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Short-Term Ability of Concrete Containing Palm Oil Fuel Ash Exposed to Sodium Sulphate

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Abstract: Uncontrolled palm oil waste disposal can lead to an environmental problem and recycling the waste can assist in reducing the disposal problem. On another side, concrete exposed to sulphate normally will lose its strength after some time. Replacing cement with palm oil fuel ash (POFA) can lower the disposal issue and help reduce the concrete from strength losses. The main objective of this study is to investigate the short-term effects on the strength of concrete containing POFA exposed to sulphate solution. The POFA was prepared by drying in an oven for 24 hours at 105°C and sieved passing through a 300 μm sieve. Then, the POFA had been refined using ball mills for two hours. The percentage of POFA as cement replacement used in this study is 10%, 20% and 30% by volume of cement. Two types of specimens were prepared, i.e., cube specimen (100 mm × 100 mm × 100 mm) and prism specimen (500 mm × 100 mm × 100 mm) that fully immersed in water and 3.5% sulphate solutions. Density test, water absorption test, compression strength test and flexural strength test were conducted after 7 and 28 days of the exposure period. A total of 144 specimens was subjected to these tests. The experiments show that concrete with 10% replacement of POFA had a higher slump value, while the density test showed that the 10% POFA mixture had a lower density than the other specimens. Furthermore, the water absorption test showed that more POFA in concrete contributes to higher water absorption when exposed to sulphate solution compared to water. In conclusion, the compressive strength and flexural strength test recorded replacement of 10% POFA is the highest strength of concrete containing POFA exposed to sulphate solution and water.

Keywords: Concrete, sulphate exposure, palm oil fuel ash, strength, water absorption

1. Introduction

Concrete is one of the oldest building materials widely used to construct various structures around the world these days. Advances in the rapidly growing construction sector required extensive concrete mixing. Generally, concrete comprises a mixture of cement, coarse aggregate, fine aggregate, and water.

As well known, concrete is a building material that can stand compressive strength. Studies should be conducted in an effort to enhance the strength of existing concrete compression. Thus, higher compressive strength may be achieved by mixing other alternative materials into the concrete mix. High demand usage of cement had led to research and experimental studies to improvise every aspect of cement. Pozzolanic materials that contain chemical properties similar to cement were commonly used as a cement replacement for concrete.

In cement production by fossil fuel combustion, carbon dioxide is emitted; thus, it is one of the causes of global warming, air pollution and environmental pollution [1]. The amount of CO_2 emission can be reduced in several ways,

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which is by improving the production process of cement. The replacement of cement with a waste material can enhance the durability and strength of the structure in building construction. Industrial waste such as palm oil fuel ash (POFA) can be used as a cement replacement, reducing environmental pollution and leading to global sustainable development [2]. It was selected because it had a chemical composition that contains large amounts of silicon dioxide and can be used as a cement replacement [3], [4]. In the production of concrete, the uses of POFA have great potential as a cement replacement. It also can improve concrete properties and obviously can reduce the waste material of POFA. The uncontrolled dumping of POFA in an open field can have an impact on the environment. These problems can be reduced by using POFA in concrete [5], [6].

2. Previous Study

Hussin et al. [7] studied the effect of POFA fineness on the strength of concrete containing 20% of POFA exposed to 10% of sodium sulphate (Na_2SO_4) solution. They used POFA fineness sizes of 45 µm and 10 µm in their study. They found that the concrete containing 10 µm of POFA fineness size has the highest resistance against sulphate attack compared to concrete containing 45 µm of POFA fineness size.

Sooraj [5] also studied the effect of POFA on the strength properties of concrete. The study also discussed the strength properties of concrete containing POFA in different replacement proportions and compared them to the control mixture. The concrete specimens contain 10%, 20%, 30%, and 40% POFA as cement replacements. The results show that the compressive strength, tensile strength, and flexural strength of concrete containing POFA were lower than control concrete. Sooraj [5] suggested that 20% of POFA as cement replacement could be the optimum mixture for concrete containing POFA. The concrete compressive strength declined when the POFA replacement level exceeded 20% of the cement replacement level.

Bamaga et al. [8] also studied mortar containing 20% of POFA as cement replacement level. They exposed the mortar to fully immerse in 5% sodium sulphate solution for 15 weeks. They evaluate the sulphate resistance of three types of mortar containing POFA collected from different palm oil mills. The compressive strength and flexural strength of mortar containing POFA showed higher compressive strength compared to Portland cement mortar after 28 days of exposure. POFA contains high silicon dioxide content allowing it to be used as a pozzolanic material. According to [9] they conducted a study on properties of concrete containing POFA as cement replacement with proportions of 5%, 15%, 25%, 35% and 45%. They discovered the workability of concrete with the addition of POFA on a certain amount was satisfying. The optimum concrete compressive strength was obtained at 15% cement replacement of POFA. The results showed that the flexural strength of the concrete containing 15% of POFA was slightly increased, similar to compressive strength.

Ismail et al. [4] studied the effect of 3% sodium sulphate on the compressive strength of cement pastes containing POFA up to 180 days of exposure. They found that the cement paste containing POFA was more durable than ordinary Portland cement (OPC) cement paste after 150 days of exposure. The cement paste containing POFA formed lower gypsum, ettringite and contributed more calsium silicate hydrate (CSH) to produce higher compressive strength.

Hamada et al. [6] studied the effect of ultrafine POFA on the compressive strength of concrete using a high volume of ultrafine palm oil fuel ash (UPOFA). The use of small-particle-sized ground POFA to prepare ultrafine POFA is a suitable method to improve its characteristics as supplementary cementitious material. Although high-volume POFA exhibits reduced mechanical properties in the early ages, heat treatment and further grinding reduce its carbon content and increase its pozzolanic activity. Ultrafine POFA improved the compressive strength of concrete, reduces water absorption, thus improve the durability of concrete.

The research was conducted according to several objectives. The two main objectives of this study were to determine the strength of concrete contained ground POFA exposed to sulphate solution. Secondly, to compare the strength of concrete contained POFA exposed to sulphate solution and water. The percentage of POFA used as a cement replacement was 0%, 10%, 20% and 30%. The hardened concrete was exposed to normal and 3.5% sulphate solution until 28 days.

3. Materials and Method

According to [10], POFA is the product produced from burning waste activities in the palm oil mill to generate electricity. These products are usually used as fuel in the boiler of palm oil mills and become ash. The results of previous studies have found that POFA can be used in the construction industry, especially as an additive or replacement of cement in concrete. According to a study by [11], it was determined that the physical and chemical analysis of POFA is a good pozzolanic material and contains a higher percentage of silicon dioxide than OPC. The entire study was conducted in relevant laboratories such as Materials Engineering Laboratory, Advanced Materials Laboratory and Jamilus Research Center at Universiti Tun Hussein Onn Malaysia. The materials that have been used for this study are Portland cement, coarse and fine aggregates, water, palm oil fuel ash (POFA) and 3.5% sulphate solution. POFA that had been used in this study was collected from Ban Dung Palm Oil Industries Sdn Bhd in Kangkar Senangar, Parit Sulong, Johor. The POFA was dried in an oven for 24 hours at 105°C to remove any moisture in the POFA. Then, the POFA were sieved passing 300 μm sieve and refined using ball mills for two hours. The POFA containing total SiO_2+Al_2O_3+Fe_2O_3 between 50% to 70% and its loss of ignition (LOI) is between 6% to 12 %, refer to ASTM C618 [12], the POFA in this research is classified as in between class C and F. Free of impurities of river sand were used in the study. The sand must be cleaned and dried before being used. The sand was dried in an oven for 24 hours to remove the moisture content contained in the sand. The size of coarse aggregate used in this study was a passing sieve of 14 mm. On the other hand, water plays an important role in the mixing process because it hydrates the cement and holds the mix together. Water used in concrete mixing must be free from contaminant traces from the soil, silt, organic acid and other organic material. The water-cement ratio for concrete specimens was 0.64 per fresh mix to achieve the target slump. Table 1, Table 2, and Fig. 1 below describe the properties, chemical composition and sieve analysis of the material that has been used for this research.

Table 1 - Properties of material

Material	Type/Properties	Density (kg/m^3)	Specific Surface Area (m^2/g)	Particle Size Mean (µm)
Cement	Normal Portland Cement	1164	1.16	16.4
POFA	POFA passing sieve 300µm and refined for 2 hours in ball mill	564	0.87	35.3
Coarse Aggregate	Passing sieve 14 mm	-	-	-
Fine Aggregate	Passing sieve 5mm	-	-	-
Water	Tap Water	-		-

Table 2 - Chemical composition of materials

Chemical composition	OPC %	POFA %
Silicon dioxide (SiO_2)	20.57	45.5
Aluminium oxide (Al_2O_3)	4.93	11.7
Ferric oxide (Fe_2O_3)	3.8	4.5
Calcium oxide (CaO)	63.85	9
Magnesium oxide (MgO)	0.9	5
Sulphur trioxide (SO_3)	2.4	2.6
Sodium oxide (Na_2O)	0.05	0.4
Potassium oxide (K_2O)	0.9	5
Phosphorus pent oxide (P_2O_5)	0.12	6
Loss of ignition (LOI)	2.48	10.3
SiO_2+ Al_2O_3+ Fe_2O_3	29.3	61.7

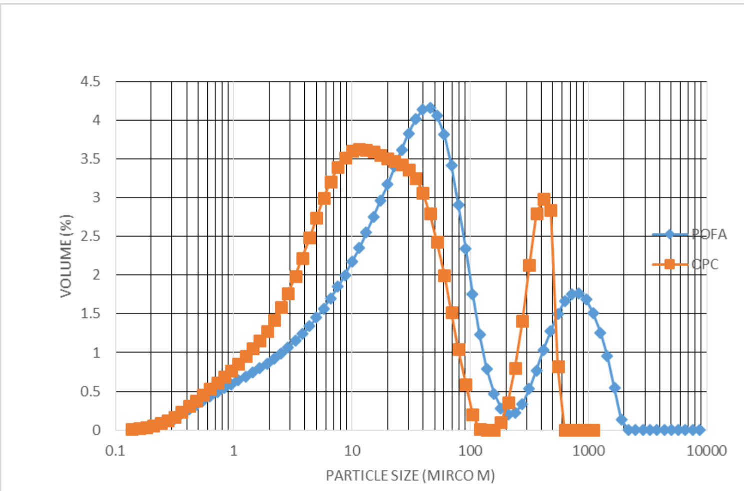

Fig. 1 - Particle size analysis of OPC and POFA

3.1 Specimen

The design of concrete mixtures is an important process for determining the ratio of mixtures to be used in the concrete mixing process. This technique allows the mixture to achieve the desired concrete grade. The concrete grade required in this study is 30 N/mm^2. The mixture design proportion is summarised in Table 3.

Table 3 - Mix design proportion

Term	POFA Percentage	OPC (kg/m^3)	POFA (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)
P0	0%	390	0	1170	625	250
P10	10%	351	19	1170	625	250
P20	20%	312	38	1170	625	250
P30	30%	273	57	1170	625	250

Specimen were cast in cubes, and prisms had been produced for the testing. The size of the cube was 100 mm × 100 mm × 100 mm, and the size prism was 500 mm × 100 mm × 100 mm. For mixture, proportions were made for normal water and sodium sulphate exposure. Total specimens of 144 were produced for this study. The cement was replaced by POFA by volume. The ingredients of concrete were thoroughly mixed in a mixer machine till uniform consistency was achieved. The concrete specimens were exposed to water and 3.5 % sodium sulphate solution after 24 hours of casting. All the specimens were immersed in water and sulphate solution until 28 days. When the testing age is reached, they were tested for water absorption, compressive strength, and flexural strength at 7 and 28 days.

3.2 Testing Method

The water absorption test was conducted before concrete being tested for compression test. Based on BS 1881-122:2011 [13], water absorption is important where it has relation with strength. After specimen of concrete curing for 7 and 28 days, the concrete was dried in an oven for 72 ± 2 hours. Then, each specimen was removed from the oven, allowed to cool for 24 ± 0.5 hours, and the weight of the specimen was recorded. The specimens were immersed in the water for another 30 ± 0.5 minutes. Each specimen was removed and dried with a cloth until all water was removed from the surface. Each specimen was weighed and recorded as wet weight. The compression test conducted on the concrete cube was a size of 100 mm × 100 mm × 100 mm. Testing was conducted according to the method states in BS EN 12390-3:2019 [14]. The compressive strength of the specimen is determined by dividing the maximum load carried by the specimen during the test by the area of concrete. While the flexural strength test was conducted according to the method states in BS EN 12390-5:2019 [15]. The prism with the size of 500 mm × 100 mm × 100 mm was used.

4. Results and Discussion

4.1 Slump Test

A slump test is conducted to determine the workability of concrete in wet conditions. This test is carried out in accordance with the specification of BS EN 12350-2:2019 [16]. Fig. 2 showed the slump test values of specimens containing POFA in which with higher percentage of POFA reduces the workability of concrete. The slump test value of 75 mm ± 25 mm was determined based on the concrete mixes that were designed. Water cement ratio and water content are very important as they will affect the strength of the concrete. The same water-cement ratio was used in this study. It showed a specimen of P0 recorded the highest workability of 70 mm, and concrete with 30% of POFA (P30) recorded the lowest workability compared to other mixed concretes. Besides that, the slump values for P10 and P20 were 50 mm and 34 mm, respectively. The slump test shows that higher POFA replacement lowers the concrete workability. According to [17], the decline in slump value is due to the water-absorbing material. Thus, the mixing water is depleted due to absorption by POFA in the mix, causing the concrete workability to decline. The consumption of POFA in concrete increased the water demand of the fresh concrete. Studied by [11] and [18] also experienced the same condition as higher cement been replaced by POFA lower the concrete workability.

4.2 Density

Fig. 3 showed the density graph of water curing and sulphate exposure. Curing and exposure of 28 days begin as early as the first day of hardened concrete. This test was carried out in accordance with BS EN 12390-7:2019[19]. Fig 3 showed the density of each specimen when collected after being cured and exposed for 28 days in a curing tank. The density for the P0 specimen that was cured underwater was 2319 kg/m^3. The highest value of concrete density containing POFA was from concrete P10 contained 10% of POFA with 2318 kg/m^3. Followed by P20 with 2316 kg/m^3, and the lowest concrete density was from 30% of POFA with 2312 kg/m^3. For concrete exposed to sulphate, the density of concrete P0 was 2326 kg/m^3 at 28 days. Following by concrete replacement of POFA 10%, 20% and 30% respectively recorded 2324 kg/m^3, 2319 kg/m^3 and 2314 kg/m^3. These indicated that P10 concrete with 10%

replacement of POFA had the highest density compared to other concrete containing POFA exposed to sulphate solutions. The density test results show a higher declination in the density of concrete containing POFA for both exposures with a higher cement replacement percentage. There was an increase in concrete density when exposed to sodium sulphate compared to concrete fully immersed in water after 28 days. A similar pattern was experienced by [8], with concrete undergoing expansion and the concrete density increases when exposed to sulphate. The decrease in concrete density in water is due to the reduction in the formation of hydration products during the hydration process resulting from cement replacement with POFA. At the same time, the increase in concrete density is due to the formation of gypsum in concrete when concrete is exposed to sulphate due to the hydration reaction of the product with sulphate ions. Thus, concrete containing less cement produces fewer hydration products will undergo less gypsum formation resulting in less increase in concrete density.

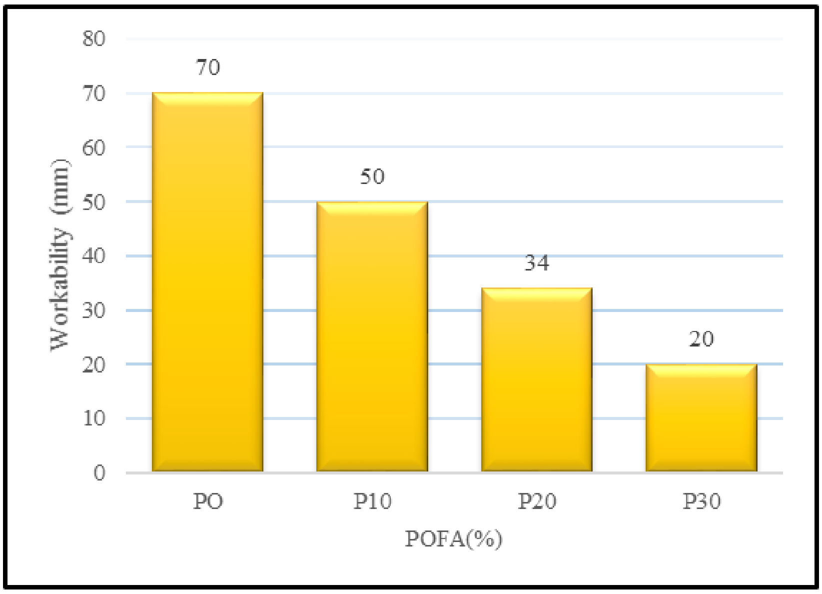

Fig. 2 - Concrete workability graph

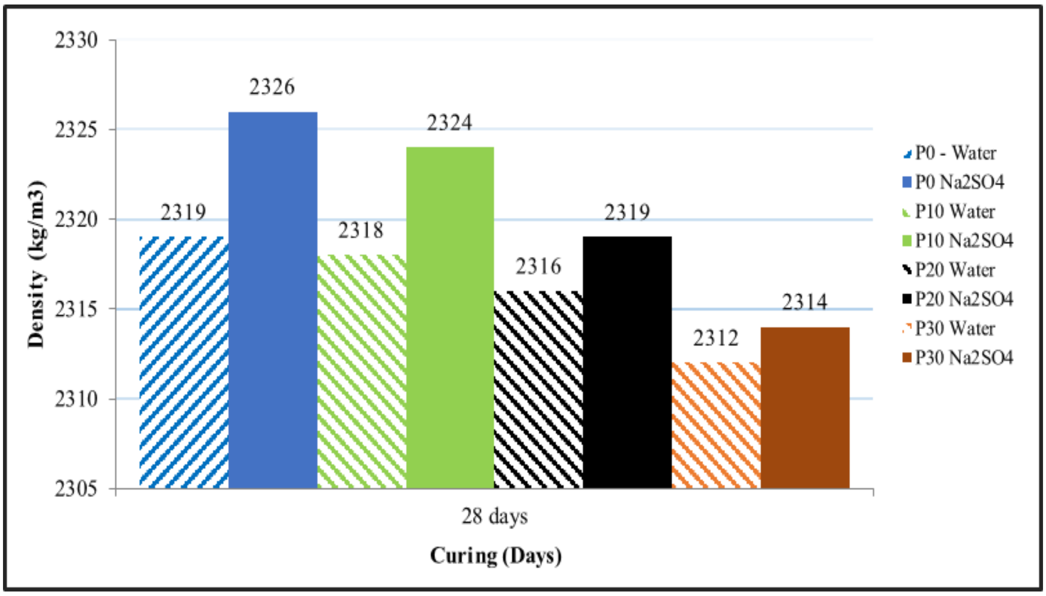

Fig. 3 - Density graph of water curing and sulphate exposure

4.3 Water Absorption

The water absorption was measured by immersing the concrete in the tank for 7 and 28 days. Fig 4 showed the average water absorption of concrete after curing with two different curing conditions. The results showed that the average percentage of P0 on day 7 for sulphate curing recorded the lowest value among all specimens with 4.82%. For specimens containing POFA, the highest water absorption value for sulphate curing was 6.69%, which was from the P30 specimen. P20 specimen was slightly higher with 5.42% compared to P10, which only absorbed 5.33%. For 28 days, specimens exposed to sulphate solution recorded the highest value of water absorption was from P30 concrete, which contained 30% POFA with 6.99%. Then, following by P20 and P10 with 5.93% and 6.04%, respectively. The water absorption for the P0 specimen was 4.9%. It also showed the average percentage of water absorption of concrete in normal water for 7 and 28 days in Fig 4. On day 7, the highest value of water absorption was from P30 with 5.87% compared to concrete P0, the lowest water absorption with 4.63%. For 28 days, it still showed the highest water absorption from the P30 specimen with 5.08% and the P0 specimen with 4.55%, the lowest value. Overall, it showed that the specimen contained 30% replacement of POFA caused the highest water absorption for sulphate curing and water curing. Concrete contained POFA produced higher water absorption than the control mix. A comparison of the average percentage of water absorption for concrete exposed to sulphate solution and normal water for the curing period of 7 and 28 days can be concluded. Concrete P30 or containing POFA of 30% exposed to sulphate solution and normal water was more likely to absorb moisture compared to OPC concrete in normal water and sulphate solution that recorded the lowest percentage on day 7 and 28. Studies by [20] also show a similar pattern where the water infiltration rate to concrete containing POFA is higher than that of control concrete. Based on his study, concrete containing 30% POFA is the concrete with the highest water permeability rate on the 28th day. Concrete containing POFA exposed to normal water showed decreased absorption rate at 28 days compared to 7 days. The reaction of pozzolan with CH occurs and causes the pores to become denser and closed by the formation of calcium silicate hydrate CSH [21]. A study by [22] and [4] showed that concrete exposed to sulphate solution experiences expansion, loss of strength, cracking, and external and internal concrete damage.

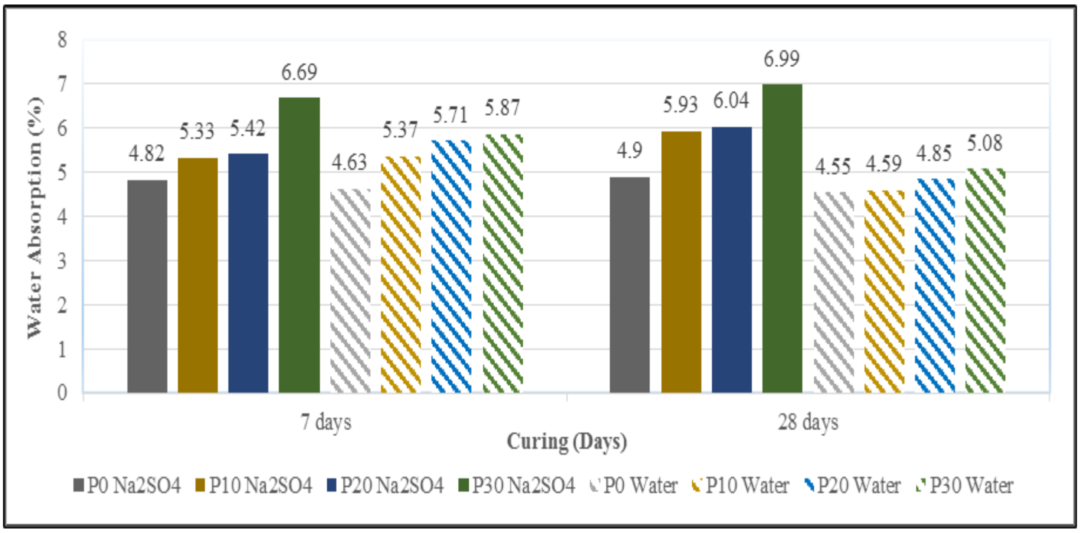

Fig. 4 - Water absorption graph against 7 and 28 days of concrete curing period

4.4 Compressive Strength

The compressive strength of concrete was measured by breaking the specimens in a compression testing machine. Fig. 5 shows the compressive strength of the concrete specimen. The graph showed that the compressive strength of concrete exposed to water and sulphate increased with time up to 28 days, but the compressive strength of the concrete was declining with the increment of POFA replacement. The compressive strength at day 7 for concrete exposed to sulphate for the P0 specimen was 27.6 MPa. The highest compressive strength among all concrete contained POFA was 26.0 MPa obtained from the P10 specimen that contained 10% of POFA. P20 had compressive strength with 24.7 MPa, and the lowest compressive strength was 24.1 MPa from the P30 specimen that contained 30% of POFA. For 28 days, average concrete compressive strengths exposed to sulphate solution showed a similar pattern as day 7. The compressive strength for P0 was 35.4 MPa, which the OPC specimen do not undergo cement replacement. Therefore, CH in OPC specimen reacted with sulphate solution, and abundant gypsum formation occurred and resulted in higher compressive strength [4], [8]. The lowest compressive strength was a concrete specimen containing 30% of POFA, which carries 25.6 MPa of compressive strength at day 28. P10 specimen recorded the highest value among all specimen containing POFA with 31.6 MPa. In contrast, P20 has a strength of 30 MPa. The formation of gypsum in the concrete has stressed the concrete and turned to lower the strength of the concrete. Furthermore, CH formation reduces as it acts to form gypsum, thus reduces the formation of CSH in pozzolanic reaction. The reduction of CSH and the formation of internal stress weakened the concrete. Studied by [23] also proves that concrete exposed to sulphate will experience expansion, cracking, loss of strength and damage of concrete externally and internally, similar to [4], [22].

It is also shown in Fig. 5 the concrete was immersed in water for 7 and 28 days. The compressive strength from the P0 specimen was 30.2 MPa. P10 specimen showed the highest strength among all concrete contained POFA with 29.6 MPa. Compressive strength from the P20 specimen was 21.7 MPa. The lowest compressive strength was 21.5 MPa from the P30 specimen that contained 30% of POFA. For 28 days, concrete cured in water showed for P0 specimen, the compressive strength was 40.5 MPa, and P30 was 25.8 MPa, i.e., the lowest strength. The declination of strengths was due to the fact that the pozzolan reaction acts more slowly, and thus the concrete added or replaced by pozzolan will not be as high as concrete made using only cement [18], [24].

Based on Fig. 5, it can be concluded that the compressive strength of concrete for each specimen exposed to sulphate solution and normal water decreases in proportional to the increase in POFA percentage and concrete curing period. If we compare the compressive strength of concrete exposed to sulphate solution and normal water, there was a decrease in the strengths of concrete exposed to sulphate solution. This can be attributed to the pozzolanic reaction, which produces less calcium silicate hydrate (CSH) and calcium hydroxide (CH), which reacts with sulphate and formed more gypsum. Gypsum formation in the early 28-day stage has filled the pore in concrete and causes reduction of strength. This can be evidenced by the formation of gypsum, resulting in internal stress and subsequent expansion that lowers the strength of concrete [23].

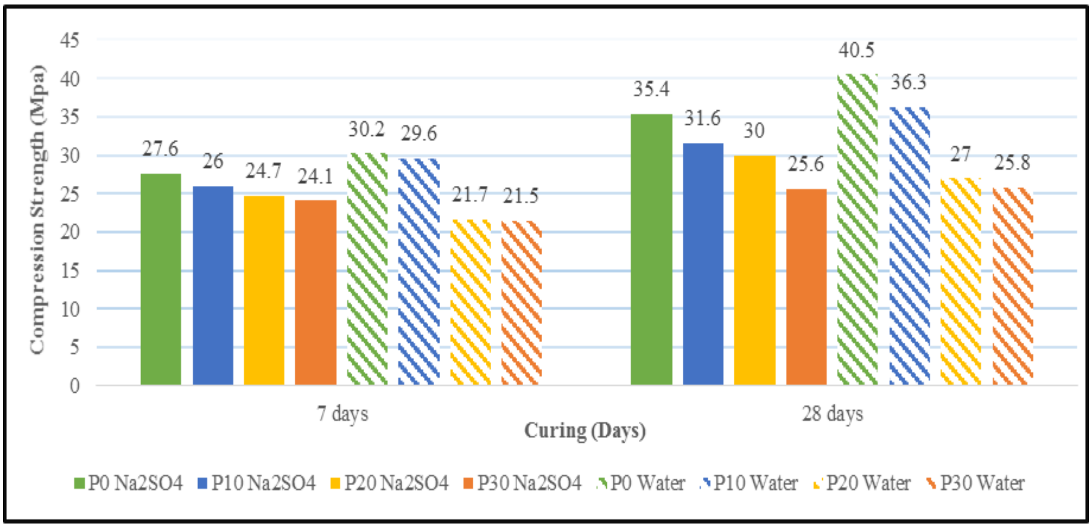

Fig. 5 - Compressive strength graph against 7 and 28 days of concrete curing period

4.5 Flexural Strength

This test was conducted on the specimen prism sized 500 mm × 100 mm × 100 mm. The purpose of this test is to obtain the bending strength of the concrete specimen using the three-point axial load method. Fig 6 shows the flexural strength for specimens P0, P10, P20 and P30. The flexural strength at day 7 for the P0 specimens recorded the highest strength value among all specimens in sulphate curing with 10.2 MPa. The lowest flexural strength was 8.5 MPa from the P30. Furthermore, for 28 days sulphate curing specimens, it showed that the highest flexural strength was 12.1 MPa from the P10 specimens. The lowest flexural strength was 9.4 MPa from the P30 specimen that contained 30% POFA. It was found that the flexural strength for all specimens increased after the 7th day of curing except for the P0 specimen. The P0 specimen had loss it flexural strength at the 28th days of the specimens. The losses of flexural strength in the P0 may due to the increase of density in the concrete caused by the gypsum formation. Excessive of gypsum and ettringite causes internal stress in the concrete which lead to reduction of the performance of the concrete [4]. The highest bending strength was achieved by the P10 specimen. The P30 specimen still recorded the lowest reading of 9.4 MPa. The reaction of pozzolan in concrete with higher POFA content and producing less calcium silicate hydrate (CSH), and CH reacts with sulphate and causing the strength of concrete to decrease [8].

For the 7 days of water curing, the flexural strength was 9.5 MPa, which recorded the highest flexural strength value for concrete P0. P10, P20, and P30 showed decreased strength of 9.0 MPa, 8.6 MPa and 7.3 MPa, respectively. In addition, for 28 days of water curing, concrete P0 was 10.8 MPa recorded the highest value compared to the other POFA replacement specimen. Moreover, on the 28th day of curing, the OPC with 10.8 MPa recorded the highest value compared to the POFA substituted specimen. This is because the cement mixture on OPC concrete can react fully as it does not experience any obstruction from POFA compared to other specimens that have been mixed with POFA [9]. Based on a study conducted by [5], he stated that the flexural strength of concrete that has been replaced by 10% of POFA has a strength value that is almost the same as the control concrete. But when the POFA increases by more than 20%, it will reduce the flexural strength of the concrete.

4.6 Influence of Density and Water Absorption on Compressive Strength

Among all specimens in sulphate solution and water, P0 specimen had the highest density values. The density of the P0 specimen in sulphate solution shows higher value than in water. The density of concrete containing POFA decreases when exposed to sulphate solution and water. The decreases in the density of concrete were due to the replacement of cement with POFA affects the weight, as more and more the replacement of POFA, concrete becomes lighter and causes the density to decrease. Concrete containing POFA that exposed to sulphate solution had higher density compared to concrete containing POFA in water. Concrete P10 had the highest density among all concrete containing POFA. The increase in concrete density exposed to sulphate solution were cause by the formation of gypsum in concrete.

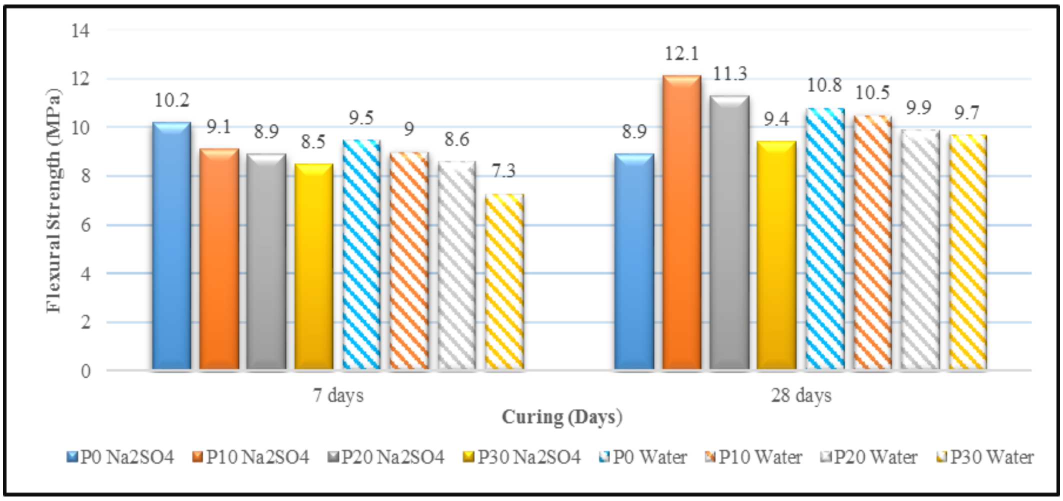

Fig. 6 - Flexural strength graph against 7 and 28 days of concrete curing period

Besides that, the water absorption value showed that the concrete containing POFA absorbs more water than P0 when exposed to sulphate solution and water. Among all specimens in sulphate solution and water, P30 specimen absorb water the highest. The water absorption of P30 specimen in sulphate solution shows higher value than in water. The water absorption of concrete containing POFA increases when exposed to sulphate solution and water. The average water absorption on day 7 and 28 showed that the more POFA substitution in the concrete, the higher the water absorption value compared to P0. Based on the studies of [17] proved that POFA has the ability to absorb more water than P0.

The compression strength graph pattern also showed the same pattern as the density. The compressive strength values of the specimen P0 exposed to sulphate and water curing showed the highest values, whereas, for the specimens containing POFA, the strength decreased when the POFA increased. However, 10% replacement of POFA showed the highest strength among all specimen containing POFA. Replacement of 10% POFA had been achieved by 89% of the compressive strength of P0 within 28 days.

Furthermore, the specimens exposed in the sulphate solution also showed higher density compared to water, but its density pattern remained declining. This is due to the replacement of cement with POFA and reaction with sulphate causing CH to further decrease. It can be concluded here that the more POFA substitution, the lower the concrete density in sulphate solution and normal water.

In addition, specimens containing POFA exposed to sulphate solution had a higher absorption rate than normal water. The reaction of CH with sulphate forms gypsum and causes more crack lines to form and causes more water absorption to occur. The formation of gypsum causes water absorption of concrete to increase. When more gypsum is formed, this will cause the crack to occur and cause an increase in water absorption. Gypsum that has formed too much will cause the expansion to occur and result in cracking [22], [23]. The sulphate reaction internally presses the concrete as the formation of gypsum occurs in the concrete, increasingly resulting in internal pressure. When there was internal pressure present, it affects the compressive strength, reducing the strength of concrete.

5. Conclusion

The curing condition and the percentage of POFA have a significant effect on the strength of concrete. This study investigated the water absorption and compressive strength of POFA as a cement replacement. After all experiments in the laboratory were completed, the results of this study were obtained and analysed. Based on the results and discussion, the replacement of POFA in concrete had reduced the strength and increased water absorption of the concrete. The highest increase in compressive strength and flexural is replaced by 10% of POFA with two types of curing. The results showed that the use of POFA in concrete influences the absorption of water in concrete.

Replacement of POFA by 10 % produces the highest compressive strength among concretes containing POFA. A decrease in concrete strength occurred when the replacement of more than 20% of POFA was used. This study showed the difference in the strength values in water curing, and sulphate curing for concrete P0 and concrete contained 10% POFA was 89%. Based on the results, it is shown that the optimum percentages of POFA were 10%. The highest strength among all concrete contained POFA was concrete P10 contained 10% POFA. Although the compressive strength of 10% POFA is lower than concrete P0, its strength was achieved as it exceeds 30 N/mm2 grade concrete. From this study's findings, it can be concluded that the optimum use of POFA is 10%.

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