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Physical and Mechanical Properties of Pumice Lightweight Aggregate Concrete

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Abstract: Concrete is now widely used as a construction material all over the world. One of the disadvantages of normal concrete is it has high self-weight which is uneconomical for being a structural material for building. This study was conducted to produce lightweight aggregate concrete (LWAC) by partial replacement of pumice and to investigate the physical and mechanical properties of the concrete by conducting compressing strength, density, workability and water absorption test. There are 4 percentage of pumice concrete block that were tested which are 0%, 10%,20% and 30% with size of 100mm x 100mm x 100mm. For the experiment result, lightweight concrete (LWC) containing pumice has lower strength and workability compare to normal concrete with reduction from 33.5 MPa to 18.8 MPa and from 26 mm to 9 mm respectively. The density also becomes lower where the 30% of pumice replacement that has 1870 kg/m^3 can be classified as lightweight concrete. The water absorption of concrete increase as the pumice replacement increases from 3.5 to 10.9%. The LWC containing pumice can be used as structural in low rise material in building.

Keywords: Lightweight Concrete, Pumice, Compressive Strength, Workability, Density, Water Absorption

1. Introduction

Lightweight Concrete (LWC) is one of a new development in concrete industry nowadays. A lightweight concrete should have a minimum compressive strength of 17 MPa for 28 days and density from 1120 to 1920 kg/m^3 [1]. Due to lightweight structural concrete that has lower density, it reduces structural weight and concrete member size, lowering construction cost, transportation and design. Natural occurring lightweight aggregate are such as pumice and scoria while fly ashes, shales and clay are produce by plant [2]. The performance of lightweight aggregate such as pumice have been studied by several researches to study the physical and mechanical properties of the lightweight concrete by partial replacement of normal aggregate. For decades, pumice aggregate that formed by rapid solidification of gas has been used in the production of lightweight concrete. The addition of pumice and admixture will significantly improve the compressive strength, density and workability of the

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concrete [3]. When using properly graded aggregates, the ratio of pumice aggregate to cement has a significant impact on strength properties. One of the major disadvantages of the lightweight aggregate such as pumice are they absorbed more water because of its highly porous structure than regular weight aggregates in concrete that can give impact in reducing the workability of the concrete. Concrete was used as building materials was made by water, cement, fine aggregate and coarse aggregate. Among the ingredients, aggregate involve large volumetric stability and durability to concrete. Aggregate is cheaper than cement and it directly helps in achieving economy in concrete [4].

2.0 Literature Review

2.1 Basic properties of pumice aggregate

The term "Pumice" refers to a class of porous vesicular materials formed during explosive volcanic eruptions. Pumice aggregate (PA) is a type of volcanic ash composed of frothy lava that has solidified. Pumice's unique foamy shape is caused by fast cooling and depressurization at the same time. Depressurization causes bubbles by reducing the solubility of gases dissolved in the lava (including water and CO2), allowing the gases to rapidly exsolve. The bubbles in a matrix are frozen by cooling and depressurization at the same time [5]. Pumice concrete also has lower thermal conductivity which results in less heat loss, and the freeze/thaw resistance is good due to the low capillary action. Pumice concrete also has higher acoustic ratings and is chemically inert, pure, and non-toxic. Pumice is a aggregate that float in water that has colourless or light grey in colour. Pumice aggregate has a density of 0.25 g/cm3. It is a completely natural raw material and also has high mechanical strength and is a great as insulator [6].

2.2 Experimental study on lightweight concrete by using pumice aggregate

The lightweight concrete study was carried out using pumice aggregate. During the study, the replacement of pumice aggregate with normal aggregate was said to have been structural lightweight concrete which can reduces the building's self-weight. The primary goal is to identify whether pumice lightweight concrete can be used as structural concrete to determine the compressive strength and split tensile strength of lightweight concrete with densities less than 1800 kg/m3 and to analyse the impact of various types of replacements (20%, 50%, 80%, 100%) of normal aggregate by lightweight pumice aggregate and conventional concrete on 7 and 28 days. According to the findings of the study, the maximum replacement level of pumice lightweight aggregate is 50 % with conventional coarse aggregate while increasing the percentage of pumice aggregate will reduces the compressive strength [7].

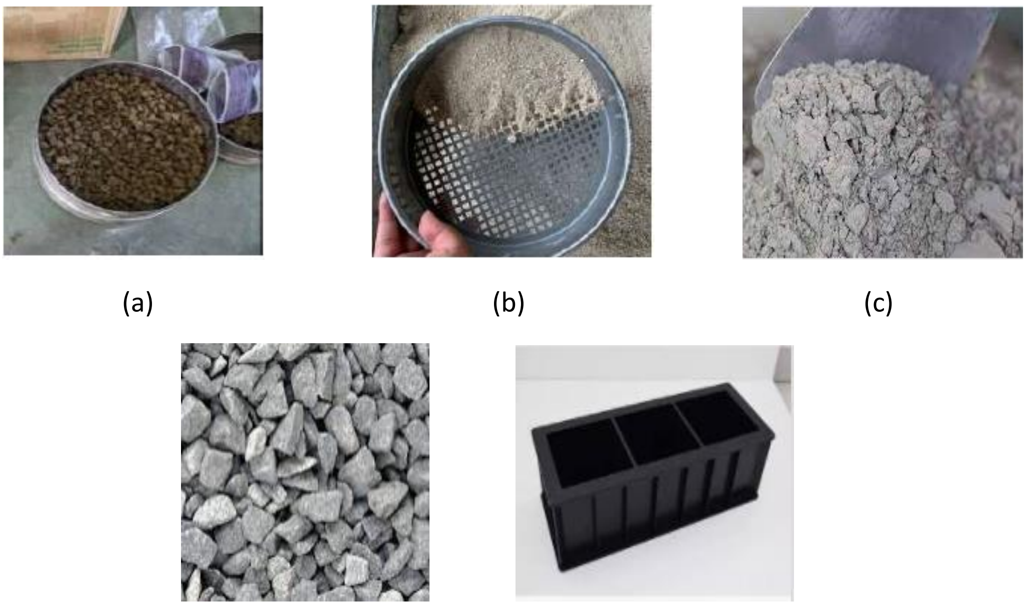
2.3 The experiment on physical and mechanical properties of lightweight concrete using lightweight aggregate

The study was carried out to investigate the durability and strength of concrete grade M30 by partial replacement of normal aggregate with pumice lightweight aggregate. Pumice was considered as the best option for the replacement of coarse aggregate because it provides better strength compare with the other lightweight material. The percentage of replacement of normal aggregate with pumice aggregate that was used in the study are 0%(controlled), 10%, 20%, 30%, 40% and 50%. From the result, it was concluded that the physical and mechanical properties of the pumice aggregate concrete excellent at 20% replacement that give sufficient value where above 20% the strength of the concrete will drop [8].

3.0 Materials and Methods

3.1 Materials

The concrete grade 30 N/mm2 has been proposed to design the mixture of the pumice lightweight concrete of every specimen. The lightweight aggregate concrete (LWAC) made up from lightweight pumice was partially replace with normal fine aggregate and was mixed with other admixture such as fine aggregate, coarse aggregate, cement and water. The LWAC was developed with the size of 100mm × 100mm × 100mm. The materials including pumice aggregate, Ordinary Portland Cement (OPC), coarse aggregate, fine aggregate, water and formwork, as shown in Figure 1. For the formwork, the size used was 100mm × 100mm × 100mm and the framework made from the waterproofing and high-quality plastic that have a hole for easier to extract the concrete from the formwork by air compressor.



(a) (b) (c)

(d) (e)

Figure 1 - Materials use for pumice LWAC: (a) pumice aggregate, (b) fine aggregate, (c) Ordinary Portland Cement, (d) coarse aggregate, (e) concrete mould

In general, Ordinary Portland cement were used as a common binding material in concrete production. The cement is a material which help to sets and hardens a concrete mixture and can bind with other materials together [9]. The cement that was used should be free from lumps and any foreign matters before it is used. To avoid from using the cement with lumps, the cement was sieved to avoid the lumps. Besides, the cement that were used must is dry condition and used for short duration. Fine aggregate is used as a small size filler material in concrete which fills the voids in between the coarse aggregate [10].

The fine aggregate and pumice aggregate was sieved using the 5 mm siever. It should be dry, clean, strong and free from any impurities that may affect the structure of the concrete. Besides, for the coarse aggregate will act as large size filler material that provide more strength to the concrete. The size that was choose for the coarse aggregate is between 5 mm to 10 mm. Pumice is a natural aggregate that was choose because it was among the aggregate that have good strength properties compare to other lightweight aggregate [11]. Pumice aggregate has higher water absorption compare to normal aggregate thus it will reduce the workability. Moreover, water is also play an important role during the mixing and hardening of concrete thus it needs to be careful for the quantity of water because its influence the strength and workability of concrete.

3.2 Casting of the test specimens

In the preparation of the materials for the casting of cube and concrete blocks, the calculation for concrete mix design by using DOE method were used to get the proportion of each material. The water cement ratio for each design is 0.54. The design mix result for each material for all specimens are shown as Table 1.

Table 1: The design mix result for each pumice concrete blocks.

Specimen	**A**	**B**	**C**	**D**
No. of specimens	3	3	3	3
Pumice percentage (%)	0 %	10 %	20 %	30 %
Cement (kg)	1.200	1.200	1.200	1.200
Water (kg)	0.645	0.645	0.645	0.645
F. aggregate (kg)	2.580	2.322	2.064	1.806
C. aggregate (kg)	2.685	2.685	2.685	2.685
Pumice (kg)	0.000	0.120	0.221	0.332

Total of 24 specimens were casted with 6 specimens for each percentage of partial replacement of pumice aggregate for the 7 and 28 days. The casting of pumice LWAC is similar to the conventional concrete. Before mixing the material, the tray was wetted by water to avoid water loss during the mixing. Slump test was conducted to measure the workability of the concrete mix. After finish casting, the specimens were kept for 24 hour and then demoulded by using air compressor. After demoulding, the concrete was labelled and immersed in curing tank for 7 and 28 days.

Figure 2: Process of batching and mixing the materials

Figure 3: Measuring the slump

Figure 4: The specimen was kept for 24h

Figure 5: Curing for 7 and 28 days

3.3 Density

Three cubes of 100 x 100 x 100 mm concrete specimens were picked out for density testing of each mix in accordance with ASTM C567 [12]. The dry density of concrete samples was determined by measuring the volume of concrete cube and the mass of each specimen as shown in Figure 6. According to Test Method C138/C138M, the fresh density of specimens was calculated from freshly mixed concrete immediately after mixing. The density is calculated by the formula shown below in kg/m^3

$$\rho = \frac{m}{v} \tag{1}$$

where ρ = Density, m = Mass, v = Volume

Figure 6: Measuring the volume of concrete

3.4 Compressive strength test

With reference to BS 1881: Part 116: 1983 (Method for determination of compressive strength of concrete cubes), 3 concrete cubes for each specimen are casted for compressive strength with a compression machine at 7 and 28 days respectively [13]. The compressive strength test was conducted after the curing process. The test samples were placed on to the compression machine as shown in Figure 7.

Figure 7: Compressive strength test

3.5 Water absorption test

By referring BS 1881-122: 2011 the concrete was placed in a drying oven after the curing of 28 days with a distance of not less than 25 mm between them or any heating surface [14]. The specimens were dried for 72 ± 2 hours in the oven for the temperature of 100 ± 5°c as shown in Figure 8. Next, the concrete was cooled in the dry airtight vessel for 24 ± 0.5 hours and the mass was recorded after that. After that, the sample was immersed in water for 30 minutes and then the concrete was weight to get the mass of wet sample.

Figure 8: Oven drying sample

4.0 Results and Discussion.

4.1 Workability

Table 2 shows the result of workability (slump) values for concrete with increasing percentages of pumice aggregate. All four mixes were subjected to slump test measurements. The slump test determines the workability (consistency) of new concrete.

Table 2: Slump result

Pumice percentage (%)	Slump value (mm)
0	26
10	22
20	16
30	9

All four mixes were subjected to slump test measurements. The slump test determines the workability (consistency) of the concrete. From the Figure 9 shows that the slump values are in the range of 9 mm to 26 mm. Slump values for normal concrete mix reach 26 mm while in the previous study conducted the result shows that increasing PA reduced concrete workability drastically [15]. The decrease value in workability with increasing percentage of pumice aggregate is caused by the higher water absorption of pumice aggregate, which has a larger porosity than conventional aggregate. Slump values for normal concrete mix reach 26 mm Slump values for mixes with a lesser w/c ratio of 0.54 are 26, 22, 16 and 9 mm respectively, as the replacement level of pumice aggregate is increased from 0 to 10, 20 and 30 %.

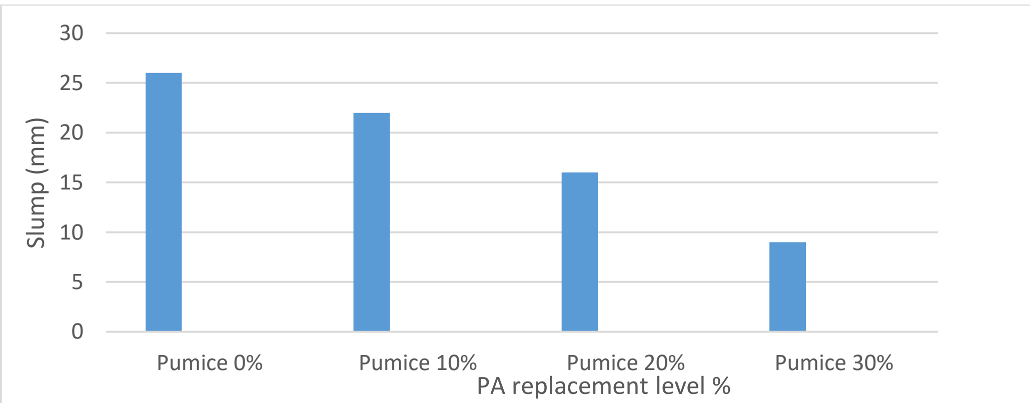


Figure 9: Slump values of the concrete

4.2 Density

Table 3 shows the result of the average density of each specimen with different percentage of pumice. The density of the specimen is calculated based on the weight of each specimen divided by the volume of specimen which are 0.001m3.

Table 3: The average dry density of concrete

Specimen	Percentage of AAC aggregate	Number of samples	Density, (kg/m^3)		Average of density, (kg/m^3)
A	0%	3	A1	2260	2260
			A2	2290	
			A3	2220	
B	10%	3	B1	2170	2150
			B2	2150	
			B3	2130	
C	20%	3	C1	2020	1970
			C2	1980	
			C3	1960	
D	30%	3	D1	1870	1870
			D2	1860	
			D3	1890	

The figure 10 shows that the average dry density of the concrete become lower when the replacement of pumice aggregate become high. The dry densities of concretes with varied quantities of pumice aggregate ranged from 2020 kg/m^3 to 2300 kg/m3. The dry density of concretes dropped as pumice aggregate replacement increased. The previous study also was observed and obtain similar findings [16]. In comparison to the control, the fresh density decreased by 4, 9, and 12% for concrete containing 10, 20, 30% pumice aggregate respectively. The density of concrete is greatly influenced by the density and grading of aggregates, mix proportions, cement content, water/binder ratio, chemical and mineral additives, compaction process, and curing conditions. Depending on the extent of PA replacement in the concrete, LWAC can be considered lightweight. The volume and density of aggregate control the density of concrete, which can control several physical qualities of lightweight concrete.

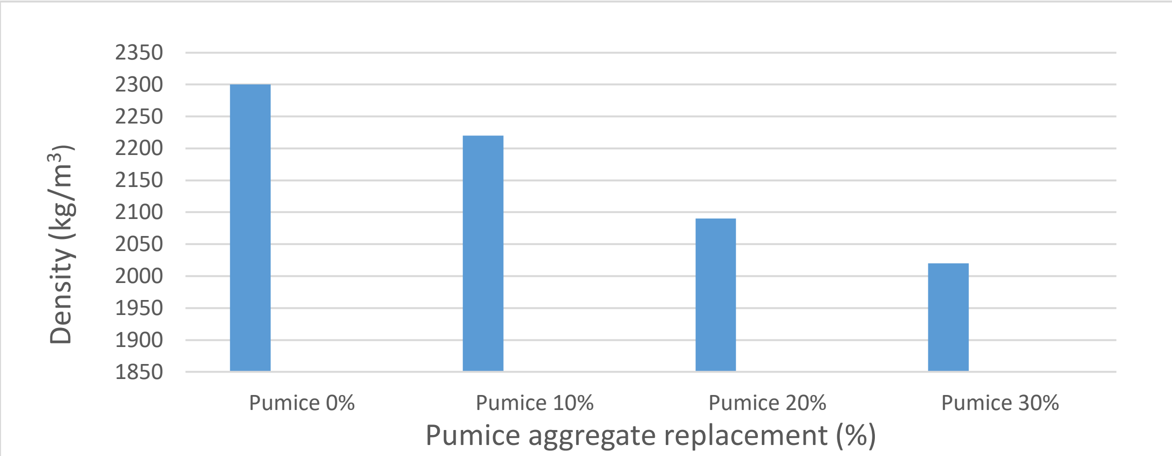


Figure 10: The average dry density of the concrete

4.3 Water absorption

Table 4 shows the total water absorption of concrete containing varying amounts of pumice aggregate. At 28 days, the total water absorption of concretes ranges from 3.5 % to 10.9 %.

Table 4: Average water absorption of concrete

Specimen	Percentage of AAC aggregate	Weight of the oven dry concrete (kg)		Average Weight of the oven dry concrete (kg)	Weight of the wet concrete (kg)		Average Weight of the wet concrete (kg)	Average percentage of water absorption (%)
A	0%	A1	2.31	2.30	A1	2.39	2.38	3.5
		A2	2.29		A2	2.36		
		A3	2.31		A3	2.38		
B	10%	B1	2.20	2.22	B1	2.37	2.35	5.9
		B2	2.23		B2	2.35		
		B3	2.22		B3	2.32		
C	20%	C1	2.10	2.09	C1	2.28	2.27	8.6
		C2	2.08		C2	2.25		
		C3	2.09		C3	2.28		
D	30%	D1	2.01	2.02	D1	2.24	2.24	10.9
		D2	2.03		D2	2.21		
		D3	2.02		D3	2.26		

From the figure 11 shows that the increasing of water absorption when the pumice aggregate replacement become high. It is obvious that increasing the amount of pumice aggregate in concrete mixes increases water absorption. Previous study also reported the same comparable results, with water absorption ranging from 7% to 11% [17]. Higher water absorption may be due to increasing of porosity structure in concrete, that will decreased the durability of concrete [18]. The findings confirmed a 10.9 % increase in total surface water absorption for a PA mix containing 30% more than a conventional concrete mix. Testing programmes determined that samples had high quality lightweight concrete when they absorbed very little water, demonstrating their low density and permeability of LWC, which was extremely low and generally equal to conventional concrete.

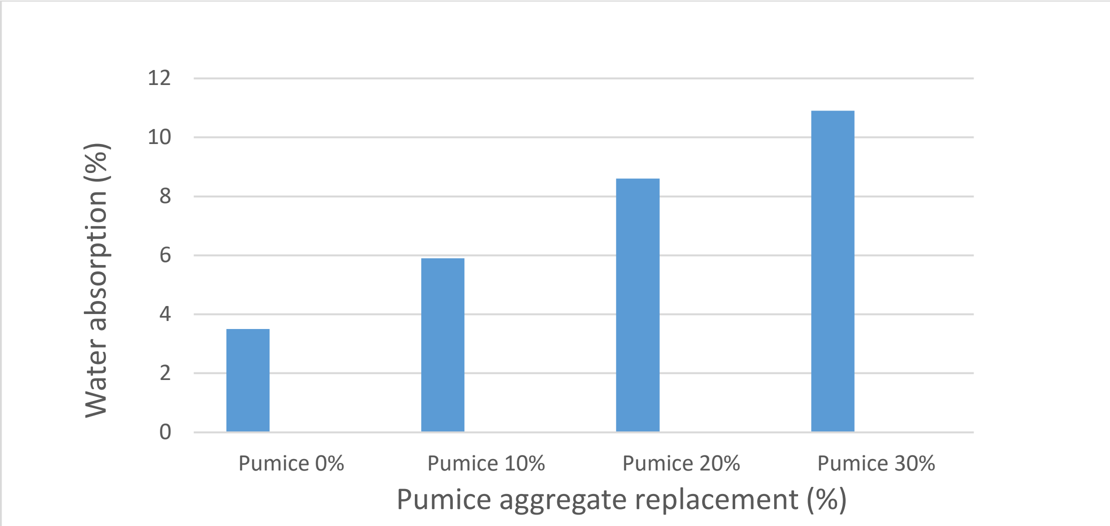


Figure 11: Average water absorption

4.4 Compressive strength

Table 4 shows the compressive strength of concrete containing varying amounts of pumice aggregate while Table 5 and 6 shows the standard deviation of each sample mix at 7 and 28 days of curing. At 28 days, the compressive strength values range from 18.7 to 33.5 MPa while for 7 days the range is from 15.9 to 25.7 MPa.

Table 4: Average compressive strength

Pumice Concrete	Compressive strength (MPa)	
	7 days	**28 days**
0 %	26.1	33.5
	25.2	33.7
	25.7	33.2
Average	**25.7**	**33.5**
10 %	22.1	27.0
	21.4	27.7
	22.8	26.9
Average	**22.1**	**27.2**
20 %	17.8	19.9
	18.9	20.2
	18.8	20.5
Average	**18.5**	**20.2**
30 %	16.4	18.8
	15.2	19.0
	16.1	18.3
Average	**15.9**	**18.7**

Table 5: Compressive strength at 7 days

Pumice (%)	*Compressive strength (MPa) (x)*	*Average (MPa)* $\bar{x} = \frac{\sum x}{n}$	*Deviation* $(x - \bar{x})$	*Square of deviation* $(x - \bar{x})^2$
0 %	26.1		0.4	0.16
	25.2	25.7	-0.5	0.25
	25.7		0.0	0.00
	Total			0.41
	Standard Deviation = 0.45			
10 %	22.1		0.0	0.00
	21.4	22.1	0.3	0.09
	22.8		0.7	0.49
	Total			0.58
	Standard Deviation = 0.70			
20 %	17.8		-0.7	0.49
	18.9	18.5	0.4	0.16
	18.8		0.3	0.09
	Total			0.74
	Standard Deviation = 0.61			
30 %	16.4		0.5	0.25
	15.2	15.9	-0.7	0.49
	16.1		0.2	0.04
	Total			0.78
	Standard Deviation = 0.62			

Table 6: Compressive strength at 28 days

Pumice (%)	*Compressive strength (MPa) (x)*	*Average (MPa)* $\bar{x} = \frac{\sum x}{n}$	*Deviation* $(x - \bar{x})$	*Square of deviation* $(x - \bar{x})^2$
0 %	33.5		0.00	0.00
	33.7	33.5	0.2	0.04
	33.2		-0.3	0.09
	Total			0.13
	Standard Deviation = 0.25			
10 %	27.0		-0.2	0.04
	27.7	27.2	0.5	0.25
	26.9		-0.3	0.09
	Total			0.38
	Standard Deviation = 0.44			
20 %	19.9		-0.3	0.09
	20.2	20.2	0.0	0.00
	20.5		0.3	0.09
	Total			0.18
	Standard Deviation = 0.30			
30 %	18.8		0.1	0.01
	19.0	18.7	0.3	0.09
	18.3		-0.4	0.16
	Total			0.26
	Standard Deviation = 0.36			

From the Figure 12 shows that the highest compressive strength for curing at 7 and 28 days are 25.7 MPa and 33.5 MPa respectively. As a result, for a target compressive strength of 7.5 MPa, all concrete mixtures with varying PA content (10, 20, and 30%) are suitable for the production of all types of blocks, including heavy duty bearing blocks [19]. Besides, the concrete containing 10,20 and 30% PA can meet the structural lightweight aggregate concrete minimum requirement, which require a mean minimum strength of 17.0 and 15.0 MPa, respectively [1]. In contrast, control concrete (0 % of PA), the failure observed with higher amounts of PA was more gradual and compressible under compressive loading, and the specimens were capable of retaining the load after failure without disintegration. In the present study, the compressive strength increases with curing age for all mixes as expected. In the first 7 days of curing, the control mix (0 % PA) gained 23% of its 28-day strength. The strength development for mixes (10% PA), (20% PA), (30% PA), are 19%, 8%, and 15% respectively. The strength development for concrete mixes decreasing with increasing PA content in concrete.

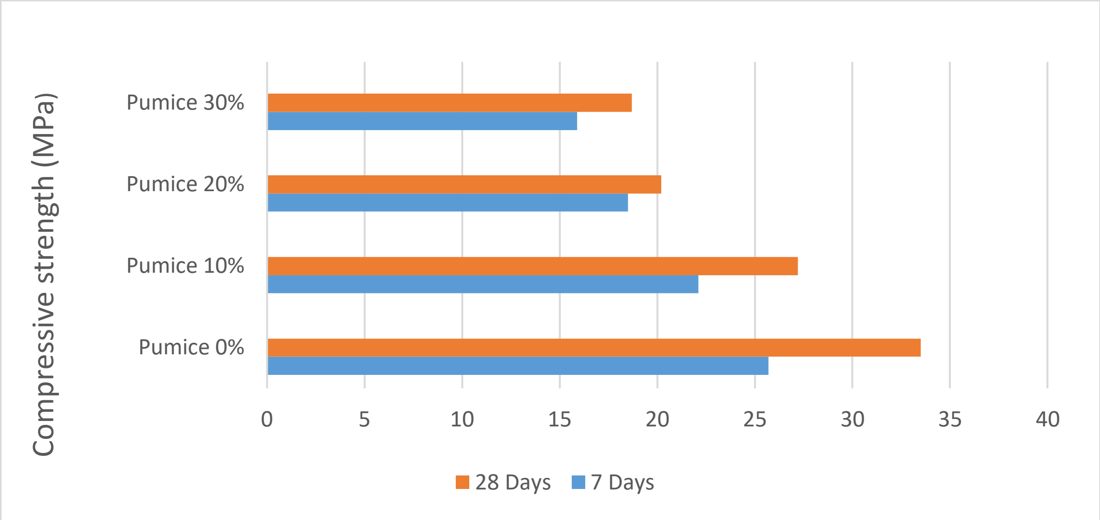


Figure 12: Average compressive strength

5.0 Conclusion

This study presents the production of lightweight aggregate concrete (LWAC) that can be used for structural purpose by replacing normal fine aggregate with pumice aggregate. Besides, This study also presents the physical and mechanical properties of lightweight aggregate concrete made by pumice such as compressive strength, workability, density and water absorption. Based on the experimental work, the following conclusions are obtained:

- The best percentage of pumice aggregate replacement was at 30% because it has density of 1870kg/m^3 which can be classified as lightweight concrete and it has sufficient strength for structural purpose with 18.7 MPa compressive strength.
- According to the findings, increasing PA reduces the workability and density of LWAC while increasing water absorption. Besides, the higher replacement level of PA influenced the greater reduction in compressive strength of the concrete.

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