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Research Article

Potential of Palm Oil Fuel Ash as a Partial Replacement of Fine Aggregates for Improved Fresh and Hardened Mortar Performance

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The growth of Malaysia has caused many industries to grow rapidly, especially construction industries due to the demand for more homes, buildings, and infrastructure. The production of concrete and mortar is highly requested. Therefore, the demand for fine aggregate becomes higher because fine aggregate is one of the main elements in concrete and mortar production. The high demand for fine aggregates will create a worrying situation where the fine aggregate crisis will worsen. An alternative was introduced to replace the fine aggregate known as palm oil fuel ash (POFA) in order to reduce the use of natural resources such as fine aggregates and lead to the reduction of fine aggregate mining activity. POFA produced from palm oil fibre, palm oil shell, and mesocarp at high temperature has no benefits in the commercial return. Thus, POFA that has accumulated in landfill has the ability to create environmental pollution. Due to the pozzolanic behaviour of POFA, it could be relevant when POFA is used in the production of mortar as a partially fine aggregate replacement. There is a limited study on the effects of POFA as a partially fine aggregate replacement in the production of mortar. The aim of this research is to study the effects of POFA on the workability of fresh mortar, and for the hardened mortar, compressive strength and microstructural analysis will be analysed. A total of 45 cubes with dimensions of 100 mm × 100 mm × 100 mm were cast at different percentages of POFA at 0%, 2.5%, 5%, 7.5%, and 10% by the weight of fine aggregates. Slump and flow table tests were conducted during the casting process to determine the workability. All the specimens were water cured at days 3, 7, and 28 before being tested with a compression test and scanning electron microscope (SEM) on the hardened mortar. It was discovered that 0% POFA recorded the highest workability. Furthermore, the laboratory results showed that the 2.5% POFA in the mortar recorded the highest compressive strength compared to other specimens. Moreover, the microstructure of the mortar specimen was observed to be denser, and the pores were refined with the presence of POFA, compared to the control specimen. Based on the findings, this research enables us to give an understanding of the effect of POFA incorporated in mortar as a partially fine aggregate replacement in terms of workability, compressive strength, and microstructural analysis. Based on the results from this research, the advantage of POFA can be fully utilized and can help reduce the environmental problems.

1. Introduction

The growing development in Malaysia has caused many industries to grow rapidly including the construction industry. In this industry, the demand for cement and fine aggregates were growing drastically for construction activities [1]. Thus, the use of materials obtained from the fine aggregate mining activities and cement production for mortar manufacture increases massively. This will lead to environmental deterioration and depletion of natural resource materials for future generations. In addition, this practice will also lead to a reduction in sustainable development and will not allow the materials from natural resources to be renewed in the future.

The construction industry is facing a critical challenge in concrete and mortar manufacturing due to the need of natural resources [2]. Besides, fine aggregate mining in a large-scale affects rivers and coastal habitats, induces sediment suspension that will lead to major problems such as soil erosion, and causes certain areas to be vulnerable to flooding reported in [2]. Thus, an alternative must be provided to prevent worsening situations and ensure that the construction industry can contribute to sustainable development.

Palm oil products in Malaysia are one of the largest export companies to other countries. Palm oil fuel ash (POFA) is an unwanted substance usually disposed of in an open area. Disposal of this material led to soil and air pollution concerns, which can cause worse environmental problems [2]. A product that is produced through the burning of palm oil waste such as palm oil fibre, palm oil shell, and mesocarp at high temperature in order to generate power in palm oil factory can be named POFA. The amount of disposed of POFA has resulted in accumulated toxic gases by contaminating the air in open areas and landfills [3]. In [4] the authors had stated that more wastes of palm oil was produced and need to manage as the palm oil industry continues to expand. Researchers in this field must focus on the use of sustainable, renewable resources, such as palm oil waste, in order to achieve greater sustainability in the construction industry [2].

Thus, research regarding the use of POFA as a partially fine aggregate replacement needs to be done in order to minimise the demand and the use of fine aggregates in the construction industry. In addition, partially replacing POFA in concrete and mortar will help minimise the environmental issues such as abundant waste materials in the palm oil industry so that the disposal of these waste products can be mitigated.

2. Materials and Methods

2.1. Materials. POFA is known as waste in landfills, which needs to be managed, as it will cause environmental problems. POFA is obtained in the form of ash when the fibre, shell, and empty fruit bunch of the palm oil trees are burnt as fuel to generate electricity and extract the palm oil [5]. The raw POFA was gained from the United Palm Oil Mill, Nibong Tebal, Pulau Pinang, as shown in Figure 1(a). In this study, the collected POFA was dried for 24 hours at a temperature of 100°C in the oven as shown in Figure 1(b). This is to ensure that the raw POFA is free from moisture content. The dried POFA was then sieved by 212 μm after 24 hours to remove any waste or unwanted materials and larger-sized particles. In [6], the authors added that POFA that have sieved into 212 μm is much finer than the raw POFA that is able to improve the strength.

Then, the type of cement chosen throughout this study was ordinary Portland cement (OPC), the common type of cement being used. It acts as a binder that mixes with fine aggregates and POFA in the mortar mixture, and according to [7], the standard strength for day 28 was ≥32.5 MPa. The OPC must be kept in an airtight container to prevent contact with air moisture. Furthermore, fine aggregates, water, and Master Glenium Ace 8538 super plasticizer (SP) will be prepared accordingly based on the mix design.

2.2. Mixing and Curing. In this study, in order to determine mix design, a modified mix design was used instead of the mortar standard ratio 1 : 3 of cement to fine aggregates as stated in [8]. The number of cubes used in this study is 45 cubes with standard cubes sized 100 mm. For each mix that has different amount of POFA, 9 cubes were used. The fine aggregate was partially replaced by POFA at 0%, 2.5%, 5%, 7.5%, and 10% by the weight of filler, as shown in Table 1.

The process of curing is very important in gaining the strength for the mortar specimens through the hydration process and preventing the occurrence of shrinkage cracks. Moreover, this curing process helps in increasing the durability of the concrete. In this study, the specimens were cured in the water tank for 24 hours to ensure the mortar specimens had hardened on days 3, 7, and 28.

2.3. Tests and Methods

2.3.1. Slump Test. The slump test was performed according to the specified standard[9] to determine the consistency of fresh concrete. The slump value can be determined by measuring the difference between the height of the slump cone and the highest point of the slumped test specimen, as shown in Figure 2.

2.3.2. Flow Table Test. The flow table test was done by referring to the specified standard which is [10]. Figure 3 shows the flow table test conducted after the casting process.

2.3.3. Compression Test. Using compression machine, a compression test was performed to determine the compressive strength of mortar at different percentage of POFA as a partially fine aggregate replacement. The test was carried out in accordance with [11]. Before the test was conducted, all the specimens must be dried after they were taken from the curing tank. The specimen is placed centrally on the machine and placed in a position where the surface is perpendicular to the load applied. An axial load with a specified rate of loading 3.00 kN/s was applied to the 100 mm cube until failure happened. The average values of

(a) (b)

Figure 1: Raw POFA (a) and oven-dried POFA (b).

Table 1: Mix proportion of mortar cubes.

Mixture	Materials							
	Fine aggregate (kg/m^3)	POFA (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	*Total samples for curing (days)*		
						3	7	28
Control	11.28	—	4.87	2.43	0.0097	3	3	3
2.5% POFA	11.00	0.28	4.87	2.43	0.0097	3	3	3
5% POFA	10.72	0.56	4.87	2.43	0.0097	3	3	3
7.5% POFA	10.44	0.85	4.87	2.43	0.0097	3	3	3
10% POFA	10.15	1.13	4.87	2.43	0.0097	3	3	3

Figure 2: Slump test.

Figure 3: Flow table test.

the three specimens were taken as a compressive strength of the cube. Figure 4 shows the compression test machine.

2.3.4. Microstructural Analysis. Microstructural image analysis was conducted by the mean of scanning electron microscope (SEM). The analysis is to analyse the morphological properties of POFA as a partially fine aggregate replacement in mortar. Hitachi TM3030 Plus was used for this microstructure study. The cube specimen for each different percentage of POFA used as a partially fine aggregate replacement was crushed into small pieces to do the microstructure analysis and kept in an airtight container to avoid moisture. The SEM was carried out at different ages, which were on day 3, 7, and 28, and a 1500 magnification was used for the analysis. Figure 5 shows the SEM that was used for this study.

3. Results and Discussion

3.1. Fresh Mortar. The quality of the fresh mortar incorporated with POFA as a partially fine aggregate

Figure 4: Compression test machine.

Figure 5: Scanning electron microscope.

replacement in terms of workability can be measured by conducting a slump test. During casting, a slump test was carried out on the fresh mortar and the slump value was measured by the distance of the fresh mortar that has slumped. Figure 6 shows the outcome obtained from the slump test.

Figure 6 shows the results of the slump value of fresh mortar at different percentages of POFA which were 0%, 2.5%, 5%, 7.5%, and 10%. Based on the findings, mortar with 0%, 2.5%, 5%, 7.5%, and 10% of POFA was recorded as 40 mm, the highest slump value, 15 mm, 0 mm, 0 mm, and 0 mm, respectively, which showed a decreasing pattern. By considering the slump value of 2.5%, 5%, 7.5%, and 10%, it was recorded that the workability was reduced compared to the control specimen with the amount of super plasticizer (SP) that work to improve the workability was the same. Then, the slump value of mortar that contains POFA at 2.5%

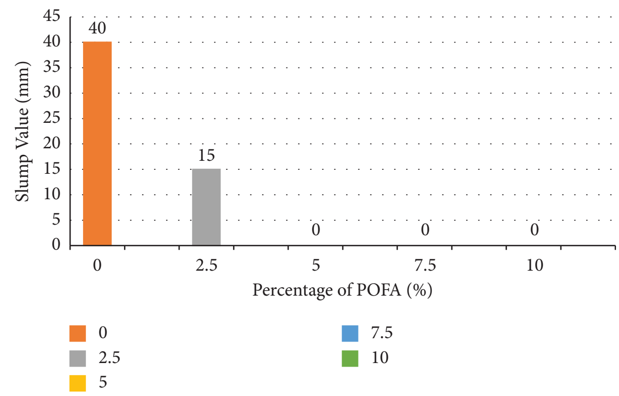


Figure 6: Slump value results on different percentages of POFA.

was recorded as the second highest compared to other percentage with 15 mm of the slump value. Mortar specimens with POFA at 5%, 7.5%, and 10% can be categorized as true slump with zero slump value and can be concluded as having the least workability.

In order to determine the flow value of the mortar, the flow table test was conducted on the fresh mortar with different percentages of POFA. The flow value can be obtained by measuring the diameter of the mortar spread on the flat surface. Figure 7 shows the results obtained from the flow table test.

Figure 7 shows the pattern of the flow value of fresh mortar at different percentages of POFA which were 0%, 2.5%, 5%, 7.5%, and 10%. According to Figure 3, POFA at 0%, known as a control specimen, the recorded flow value was 403 mm, which was higher compared to mortar incorporated with POFA as a partially fine aggregate replacement at 2.5%, 5%, 7.5%, and 10%. Then, POFA at 2.5% and 5% recorded the flow value of 385 and 380 mm, respectively. Moreover, the flow value of 7.5% of POFA as a partially fine aggregate replacement showed 328 mm, and the 10% of POFA, which had the highest percentage of POFA, showed the least flow value of 315 mm.

Based on the findings, it can be observed that the workability of the mortar with different percentages of POFA as a partially fine aggregate replacement reduced with a higher percentage of POFA being used in the mortar mixture compared to the control specimen that contains 0% of POFA. According to [1], POFA particles are spherical with coarse and agglomerate surfaces that could increase the high-water demand, thus reducing the workability.

Furthermore, the relationship between a slump and flow value of mortar incorporated with POFA at different percentages as a partially fine aggregate replacement, which were 0%, 2.5%, 5%, 7.5%, and 10%, as can be seen in Figure 8.

Based on the observation in Figure 8, it is obvious that both values brought a downturn value with an increase in POFA percentage in mortar. In terms of percentage difference, it can be clearly seen that the higher the percentage of POFA as a partially fine aggregate replacement used in mortar, the higher the percentage difference. This was due to the workability for each of the percentage of POFA decreases compared to the control specimen.

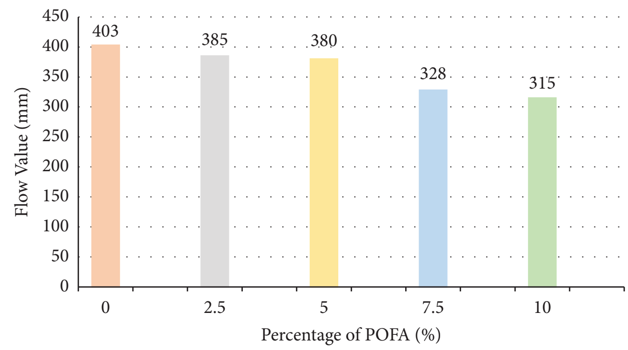


Figure 7: Flow value results on different percentages of POFA.

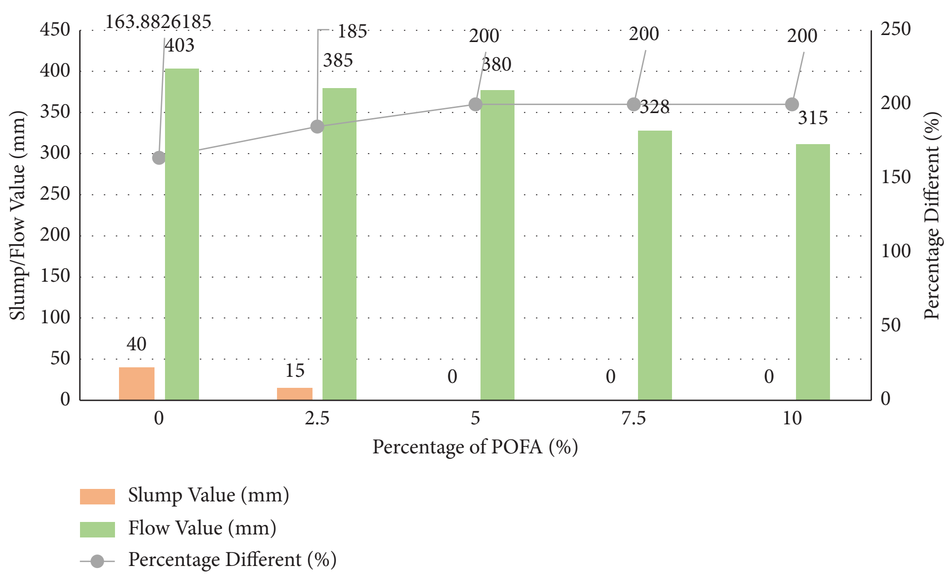


Figure 8: Relationship between the slump value and flow value of mortar.

From Figure 8, it shows the percentage difference between slump and flow values for 0%, 2.5%, 5%, 7.5%, and 10% specimens recorded difference at 164%, 185%, 200%, 200%, and 200%, respectively. It can be concluded that the lowest percentage difference between slump and flow values was the control specimen mortar while the highest percentage difference was mortar with 5%, 7.5%, and 10% since it had a zero-slump value. Thus, it indicated that the inclusion of POFA at every level of replacement did not improve the workability of mortar.

According to Figure 8, it can be seen that the higher the percentage of POFA used in the mortar will result in lower workability. This can be proven through studies conducted in [12] that the higher the amount of POFA will result in low workability compared to the control specimen. This statement can be supported by [13] which had expressed that the workability of concrete with the inclusion of POFA declined as the percentage of POFA rise in the mixture.

3.2. Hardened Mortar. A compression test was carried out on mortar specimens after being cured in water at days 3, 7, and 28 using the compression test machine. The compressive strength was recorded by taking the maximum load of the specimen that can be sustained. Figure 8 illustrates the results of the compressive strength of mortar incorporated with POFA as a partially fine aggregate replacement on the effect of age.

Figure 8 shows the results of compressive strength of mortar at different percentage of POFA, which were 0%, 2.5%, 5%, 7.5%, and 10% as a partially fine aggregate replacement. According to the results of Figure 8, it is shown that the compressive strength was increasing from day 3 to day 28 for POFA at 0%, 2.5%, 7.5%, and 10%. Meanwhile, compressive strength of mortar with 5% POFA as a partially fine aggregate replacement was increased from day 3 to day 7 with 20.37 MPa and 24.49 MPa, respectively, but suddenly reduced to 10.53 MPa on day 28.

In this study, it can be noticed that the highest compressive strength on day 3 is the mortar with the inclusion of 5% of mortar. Results on day 7 showed POFA at 0% contributes the highest compressive strength with 26.31 MPa followed by 2.5% with 25.79 MPa. Overall, based on the findings during the mature age of the concrete which is on day 28, it can be marked that 2.5% was the optimum strength with 37.70 MPa compared to the control specimen with 6% of percentage difference.

The possible effect of that particular 2.5% was that the optimum percentage of POFA comes from a good filler effect. POFA is a good filler effect that can fill in between voids. A study by Hamada et al. [14] confirmed that using POFA with fine particles will improve the compressive strength compared to the control specimen. The fineness of the POFA is the main aspect that can contribute to the compressive strength, which can be supported by [15]. In this study [15], the authors stated that the specimen that contains POFA as a partially replacement for cement or fine aggregates will be improved towards their age. This was due to the high fineness of POFA that can fill in the voids. This can be determined from the results obtained by POFA at 2.5%. The compressive strength is increasing starting from 19.87 MPa, 25.79 MPa, and 37.70 MPa on day 3, 7, and 28, respectively.

Figure 9 also shows the equation of the relationship between compressive strength and age of mortar incorporated with POFA together with the coefficients of determination (R^2). In addition, the highest value R^2, as shown in Figure 9, was mortar with 5% POFA as a partially fine aggregate replacement with 0.998. Therefore, the value was used to determine the compressive strength in improving the study of replacing POFA at longer curing age. In the study in [16], the determination of the strength to improve at a longer curing age was based on the R^2, and it was recorded that 10% POFA was the optimal percentage for the study.

POFA used in this study was taken from the same source as [2], which was from the United Palm Oil Mill, Nibong Tebal at Pulau Pinang with a high amount of silica. According to [6], the high silica content in the POFA will affect the compressive strength and make the water absorption become lesser, and it can be confirmed by [17] through XRF that had been conducted. In [17], the authors stated that waste materials which are POFA showed the highest amount of silica with 51%, as shown in Table 2, followed by CaO and other elements. In accordance with [18], a standard POFA fits the criteria for being pozzolanic and can be categorized within Class C and Class F, as shown in Table 2, which reveals the reactive oxide of POFA with 59.03% that was composed from $SiO_2 + Al_2O_3 + Fe_2O_3$.

In addition, the microstructural analysis will be analysed on the specimens of mortar with different percentage of POFA at curing ages of days 3, 7, and 28. The change in morphology was due to the different percentages of POFA incorporated in the mortar which was examined by using SEM. Figure 10 shows the SEM micrographs of mortar on day 3 at 50-micron scale with 1500 magnification at different percentages of POFA, which were 0%, 2.5%, 5%, 7.5%, and 10%.

Figure 10(a) shows the control specimen for this research at day 3 which is without inclusion of POFA. It was obvious that the control specimen has a higher volume of voids and is more porous compared to the mortar incorporated with POFA due to the large particles of fine aggregates. It can be observed that there was a formation of a tiny needle action called ettringites, as illustrated in Figure 10(a). Furthermore, the formation of $Ca(OH)_2$ was done in the mortar with 0% POFA creating more voids in the mortar. This happened during the hydration process when there was a rapid action of the cement in contact with the water, thus producing a high quantity of $Ca(OH)_2$.

Mortar with POFA at 2.5%, 5%, 7.5%, and 10% are illustrated in Figures 10(b)–10(e), respectively. It can be clearly seen that the voids in the mortar specimens were reduced. The presence of POFA in specimens helps in reducing the porous structure [19]. It shows that the main factors of the reduction come from the good filler effect caused by the POFA itself. It can be noticed that the needle action or ettringites started to disappear. Moreover, the amount of $Ca(OH)_2$ will become lesser as the percentage of POFA is higher. This can be shown from the figure below for POFA at 2.5%, 5%, 7.5%, and 10% which helps to fill in the voids and make them less porous.

Moreover, the higher the amount of POFA used in the mixture, the lesser the voids of the specimen. As illustrated in Figure 10(c), which contains 5% of POFA, it can be verified that it has less void compared to the 2.5% and control specimen. This was due to the amount of POFA being used in the mixture. When there is a presence of POFA in the mixture, the process named as the refining process will occurr. The refining process will close all the voids in the specimen, and if there are any of the voids, it is not significant as the control specimen and 2.5% of POFA. This had proven that the inclusion of POFA act as microfiller. In [20], the authors had declared that the microfilling ability and pozzolanic activity of POFA are satisfactory.

Observation on 7.5% POFA as a partially fine aggregate replacement makes the specimen become incomplete bonding. This incomplete bonding is shown in Figure 10(d). The incomplete bonding may be due to agglomeration. Due to its agglomeration, the POFA particles cannot easily roll over one another, thus increasing the interparticle friction. For Figure 10(e), which consists of 10% POFA in mortar as a partially fine aggregate replacement, there was an internal cracking between the particles, although the voids are improved through the refining process. This can be due to too much POFA incorporated in the mortar which will reduce the strength. Besides, the mixture of mortar will need a higher water requirement since the fineness of the particles increases. Hence, a study conducted by Saffuan et al. [13] had proved the appearance of the internal cracking that happened at the specimen of 10% of POFA.

POFA is high with silica and alumina which contributes to the pozzolanic activity. This can be proved by a study revealed in [12] that stated POFA is a good pozzolanic material and can be considered as a good supplementary cementing material (SCM). Figure 11 illustrates the SEM micrographs of mortar on day 7 at 50 micron scale with 1500 magnification at different percentages of POFA, which were 0%, 2.5%, 5%, 7.5%, and 10%.

One of the POFA's behaviour can improve strength due to its characteristic that can act as a good SCM. As can be seen in Figure 11(a), which represents the control specimen of mortar, it can be noticed that there was no SCM since it has 0% inclusion of POFA, thus the amount of $Ca(OH)_2$ will be higher. Although the 0% POFA contains $Ca(OH)_2$, it does

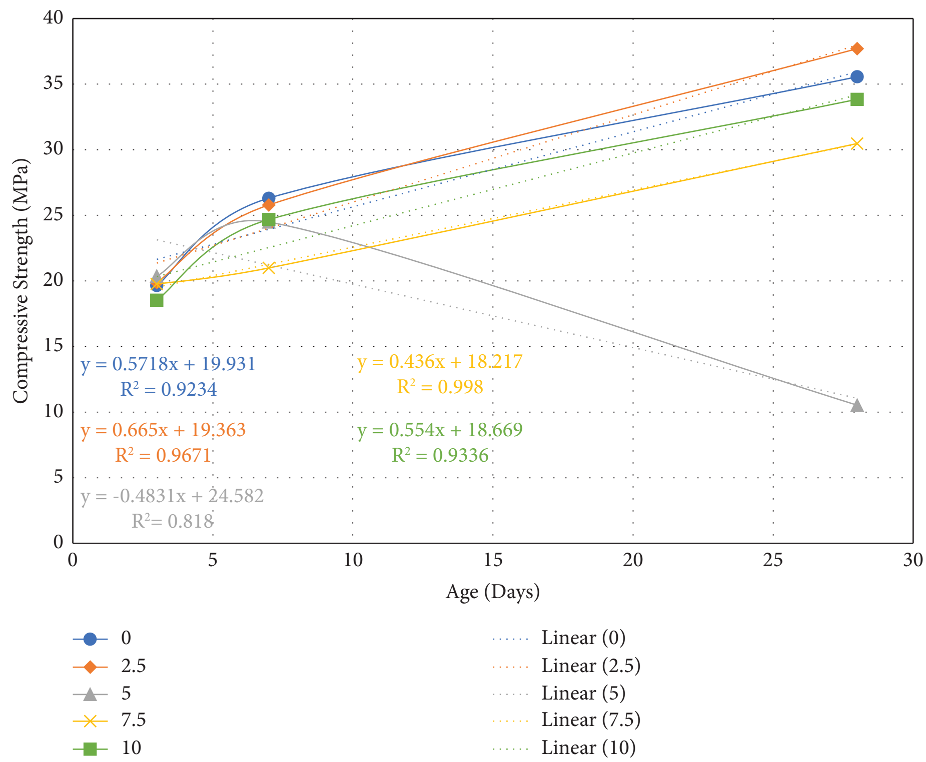
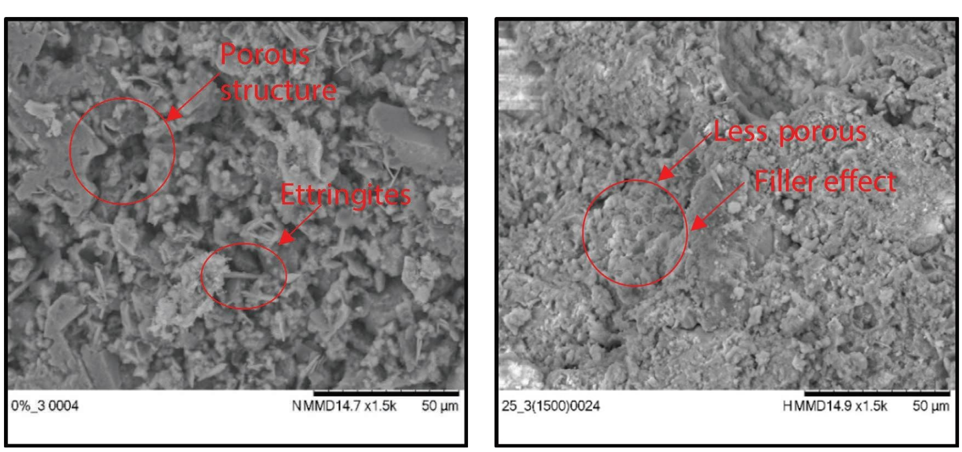


Figure 9: Compressive strength of mortar on the effect of age.

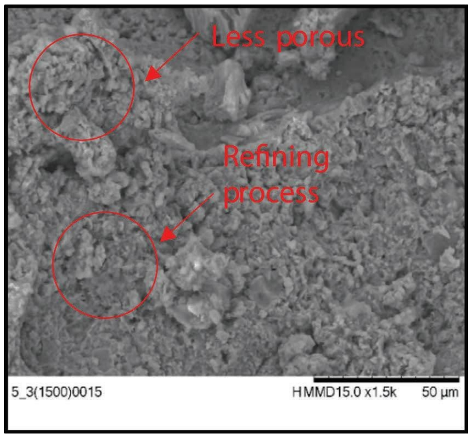
Table 2: Chemical composition of POFA (adopted from reference [17]).

Chemical composition (%)	POFA
SiO_2	51.00
Al_2O_3	4.61
Fe_2O_3	3.42
CaO	6.93
MgO	4.02
Na_2O	0.06
K_2O	5.52
SO_3	0.36
LOI	21.60



(a) (b)

Figure 10: Continued.



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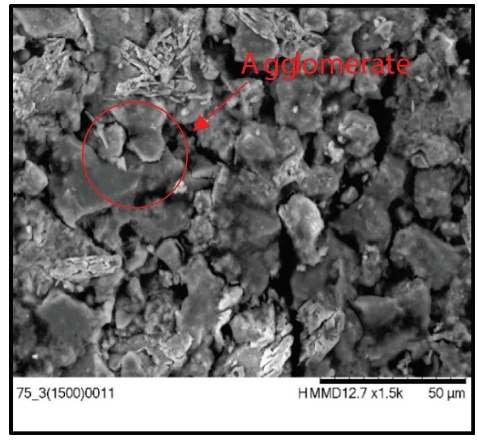

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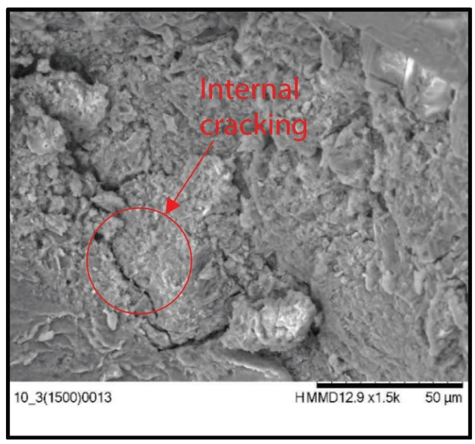
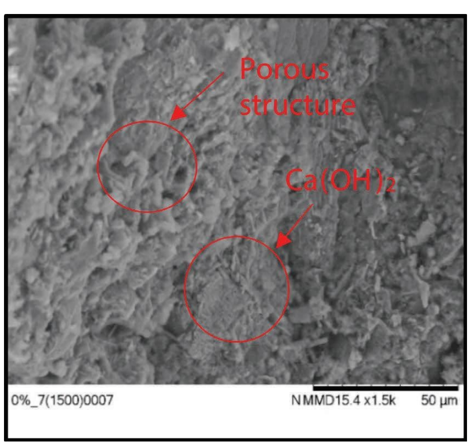
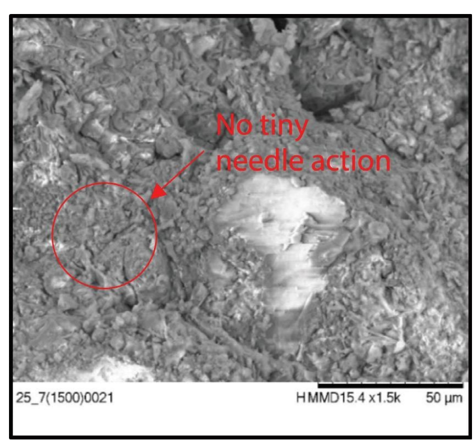


(e)

FIGURE 10: SEM micrographs of mortar on day 3 at 50 micron scale with 1500 magnification: (a) 0% POFA, (b) 2.5% POFA, (c) 5% POFA, (d) 7.5% POFA, and (e) 10% POFA.

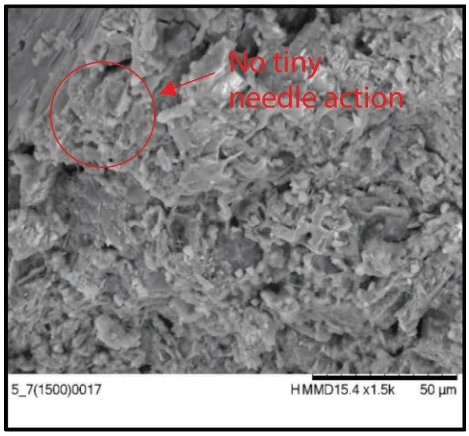


(a)



(b)

FIGURE 11: Continued.



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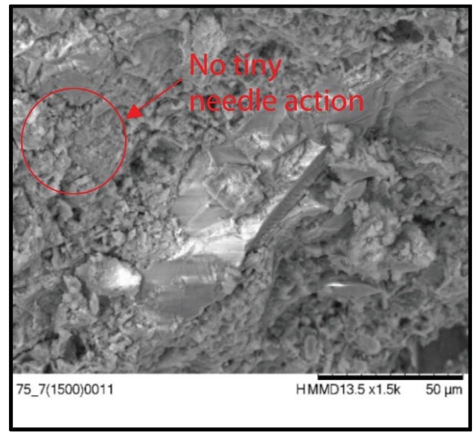
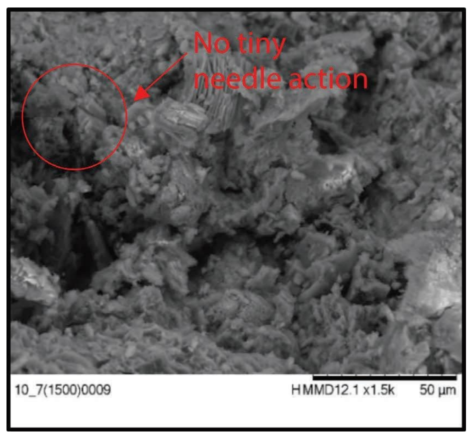


(d)



(e)

FIGURE 11: SEM micrographs of mortar on day 7 at 50 micron scale with 1500 magnifications: (a) 0% POFA, (b) 2.5% POFA, (c) 5% POFA, (d) 7.5% POFA, and (e) 10% POFA.

not notice as much as on day 3. Furthermore, the SEM images showed a porous structure, as illustrated in Figure 11(a). The porous structure of the specimen is improved compared to earlier ages at day 3.

Based on Figures 11(b)–11(e), it shows the specimen of mortar with 2.5%, 5%, 7.5%, and 10% of POFA, respectively. Due to the presence of POFA, which can be classified as a good SCM by [12], the amount of $Ca(OH)_2$ can be reduced. The higher the usage of SCM, which in this study is POFA, the lower the value of $Ca(OH)_2$, and this statement was supported by [21]. Moreover, it can be observed that there is no formation of tiny needle action as a result of $Ca(OH)_2$ present in the specimen at POFA at 2.5%, 5%, 7.5%, and 10%.

POFA has a higher amount of silica and alumina. The pozzolanic activity can be enhanced due to the presence of silica in the POFA composition [3]. The oven-dried POFA used in this study has a high fineness particle that could improve the strength of mortar. Moreover, due to high fineness and less unburned carbon in POFA particles, it will increase the rate of the pozzolanic activity. In [17], the authors added that SiO_2 will increase with increasing POFA fineness. The unique behaviour of POFA was due to pozzolanic behaviour making it resistant to other chemicals [12]. Figure 12 shows the result of the microstructural analysis on day 28.

The SEM images on the inclusion of 0% POFA show that the mortar specimen is less dense than others, as evidenced in Figure 12(a). Since mortar at 0% POFA has no existence of POFA, then the pozzolanic activity could not be encouraged in the mixture. This was because the POFA content has a high amount of silica that helps in improving the pozzolanic activity.

Based on Figures 12(b)–12(e), the amount of the pozzolanic material was higher as compared to the control specimen since it contains POFA as a partially fine aggregate replacement in the mixture. Thus, the amount of C-S-H gel produced due to high silica in the mixture was also high. In addition, the additional C-S-H produce makes the microstructure much denser and able to improve the interfacial bond between aggregates and binder paste. Thus, it will help in improving the strength [19]. This can be proved based on Figure 8 which shows the SEM images of POFA at different percentages were much denser compared to 0% POFA at the mature age of mortar.

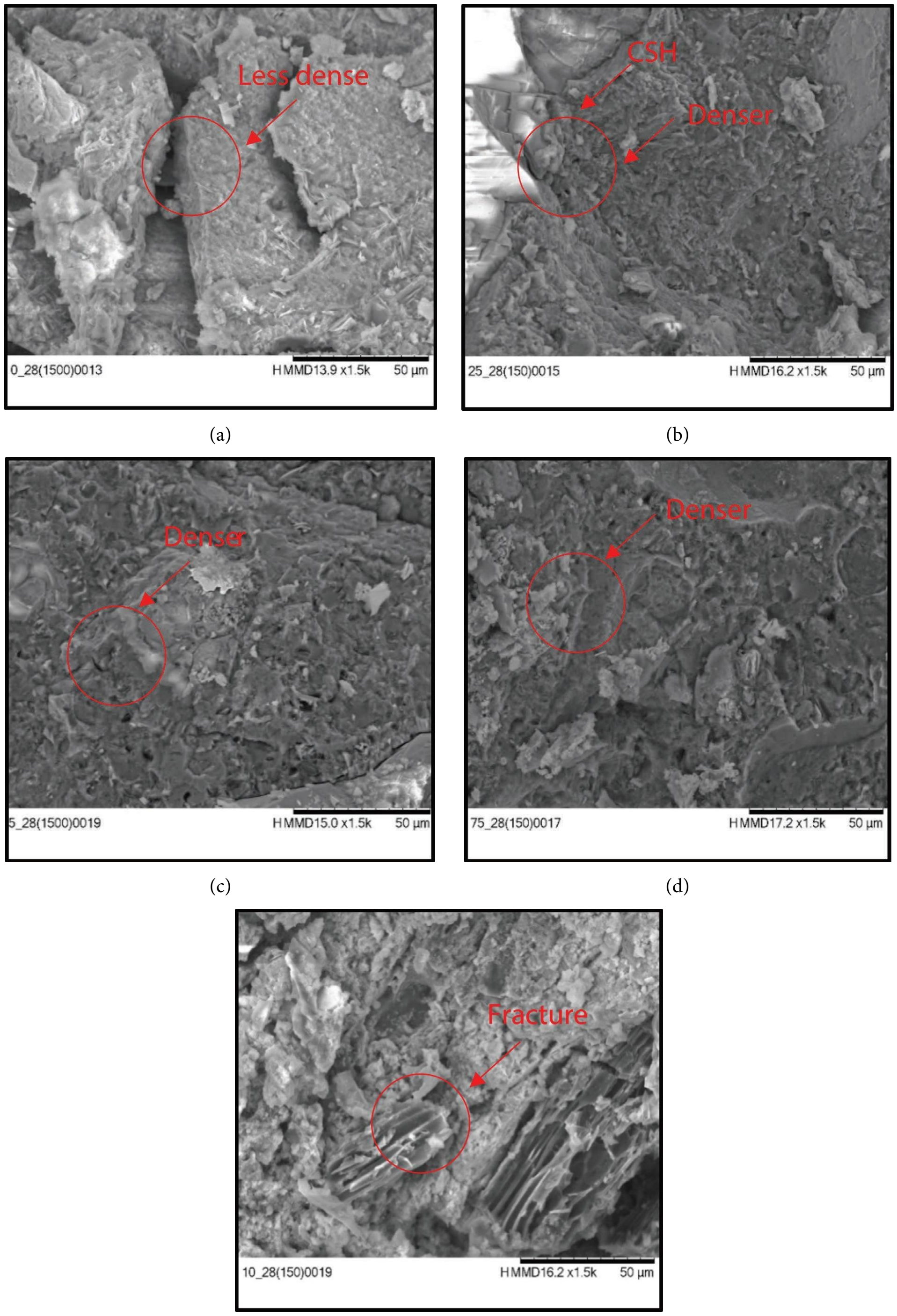


Figure 12: SEM micrographs of mortar on day 28 at 50 micron scale with 1500 magnification: (a) 0% POFA, (b) 2.5% POFA, (c) 5% POFA, (d) 7.5% POFA, and (e) 10% POFA.

The highest compressive strength on day 28 was achieved by POFA at 2.5%. This was due to the high fineness of the POFA itself, which contributes to the strength and high amount of SiO_2. As a result of high SiO_2 in the specimen, the reaction between $Ca(OH)_2$ and SiO_2 was improved, thus resulting in a large quantity of C-S-H gel that helps to improve the compressive strength [19]. In [19], the authors also added in the research that the optimum percentage that improved the strength was due to the maximum amount of C-S-H on the specimen which was fully used, and it produced low permeable porosity by filling microvoids with C-S-H.

4. Conclusions

The following conclusions can be drawn from the laboratory results according to the respective objectives specified at the beginning of this study.

(1) Mortar with 0% of POFA as a partially fine aggregate replacement recorded the highest slump and flow value with 40 mm and 403 mm, respectively. This is because no inclusion of POFA has the ability to absorb water.

(2) Mortar with 5%, 7.5%, and 10% recorded as true slump in the zero slump value. Meanwhile, mortar with 10% recorded the lowest flow value.

(3) Mortar incorporated with POFA requires high water demand due to high fineness in particles that increases the surface area and contains a high amount of carbon.

(4) Mortar with 2.5% inclusion of POFA recorded the highest compressive strength, making it the optimum percentage of POFA as a partially fine aggregate replacement to the mortar specimen at mature age at day 28.

(5) Mortar having 5% of POFA measured the lowest compressive strength at mature age which is at day 28.

(6) Due to the POFA acting as a filler in the void of mortar, the compressive strength was improved.

(7) During the water curing process, the pozzolanic reaction of the mortar produced by silica in the POFA helps to enhance the compressive strength of the mortar.

(8) Microstructural analysis on day 3 had successfully shown that POFA acts as a filler between the voids in mortar mixture and reduces the formation of calcium hydroxide ($Ca(OH)_2$) that produced a tiny needle action.

(9) Microstructural analysis on day 7, POFA can be classified as a good supplementary cementing material (SCM) that produces calcium silicate hydrate (C-S-H) gel and results in the reduction of $Ca(OH_2)$.

(10) Some future recommendations are listed below so that future researchers can refer to this study to achieve better results:

   (a) Increase the fineness of the POFA particles in mortar mixture
   (b) Observed the physical properties of POFA as a partially fine aggregate replacement in mortar through the particle size distribution
   (c) Discover the microstructural analysis on the material of POFA

(11) This study intends to highlight the usage in the IBS industry since it can produce a lighter structure due to the incorporation of POFA as a partially fine aggregate replacement.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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