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Strength and sulphate resistance of high performance concrete containing different fineness of Palm oil fuel ash

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Abstract. This research aims to study the effect of different fineness of Treated Palm oil fuel ash (T-POFA) on the strength and sulphate resistance of high-performance concrete (HPC). For this research, besides the control mix, two mixes with fineness of 45 μm and 150 μm of POFA were prepared with 20% replacement with ordinary Portland cement (OPC). For sulphate resistance, the concrete specimens were immersed in 5% sodium sulphate solution to investigate the sulfate resistance in accordance with appropriate ASTM standards. In addition to that, the higher fineness of T-POFA gives better resistance towards sulphate attack due to its pozzolanic reaction. From the tests that were carried out, the results showed that 20% of 45 μm T-POFA replacement in HPC concrete gives the lowest in compressive strength loss at 120 days compared with 150 μm replacement and control HPC concrete in sulphate attack. It is noticed that, the compressive strength of 45 μm T-POFA shows increment in compressive strength after 120 days of immersion due to the pozzolanic reactions that took place. This in turn gives extra layer of C-S-H to concrete which strengthened the bond. Therefore, the higher fineness of T-POFA gives better resistance towards sulphate attack. This result suggests that concrete design of high performance concrete (HPC) contains POFA 45 μm is better to be used as a cement replacement compared with POFA 150 μm and control concrete for sulphate resistance.

1. Introduction

The increasing global production of Ordinary Portland cement (OPC) in the construction sector is rapidly high due to the increase in population growth demand for construction industry. Therefore, the utilization of cementitious materials such as Palm oil fuel ash is necessary. Palm oil fuel ash (POFA) is an industrial by-product waste from the palm oil mill. Palm oil fuel ash contains silica and alumina in which can be used as a partial replacement for cement into concrete mix due to its pozzolanic content. Researchers have revealed that, the addition of POFA into the concrete mix whose chemical composition contains large amount of silica can be used as a cement replacement. Furthermore, the utilization of high performance concrete (HPC) for concrete mix design is widely used in civil engineering project throughout the worlds due to its mechanical and durability properties as well as resulting in cost savings for construction projects [11]. The addition of POFA also, has the potential to increase the bonding between the concrete paste and aggregates by creating an extra strength due to the pozzolanic reactions, thus it will improve the durability of the concrete [1]. In a study by Hamada [8] shown that, with the addition of POFA in concrete mixture thus it will improve the resistance to the chloride and sulphate attacks. Besides, Kroehong, Sinsiri, and Jaturapitakkul [10] claimed that, the ground palm oil fuel ash in high fineness will show the increase in compressive strength. Another research done by Alsubari et al. [12], which investigate on the effect of treated Palm oil fuel ash (T-POFA) in acid attack resistance. Many researchers have studied the use of POFA in normal concrete, higher fineness POFA, acid attack, lightweight concrete etc. However, there are no researches yet to investigate the different addition fineness of T-POFA tested in high performance concrete (HPC) with the comparison of control HPC concrete towards sulphate resistant in terms of the concrete compressive strength and durability. This paper presents the experimental results of the utilization of two different fineness of palm oil fuel ash and the control HPC concrete to evaluate on the resistance of concrete towards sulphate solution.



2. Review and Discussion

2.1. Compressive strength

The compressive strength of control HPC concrete and concrete containing micro palm oil fuel ash (POFA) were determined after curing in a water tank for 28 days. In every batch of concrete mix, the average of the concrete compressive strength was determined from the three specimens of 100 mm × 100 mm × 100 mm concrete cube. The average of the compressive strength results for control concrete and the T-POFA was shown in Figure 1.0. It can be seen from the results that, the concrete mix contained POFA 150 and POFA 45 exhibit higher strength than control mix. According to the standard in ACI 211.4R-93, the concrete mix design of high-performance concrete should have at least 62 MPa of compressive strength at 28 days. Therefore, the results indicated that the design of the concrete mix can be considered as high-performance concrete (HPC) because concrete contains POFA 150 and POFA 45 have achieved the strength of 62.50 MPa and 66.20 MPa respectively. Thus, the concrete will be categorized as high-performance concrete and with the utilization of palm oil fuel ash (POFA) will then reduce its permeability and improves the sulphate resistance of the concrete. The observation shown that, the control mix shows the lowest in strength, but an impressive achievement for the addition of 20% micro fine POFA replacement with the fineness of 150 μ m and 45 into the concrete paste to achieve increment of compressive strength after 28th days of water curing. These results are in agreement with the finding by Muthusamy [2] where the utilization of 20% pozzolanic materials into concrete paste will assist concrete to achieve the highest compressive strength. Based on the results, the high fineness of POFA contained in the concrete mix shows that, the compressive strength of concrete is increasing gradually towards the effect of higher POFA fineness. It was observed that, the integration of 20% T-POFA 150 and T-POFA 45 in concrete mix shows gain in strength of 9.98% (62.5 MPa) and 16.5% (66.20 MPa), respectively. The gain in strength for T-POFA 45 is slightly higher than the T-POFA 150 because of higher fineness lead to more pozzolanic reaction to occur and it might be due to the filling effect of fine particles. The POFA 150 shows only slight difference in strength as compared to control concrete with based on the experimental data below and this might be due to few factors as the contain of POFA 150 has coarse particle that reduced the reactivity of chemical reaction. The coarser particle contained in POFA is similar with research by Nguong and Awal [3] that concluded that, the higher finer of POFA will develop higher strength in compressive strength of concrete. Whereas, the control mix shows the lowest among the three batches. The concrete mix with the addition of POFA shows better results because the high silica content in POFA which result in the Pozzolanic reaction occurs, involving the reaction between calcium hydroxide with SiO₂ framework to form calcium silicate hydrate (C-S-H), which is the main reaction product of the pozzolanic reaction. Therefore, high fineness POFA is a good pozzolanic materials due to its pozzolanic activity.

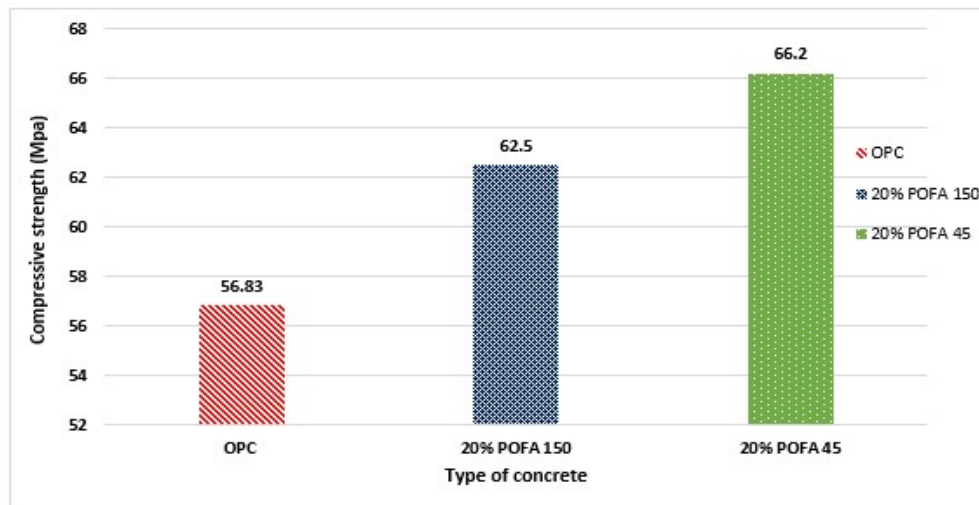


Figure 1: Compressive strength test after 28days of water curing

2.2. Compressive strength test after 28 days of water curing

The compressive strength of concrete immersed in 5% sodium sulphate, Na_2SO_4 solution for 28 days, 56 days and 120 days is compared in Figure 2. In the experiment, the compressive strength of the control concrete was compared with the concrete that contain POFA of 45 μm and 150 μm fineness to analyze on the durability of pozzolans concrete after been exposed to sulphate solution. The companion specimen comprising three OPC, three T-POFA 150 and three T-POFA 45 concrete cubes have been continuously immersed in sodium sulphate solution at the same time for comparison purposes.

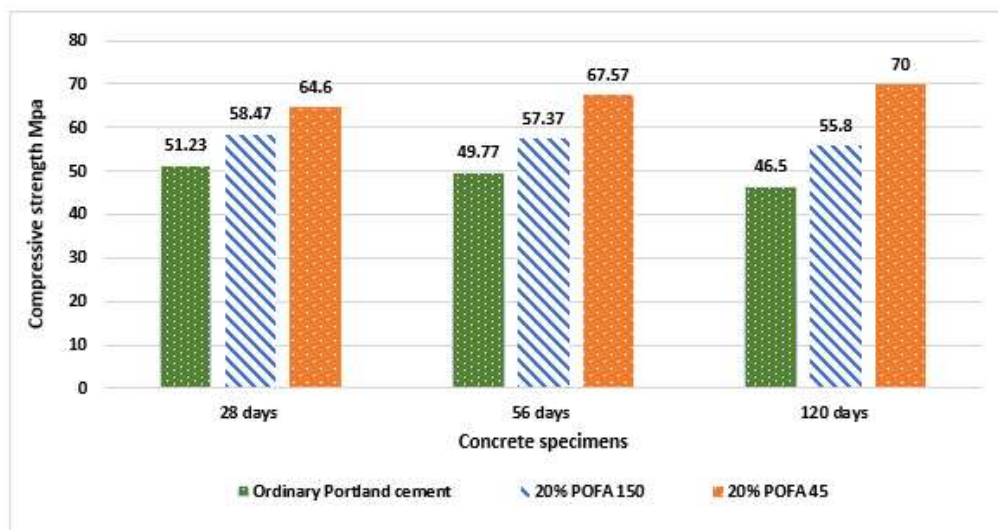


Figure 2: Deterioration process of sulphate attack

Figure 2 shows the compressive strength values on the 28 days, 56 days and 120 days of immerse in sodium sulphate; it is obvious that the control concrete is gradually decreasing in strength with the average of 51.23 MPa ,49.77 MPa and 46.5 respectively. Meanwhile, the concrete with the usage of T-POFA 150 to replace OPC at rates of 20% by the weight of binder shows only slightly decrease in compressive strength compared with control concrete after 120 days of sulphate curing. It is observed that, the control specimens exhibit highest strength reduction as compared to both cubes with the addition of POFA in the concrete mix. However, there is a continuous increment in strength with the addition of T-POFA 45 into the concrete mix after 56 days to 120 days of immersed in sodium sulphate compared with the other specimens for sulfate attack. Based on the experimental data, it is noticed that there is a small difference in the rate of strength gain at the early age of pozzolan concrete and significant development of strength was formed at the later age. It is reasonably enough to indicate that, the strength of concrete contain POFA was slowed in the early curing period, but it was significantly increased at the later age due to the chemical composition between the high content of silica in POFA over the calcium content in Portland cement, which resulted in the delay of the reaction of calcium hydroxide $\text{Ca}(\text{OH})_2$. At the later age, the compressive strength of concrete contain POFA was increased with respect to the extension of time of immersion. In a recent study by Aprianti [4] it was reported that, the pozzolan concrete showed a minimal characteristics of pozzolanic reaction at the early age, but it showed an increment in the development of strength in a pozzolans concrete at a later age. This is because the pozzolanic reaction was taking place with the production of calcium silicate hydrate (C-S-H) from the reaction of cement hydration together with the high silica content in POFA which caused the strength to increase and improve the resistant of concrete to sulfate attack or expose in any aggressive environment.

2.3. Relative Compressive strength

Comparison between the difference in the reduction of strength value of specimens immersed in sulphate solution and water cured specimens are illustrated in Figure 3 and the tabulated data of compressive strength can be seen in Table II. At the end of the experiment, the specimens were tested for compression to identify the differences of residual strength between the companion specimens under curing of 28 days in water at room temperature along with the test specimens suffer in sulfate attack at the end of the immersion period of 120 days. The strength characteristic of the companion specimens compared with the other test specimens that immersed in sulphate solution is regarded as strength loss.

Table 1. Sulphate resistance test result

	Compressive strength (MPa)		
	0% POFA (Control concrete)	20% POFA 150	20% POFA 45
Water curing (28 days)	56.83	62.50	66.20
Sodium sulphate (120 days)	46.50	55.80	70.00
Strength loss (MPa)	10.33	4.47	0

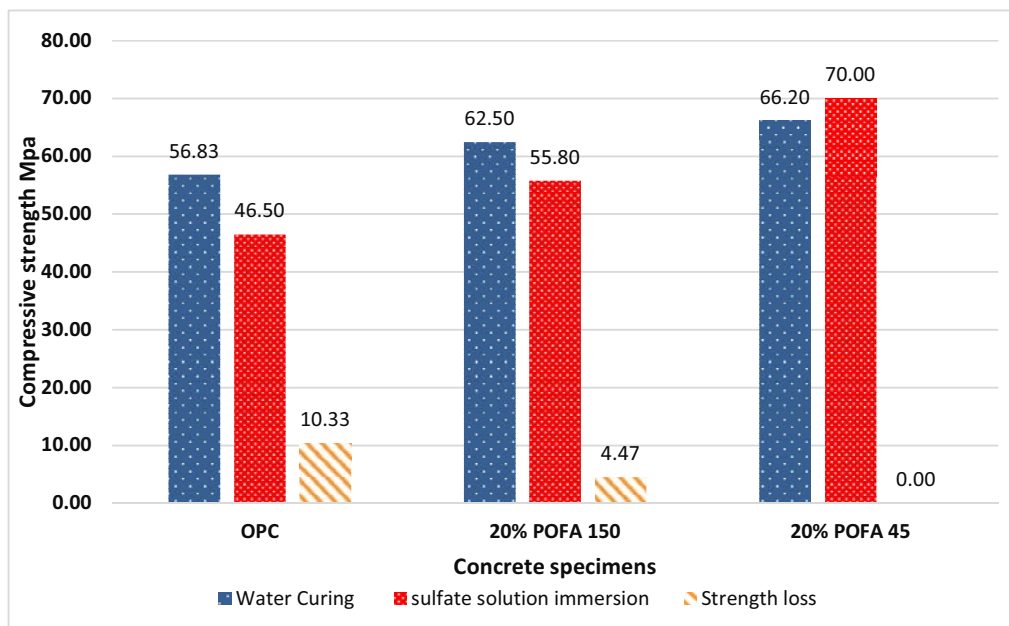


Figure 3: Average compressive strength comparison of concrete after immersed in sodium sulphate solution and water curing

It was observed that, the T-POFA 45 shows an increment of compressive strength at 120 days of immersion in sulphate solution as compared to 28th days of water curing with reference to Figure 3. Whereas, the strength of the control concrete and T-POFA 150 shows continuously loss in strength with respect to time at the loss of 10.33 and 4.47 respectively as shown in Figure 3. From the figure, it is apparent that the specimens for control concrete exhibits highest strength loss as compared to those concrete with the addition of POFA. The strength loss experience by control HPC concrete and the T-POFA 150 fineness specimens is understood to be the consequence of the prolonged submersion into sodium sulphate solution. The control HPC concrete without the addition of pozzolanic materials will developed fine cracks on the surface due to the greater heat developed during the cement hydration process in which may lead to the reduction of strength during the effect of deterioration process take place. This is to note that the control specimens considerably contain higher C_3A during the first day of hardening should in theory make it more active to sulphate attack or exposed to aggressive environment. Therefore, the reduction of calcium oxide in the concrete paste is necessary as it is one of the reasons that may lead to failure in concrete strength. Many researchers have reported that, the strength of concrete that was exposed to sulphate solution can be improve with the utilization of POFA in the concrete mix. This is because POFA has less calcium content but high in silica, which pozzolanic reaction will takes place with the right amount of calcium and moisture presence and thus pozzolanic reaction will takes place resulting in formation of the C-S-H gel Ahmadi [5]. The formation of the secondary layer of C-S-H will produce when it reacts with the abundant free lime of hydration process, thus producing high resistant concrete to sulfate attack and increase the durability of the concrete. The internal structure of the concrete will become denser with the formation of calcium silicate hydrate (C-S-H), which will reduce the porosity and permeability of the concrete making it unavailable for sulphate, ettringite or gypsum to form, thus the chances for Sulphate ion penetrating the concrete will be lower [6]. The results of specimens immersed in sulphate solution for 120 days suggested that the replacement of treated POFA at 20% with higher fineness of 45 μ m yielded a compressive strength of 70 MPa compared with that of T-POFA 150 and control mix, which was 55.80 MPa and 46.50 MPa, respectively.

It has been found that the fineness of ash was formally influence the strength development of concrete. This is due to the fact that, the higher development of strength in concrete with fine ash was therefore had a greater pozzolanic reaction and the high surface area of fine particles contained in the fineness of POFA could also fill in the voids of the concrete mixture, which improves the pozzolanic activity and hence the strength [3]. On the other hand, it is observed that the T-POFA 150 shows less effectiveness in terms of pozzolanic activity because the T-POFA 150 and control concrete still experience loss in strength after 120 days of immersion in sulphate solution. This is because, the T-POFA 150 might contain some coarser particles in the ash that will reduce the pozzolanic reactivity of particle in the mixture. This results discussion is in full agreement with the research done by Thomas, Kumar, and Arel [7] where the researchers mentioned that the coarser particle size of POFA will lead to the delay in setting time due to the more water absorption of the coarser particle in POFA which may delays the hydration process. The delays in the hydration process due to the formation of important product of calcium hydroxide during the hydration of Portland cement will affect drastically on the pozzolanic activity of concrete that contains POFA because the silica content from POFA cementitious to produce secondary gel of C-S-H will be less effective due to the less formation of C-S-H and calcium salt that may lead the concrete become less dense, thus the durability of the pozzolan concrete that contain lower fineness will be impact. As reported by Hamada [8], the concrete specimens will resist to sulfate attack when a higher fineness of pozzolanic material is used with the reduction in the content of calcium hydroxide. This result also suggested that T-POFA 45 exhibited higher resistance to sulphate attack compared to T-POFA 150 because T-POFA 45 contains more secondary C-S-H gel and lesser calcium hydroxide, thus the pozzolan concrete will achieved better resistance to sulphate attack by increasing the durability. The result trend is similar with research done by Mohd Warid Hussin [9]. where it can be seen that, POFA provides good pozzolanic effect and high sulphate resistance as it is tested with higher fineness of POFA in high strength concrete. Thus, the results suggested that the finer ash contain is POFA will provide better pozzolanic reaction and the ductility of concrete in exposed to aggressive environment will be increases.

3. Conclusion

At the end of the experiment, it is found that the higher fineness of Palm oil fuel ash (POFA) had a greater pozzolanic reaction. This is because, the fine particles contain in POFA after grinding and treated will increases the surface area of POFA particles and the increase in surface particles of POFA has various advantages in terms of increased the pozzolanic activity, thus increase the performance of concrete and enhance the durability of concrete in any aggressive environment exposure. It is interesting to note that the compressive strength of concrete contains higher fineness of palm oil fuel ash is greater than that in case of less fineness POFA or control concrete. In addition to that, the High-performance concrete (HPC) can be produced from the combination of Palm oil fuel ash and the additives of superplasticizer into the concrete mix design. Therefore, it is to conclude that the sulphate resistance test of HPC with higher fineness palm oil fuel ash (T-POFA 45) had a less value in terms of compressive strength loss compared with concrete mixes with less fineness and control concrete at the ages of 28 days, 56 days and 120 days of sulphate attack.

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