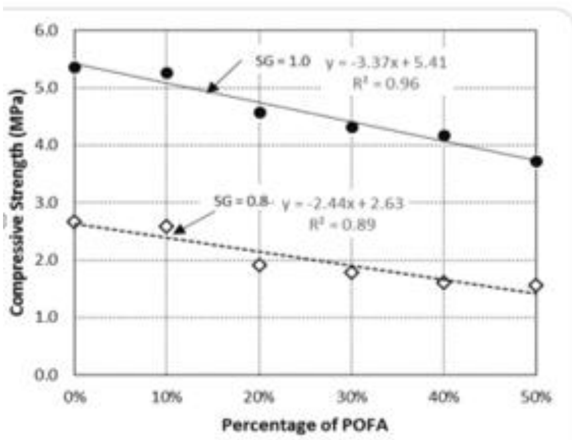

Figure 1. The compressive strength foamed concrete with all variations of POFA (Munir *et al.,* 2015)

Ground Granulated Blast-furnace Slag (GGBS) is a by-product of the iron in the blast furnace. The expansion of steel industry in Malaysia leads to the production of GGBS as waste products. The GGBS is non-metallic product consisting silicates an Alumina Silicates of lime which will react as cement with water. The use of GGBS improved the characteristics of the pore structure after going through the appropriate curing (Naresh & Karisiddappa, 2013).

The advantages of using the GGBS is reduction in the heat of hydration and minimise of thermal cracks. The GGBS is used to make durable concrete structure in combination with ordinary Portland cement and other pozzolanic materials (Sooraj, 2013). Besides that, the use of GGBS as the cement replacement material leads to a reduction of CO_2 as refer to Figure 2 show that GGBS improve the strength of the concrete for early strength (Naresh and Karisiddappa, 2013). Table 3 shows the chemical percentages of GGBS (Muthusamy *et al.,* 2014).

Table 3. Chemical percentages of GGBS by previous study

Chemical Composition	Percentages (%)
Silicon Dioxide (SiO2)	16.34
Aluminium Oxide (Al2O3)	6.95
Ferric Oxide (Fe2O3)	5.38
Calcium Oxide (CaO)	60.84
Magnesium Oxide (MgO)	2.32

Source: Nagendra, 2016

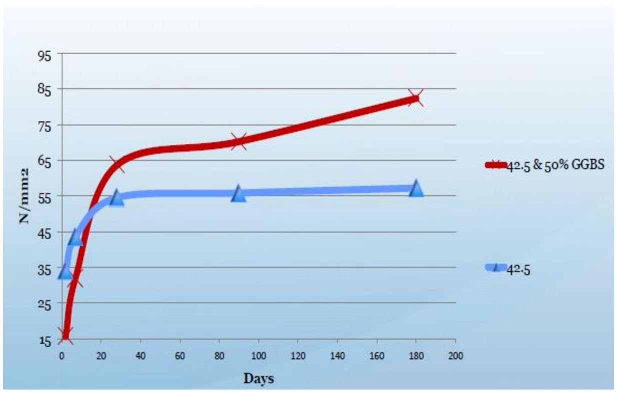

Figure 2. The comparison compressive strength between Portland cement and GGBS

II. MATERIALS AND METHOD

The materials used in preparing the lightweight concrete blocks are Portland cement, Ground Granulated Blast-furnace Slag (GGBS), Palm Oil Fuel Ash (POFA) sand and foam agent.

A. *Portland Cement*

Portland cement which is the basic material of a concrete act as the binder of the concrete. This research was conducted by reducing the cement amount with the replacement material by 10%, 30%, and 50%.

B. *Palm Oil Fuel Ash (POFA)*

The Palm Oil Fuel Ash (POFA) were taken from the Palm Oil factory is located at Kluang Oil Palm Processing Sdn. Bhd. The POFA must be passed the size 63µmm to replace the cement. The materials must be dry under the sun first before used as the replacement of cement.

C. *Ground Granulated Blast-furnace Slag (GGBS)*

GGBS is the granular material formed iron ore is moulted blast furnace slag is by-product of steel manufacture which is well known as the substitute for Portland cement. The GGBS is supplied by YTL Sdn Bhd. The size of GGBS used must be passed size of 63µmm in order to replace the cement.

D. *Foam Agent*

The foam agent will have induced well-separated pores and that the size of the pores ranged from 50 to 100 µm. The foam agent used in the lab is Sika AER-C admixture. It is an air-enhancing admixture for concrete based on neutralised Vinson resin. Sika AER-C meets the requirements of ASTM C-260. The normal ratio of foam agent used is 1:20 from the value of the previous study.

E. *Design Mix*

The research of the lightweight concrete stated that the density of the lightweight concrete block must be in range 650-1900 kg/m^3 (Thomas, 1991). However, different percentages of POFA and GGBS was used. Table 4 show the number of specimens done and the percent of cement replacement material used. Table 4 show the mix design from the optimum value stated in the previous study which is will not reduce the strength of concrete.

Table 4. Mix design of the lightweight concrete block with the ratio of the cement and the replacement materials

Sample	**Cement: Sand**	**Water: Cement**	**Foamed Agent: Water**
NB	1:2	0.5:1	
Sample	**Cement:POFA: Sand**	**Water: POFA**	
PB (10%)	0.9:0.1:2		
PB (30%)	0.7:0.3:2	0.5:1	
PB (50%)	0.5:0.5:2		1:20
Sample	**Cement:GGBS: Sand**	**Water: GGBS**	
GB (10%)	0.9:0.1:2		
GB (30%)	0.3:0.7:2	0.5:1	
GB (50%)	0.5:0.5:2		

F. *Preparation of Samples*

The preparation of lightweight concrete contains different types of materials as the replacement of cement. The mixing of the concrete will follow the general ratio of the lightweight concrete. The procedure must be followed ASTM C-90.

The materials were scaled as the ratio in Table 4 and the mixture was mixed well. The mixing was put in the container which has density 1kg/m^3 to get the wet density of the mixture. The foam agent was added into the mixing to control the density of the concrete block below the density of water. The formwork of the lightweight concrete size is about 250mm x 125mm x 100mm was prepared. The formworks were cleaned and the oil was poured on the surface in the formwork to easier the process to take out the sample. The mixing of concrete was poured be in the formwork. The surface of the concrete was trimmed. The concrete sample was left for hardening process in 24 hours before the mould was taken out. The concrete sample was placed under wet blanket for the curing process for 7 and 28 days.

G. *Lab Testing*

The testing's that has been done to achieve the objective earlier are divided into two types of purpose. The first purpose is to evaluate the mechanical properties of the lightweight concrete while the second purpose is the chemical properties of the block. The lightweight concrete block must meet the requirements of ASTM C 90 (Standard Specification for Loadbearing Concrete Masonry Units). The requirement of minimum compressive strength (average of 3 units) is in range of 6.96MPa-17MPa, the dry density must less than 1900 kg/m3 and maximum water absorption is 20% (Thomas, 1991; Muthusamy *et. al.,* 2014; Awalludin *et al.,* 2015).

Figure 3. Testing flow

III. RESULT AND DISCUSSION

A. Chemical Properties

Table 5 shows the chemical composition between Ordinary Portland Cement, Ground Granulated Blasts-Furnace and Palm Oil Fuel Ash. The percentage of Calcium Oxide (CaO) of the cement leading the value is about 57.3% followed by the GGBS is about 39.40% and POFA is about 4.86%. Besides, the composition of Silicon Dioxide (SiO_2) shows the vice versa condition which means that the POFA is leading the value about 31.10%, followed by the GGBS is about 23.80% and the cement is about 14.10%. Meanwhile, the percentage difference composition of Calcium Oxide (CaO) in GGBS is about 45.4% lower compared to the cement while the percentage difference composition of Silicon Dioxide (SiO2) in GGBS is about 68.8% higher compared to the cement. Whereas the percentage difference composition of CaO in POFA is about 91.0% lower than the cement but the percentage difference composition of the SiO2 is about 80.6% higher compared to the cement.

The result of XRF testing can be compared with the previous study in the earlier chapter in Table 2 and Table 3. The GGBS contain high SiO_2 in this research than the previous study. Meanwhile, the value of CaO of the previous study was higher than the GGBS used.

The SiO_2 of POFA and CaO lower than the previous study. The various different percentages of chemical composition in the materials lead to different expected result than the previous study based on the silica content that react to the Calcium Hydroxide (Tangchirapat *et al.,* 2009).

Table 5. Percentages of chemical composition of OPC, POFA and GGBS to previous study

Chemical Constituents	**OPC Concentration**	**GGBS Concentration**	**Previous GGBS Concentration (Eldagal, 2008)**	**POFA Concentration**	**Previous POFA Concentration (Bhavana, 2016)**
Calcium Oxide (CaO)	57.3%	39.40%	60.84%	4.86%	11.69
Silicon Dioxide (SiO_2)	14.10%	23.80%	16.34%	31.10%	48.99

B. Density

The density of the lightweight concrete block is presented in Table 4.2 and compared through the graph in Figure 4. The density of the overall lightweight concrete block by the different percentage of the cement and replacement material shows the density of the lightweight concrete block by the GGBS is about 10% as the cement replacement materials obtain the denser density than the other lightweight concrete block while the percentage difference between the normal lightweight concrete block are only 8.6% higher than normal lightweight concrete block.

Meanwhile, the replacement cement about 10% by POFA shows the percentage difference about 1.2% higher than the normal lightweight concrete block. The graph shows the use of cement replacement cement materials resulting to the higher density of lightweight concrete block due to the different composition of chemical materials in the cement compared to GGBS and POFA (Munir *et al.*, 2015). The higher composition of the SiO2 in the GGBS than the cement and lower composition of the CaO than the POFA must be promoted the hydration process and resulting to the higher density than the other Lightweight Concrete Blocks.

The increasing percentage of the cement replacement in the lightweight concrete block reduced the density of the lightweight concrete block. However, the density of lightweight concrete block are less than 1900kg/m³ and can be classified as the lightweight concrete block as the earlier chapter, Table 1.

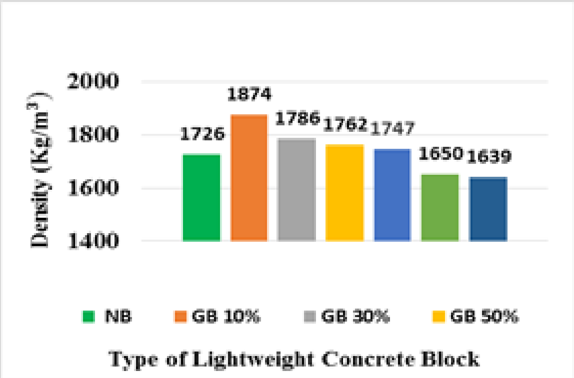

Figure 4. The density by different percentages of cement replacement materials

C. *Water Absorption*

Figures 5(a) and (b) show the percentage of the water absorption by the lightweight concrete block. The overall percentage of water absorption shows the small amount of water absorption by the lightweight concrete block by the different percentages of the POFA and the GGBS. The comparison percentage of the water absorption between the lightweight concrete block show that the higher percentages of cement replacement by the POFA and GGBS resulting to the increasing percentages of the water absorption and the lower percentage of the water absorption is the 10% GGBS in the lightweight concrete block. The increasing of the percentages of the GGBS as the cement replacement materials lead to the increasing of the percentage of water absorption. However, the percentage of water absorption of GGBS Block (GB) still better than Normal Lightweight Concrete Block (NB).

Meanwhile, the replacement of cement by POFA in lightweight concrete block show a higher value of the percentage of the water absorption than the NB. POFA is known as agriculture waste, and the contain of fibre may lead to the need of water absorption due to the pores and porosity of the block. The water absorption also related to the density of the lightweight concrete block. The graph in Figure 4 shows that the increasing of density of the lightweight concrete block reducing the percentage of water absorption of the lightweight concrete block. The higher density of the lightweight concrete block has the higher water absorption as the best fit in the graph. The reducing of the voids by the higher density reduces the potential for the water to absorb into the lightweight concrete block. (Wibowo, 2017) Hence, the replacement of cement by GGBS and POFA are practical in promoting to the reducing of water absorption to the lightweight concrete block in order to avoid the shrinkage or cracking (Lim, 2012).

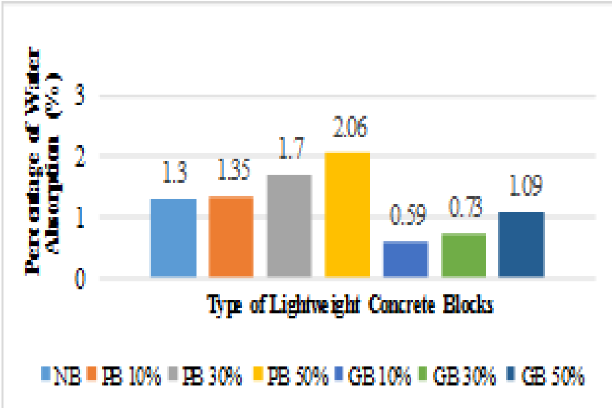

Figure 5(a). Percentages of water absorption by different percentages of cement replacement

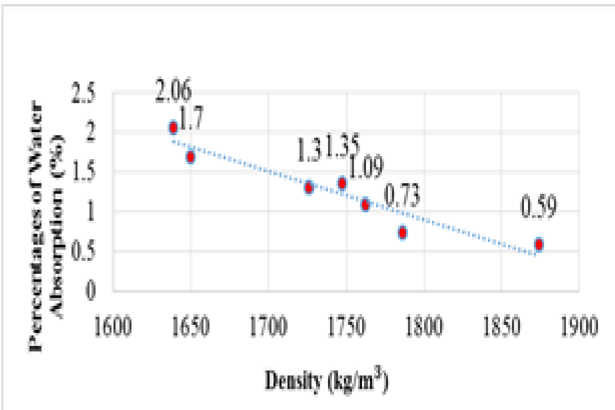

Figure 5(b). Percentages of water absorption by compressive strength

D. Compressive Strength

Table 6 and graph in Figure 6(a) show the result of the compressive strength of the lightweight concrete block for 7 days and 28 days. The increment strength is shown of the blocks from 7 days to 28 days, for the Normal Lightweight Concrete Block (NB) is about 30% while for the POFA Blocks (PB) is about 50%. Meanwhile, the increment strength for the GGBS Block (GB) is increasing as the increasing of the percent replacement of the cement by the GGBS from 53%, 63% and 69%. These results show the GGBS and POFA are very effective for the early strength of the concrete.

The graph in Figure 6(b) shows the comparison of the compressive strength among the lightweight concrete block where the GB 10% lead the strength of the lightweight concrete block followed by GB 30% and GB 50% The strength of the lightweight concrete block by the GGBS as the cement replacement materials show the higher strength than the NB. Hence, the GGBS is qualified to improve the strength of Lightweight Concrete Block. Meanwhile, the compressive strength of the PB 10% lead the strength between the PB 30% and the PB 50%. Even though the strength is lower compared to the Normal Lightweight Concrete Block, the value obtains still in the range of 6.9 MPa and 17.3 MPa and suitable for lightweight structures as the partition or non-structural wall.

The strength of the lightweight concrete block is also affected by the density of the lightweight Concrete Blocks. The compressive strength of the lightweight concrete block increases as the density decreases as shown on the graph in Figure 6(c). Meanwhile, the percentage of water absorption affected the compressive strength of the block where the higher percentage of water absorption lead to the decreasing of the strength due to the best fit in the graph as Figure 6(d). Hence, the POFA and GGBS have the higher potential as the cement replacement materials in terms of the strength and density obtained as supported by Sooraj (2013) in Figure 1 and Figure 2.

Table 6. The percentages difference compressive strength of lightweight concrete blocks between 7 and 28 days

Type of Light Weight Concrete Blocks	**Compressive Strength for 7 Days (MPa)**	**Compressive Strength for 28 Days (MPa)**
NB	8.61	11.1
PB 10%	7.24	10.9
PB 30%	6.6	9.6
PB 50%	6.18	9.18
GB 10%	11.5	17.6
GB 30%	9.4	15.3
GB 50%	7.4	12.5

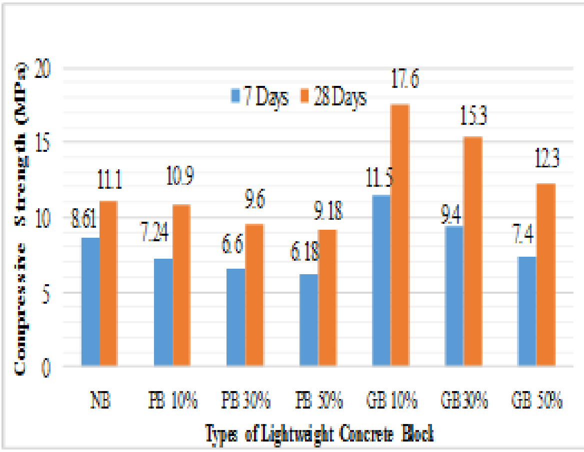

Figure 6(a). Compressive strength of the lightweight concrete block with the different percentages of the cement replacement materials in 7 days and 28 days

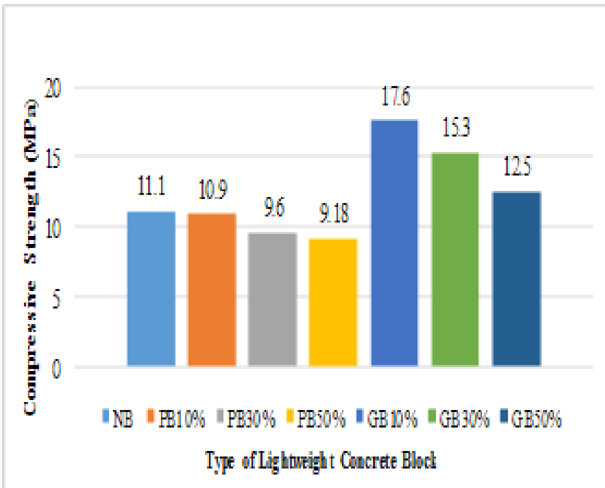

Figure 6(b). Compressive strength of the lightweight concrete block with the different percentages of cement replacement materials

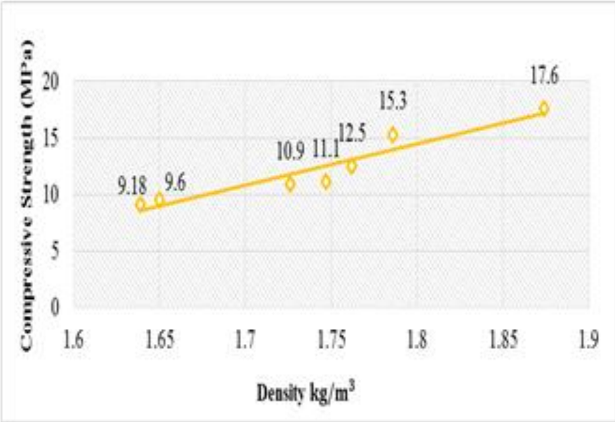

Figure 6(c). Compressive strength of lightweight concrete block with density of lightweight concrete blocks

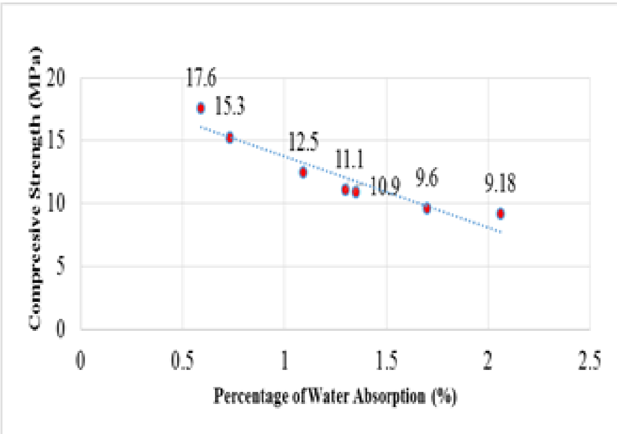

Figure 6(d). Compressive strength of lightweight concrete block with percentage of water absorption

IV. CONCLUSION

Based on the laboratory result, the following conclusion can be drawn due to the objective that mentioned in the earlier chapter.

The first objective is to determine the chemical composition of POFA and GGBS. This is achieved through the XRF Testing that show the different chemical composition. The previous study stated that the optimum percentages of the cement replacement by the POFA and GGBS are about 30%. Hence, the trial mix for 10%, 30%, and 50% was applied. However, the result shows that 10% cement replacement obtained the optimum result of strength and water absorption. The increasing percentages of the cement replacement materials lead to the reducing of the density supported by the previous study (Hodzic, 2012).

The second objective is to determine the compressive strength of the Lightweight Concrete Block with POFA and GGBS as the cement replacement materials. The compressive testing achieved the objective by the result of the compressive strength test. The compressive strength of the Lightweight Concrete Block with GGBS are higher than Normal and POFA Block within 10% replacement as supported by previous study Sooraj (2013) and Lim (2012) where the higher percentages of replacement lead to reducing of the compressive strength. This strength is also affected by the density of the lightweight concrete block where the decreasing of density, reduce the strength of the block supported by the previous study in Figure 2 and Table 2. Hence, the density optimum density obtained is 1874 kg/m³ below than the standard 1900 kg/m³ to fulfill the Lightweight Concrete Blocks' properties (Thomas, 1991). The optimum percentage of water absorption is 2.06% is lower than the allowable standard which is 20% (Wibowo, 2017). The result shows the effectiveness of POFA and GGBS as cement replacement material in terms of water absorption better than the previous study of the water absorption of Lightweight Concrete Block (Eldagal, 2008). Hence, the effectiveness of GGBS and POFA in terms of water absorption is proved.

The third objective is to find the properties of block assembling by the prism test. The results of crack failure and prism compressive strength of Lightweight Concrete Blocks are compared. The cracking failure of Lightweight Concrete Block shows the improvement by replacement of the cement by the GGBS than the POFA. The increasing of water absorption resulting in the worst condition of cracking failure due to increasing of voids (Nair & Johny, 2016; Shyamala *et al.,* 2016). Hence, the lower percentage of cement replacement by POFA and GGBS resulting in the lower percentage of water absorption. The better cracking failure condition show the properties of block as the application to the wall (Ismail *et al.,* 2017). Meanwhile, the optimum prism compressive strength is 11MPa is less than 13MPa as mention earlier referred to ASTM C90 are suitable for non-loading bearing wall.

Hence, is the final findings in term of the most suitable mix design of the research is 0.1:0.9: for ratio of GGBS/POFA: Cement: Sand The previous study in Figure 2 and Table 2 also stated the increasing of percentage of POFA and GGBS in the concrete reducing the compressive strength of the concrete hence, the recommendation for the longer period of curing will lead to the better performance of the concrete.

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