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Effect of combining Palm Oil Fuel Ash (POFA) and Rice Husk Ash (RHA) as partial cement replacement to the compressive strength of concrete

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Abstract: The increase in agricultural waste has been one of the main concerns today. Usually, the excessive waste is dumped in the landfill without any consideration to the environment. Previous research has found that waste containing highly reactive silica can react with calcium hydroxide in concrete resulting in a compact concrete microstructure. Hence, this paper focuses on the mechanical properties of concrete containing Palm Oil Fuel Ash (POFA) and Rice Husk Ash (RHA) as replacement of cement in concrete and also the combination of both materials as pozzolan in one concrete mix. Properties studied include its workability for fresh concrete, and compressive strength of hardened concrete. Replacement level for POFA and RHA was at 10%, 15%, 20%, 25%, and 30% by weight of Ordinary Portland Cement (OPC). Results show that the addition of 10% to 30% of POFA and RHA reduces concrete workability from 35 mm to 20 mm for POFA and 39 mm to 21mm for RHA. Replacement of POFA and RHA at 10% has the highest compressive strength compared to other replacement level. Finally, the optimum combination for POFA and RHA to achieve the targeted strength of 30 MPa was recorded at 10% POFA and 15% RHA.

Keywords: Partial cement replacement, Palm Oil Fuel Ash, Rice Husk Ash, Compressive Strength

1. Introduction

In Malaysia, one of the main sources contributing to the production of waste comes from the agricultural industry. The common agricultural wastes comprise of palm oil fuel ash (POFA), and rice husk ash (RHA). There are about 3.1 million hectares of oil palm trees producing over 9 million tons of crude oil. Oil palm plantation has since contributed to the production of POFA. POFA originated as a by-product of oil mill arising from the use of palm oil shell and palm oil bunches to power oil mill plants for electricity generation [1]. Meanwhile, for RHA, it is basically an agricultural residue obtained from the rice processing mill. Only a small amount of produced husk was used as fuel in rice mill and electricity generating power plant. It was estimated that 1000kg of rice grain produces about 200 kg of rice husk. From there, these rice husk will then be burnt and 20% of the rice husk or 40 kg would be turned into rice husk ash or RHA [2]. Due to the huge amount of waste, the government is expected to allocate more hectares of landfill for disposal purposes, eventually requiring high expenditure for waste transportation to the allocated landfill .

Utilizing POFA and RHA in concrete has a lot of benefit in terms of concrete mechanical performance. According to Muthusamy et al. [3], the replacement of cement to POFA in concrete from 10% to 30% resulted in achieving higher strength than control. However, an optimum maximum compressive strength at 20% replacement was observed. The increase in strength of concrete with POFA could be attributed by the filling effect of the fine ash and the pozzolanic reaction that improves the bonding between hydrated cement matrix and aggregate. During the pozzolanic reaction, the calcium hydroxide ($Ca(OH2)$) generated from the hydration process will react with silica in POFA which then produces a secondary calcium silicate hydrate gel (C-S-H) that improves the concrete strength. The secondary C-S-H gel fills up the void between cement and aggregate, generating a stronger bond between the paste and aggregate. However, POFA has been observed to have a slower pozzolanic reactivity as it tends to produce lower compressive strength at an early age of curing. Alsubari [4] found that at the early age of 1, 3 and 7 days of curing, the self-compacting concrete (SCC) containing high volumes of POFA exhibited lower compressive

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strength than the control concrete. The main reason for the low compressive strength at the early age were due to the lack of hydration product, namely calcium-silicate-hydrate (C-S-H). But as the curing period prolonged, the compressive strength of SCC increased. Based on the previous research discussed above, it was clearly observed that POFA had the potential as a supplementary cementitious material in concrete.

Meanwhile, Ephraim et al. [5] studied the compressive strength of concrete with RHA as partial replacement of cement. The study concluded that the incorporation of RHA in concrete resulted in an increased in water demand and strength. The researcher's replaced cement with various percentages of RHA at 10%, 20% and 25% and found that the 28 days compressive strength was at its optimum level when the percentage of replacement was at 10%. Unfortunately, 20% and 25% RHA replacement shows a slight reduction in strength. Lung et al. [6] uses ground RHA to replace cement and observed a higher optimum percentage of replacement at 20%. It was observed that the compressive strength of concrete with up to 20% ground RHA attain an equivalent strength of normal concrete after 28 days, even though ground RHA contains high carbon content. Mohseni et al. [7] also found that replacing cement by up to 10% of RHA increases its 28 days compressive strength. Likewise, the replacement of 20% and 30% of cement, the compressive strength decreases. As presented, literature has illustrated the potential used by agricultural waste, namely POFA or RHA as cement replacement and the ability to improve the mechanical properties of concrete at the optimum percentage [9].Previous research had proved that replacing OPC with POFA and RHA in concrete improves the durability by providing secondary C-S-H gel. The optimum percentage of POFA and RHA replacement was 10% to 30% by weight of cement but is dependent on several factors such as chemical composition, particle size, and preparation of the material.

Unlike the previous research stated above, the current research attempts to observe the effect of combining both POFA and RHA in one concrete mix. Therefore, the research work and its findings on the compressive strength of concrete with the combination of two pozzolanic materials (POFA and RHA) in one mix are as presented below.

1.1 Experimental Details

To achieve the aims of the research, the experimental program were organized and sub-divided into two phase:

Phase 1 (Determining the optimum percentage of either POFA or RHA)

The optimum percentage of concrete containing either POFA or RHA was determined by conducting the compressive test at 7 and 28 days. The replacement level for POFA and RHA was keep consistently at 10%, 15%, 20%, 25% and 30% by weight of cement. At 28 days, percentage for POFA and RHA that reaches the target compressive strength of 30MPa or higher will then be selected for further testing in Phase 2.

Phase 2 (Determining the optimum percentage of combining POFA and RHA in one concrete mix)

In this phase, the optimum percentage for combining POFA with RHA in one concrete mix was determined by conducting the compressive strength test for 7 and 28 days. The percentage of combination of POFA and RHA was depended on the optimum percentage obtained from Phase 1.

2. Experimental work

2.1 Material Preparation

In this study, Ordinary Portland Cement (OPC) Type I was used. POFA was collected from Bell Oil Palm Plantation located at Parit Ju, Batu Pahat, Johor. RHA was collected elsewhere at Kilang Beras Jelapang Selatan located at Muar, Johor. Fig. 1 and Fig. 2 respectively shows POFA and RHA before processing. Before processing, both materials were sieved through 300 μm sieve to remove any impurities and unburnt carbon. Then, it was ground for 2 hours at 5 kg per batch using Los Angeles Abrasion machine. The machine causes POFA and RHA to be finer, passing through 150 μm sieves. The size of the coarse aggregate used was fixed at 9 mm and retained at 5 mm. River sand (after passing the 5 mm sieve) was first dried before being used.

Fig. 1 Palm Oil Fuel Ash (POFA)

Fig. 2 Rice Husk Ash (RHA)

2.2 Concrete mix design and proportion

The concrete was designed by using the American concrete institute (ACI) with targeted compressive strength of 30MPa at 28 days. Replacement level for POFA and RHA at phase 1 was 10%, 15%, 20%, 25%, and 30% by weight of cement. The water cement ratio was fixed to 0.57. The mix proportion for POFA and RHA for Phase 1 are shown in Table 1 and Table 2 respectively.

Table 1 Concrete mix proportion with POFA

Concrete Type	Binder (kg/m3)		Aggregate (kg/m3)	
	OPC	POFA	SAND	NA
Control	400	0	945	688
POFA 10	360	40	945	688
POFA 15	340	60	945	688
POFA 20	320	80	945	688
POFA 25	300	100	945	688
POFA 30	280	120	945	688

Table 2 Concrete mix proportion with RHA

Concrete Type	Binder (kg/m3)		Aggregate (kg/m3)	
	OPC	RHA	SAND	NA
Control	400	0	945	688
RHA 10	360	40	945	688
RHA 15	340	60	945	688
RHA 20	320	80	945	688
RHA 25	300	100	945	688
RHA 30	280	120	945	688

2.3 Sample preparation

A total of 120 cubes, including control with a size of 100mm x 100mm x 100mm were prepared for compressive test for Phase 1 and Phase 2. Mixer with a capacity of 75 liter was used for mixing the concrete. All samples were cured in water for 7 and 28 days before testing for its compression strength. The test was conducted according to BS 1881-116:1983. Fig 3 shows the cube samples under curing.

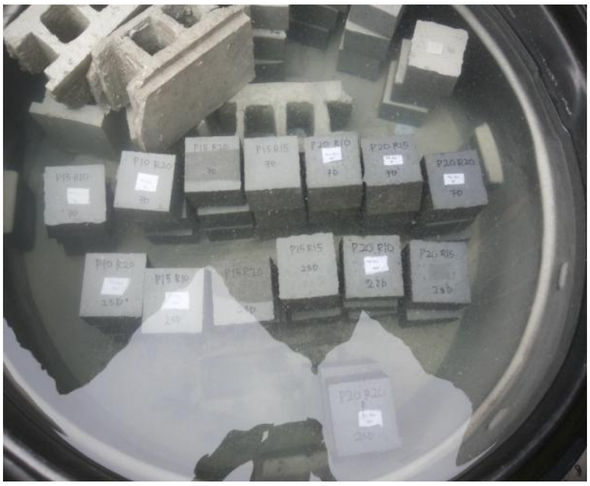

Fig 3 Sample curing process

3. Results and discussion

3.1 Properties of Palm Oil Fuel Ash (POFA)

In bulk, POFA is grey in colour and becomes dark due to the presence of unburnt carbon. After the ash was grounded for 2 hours, it was observed through the Field Emission Scanning Electron Microscope (FESEM) technique that POFA consists of irregular, thinner and crushed particle as shown Fig 4. In terms of chemical properties, POFA contains higher amount of Silica than OPC at 51.1%. The presence of Silica is important for the pozzolanic process to produce the C-S-H gel. [5]. According to ASTM C618, POFA can be classified as a C pozzolan. This is because of the total combined percentage of silica oxide, aluminium oxide and iron oxide for POFA, as shown in Table 3, achieved more than 50% whilst percentage of sulphur trioxide recorded lower than 5% [11].

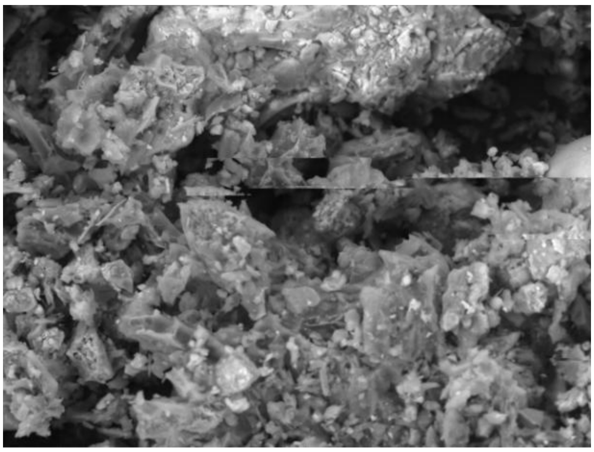

Fig 4 FESEM observation of POFA (Mag: 5000X)

3.2 Properties of Rice Husk Ash

From close proximity, RHA too has similar colour as POFA and are partly due to the presence of unburnt carbon. The morphological structure of RHA sample was examined using Field Emission Scanning Electron Microscope (FESEM) technique, it can be seen from Fig 5 that the RHA has an irregular-shaped and are closely graded [12]. For the chemical properties as shown in Table 3, it can be observed that RHA contains greater amount of silica 73.9%. According to ASTM C618, this ash can be classified as F pozzolan due to the total percentage of silica oxide, aluminium oxide and iron oxide achieving more than 70% and percentage of sulphur trioxide having lower than 5% [11].

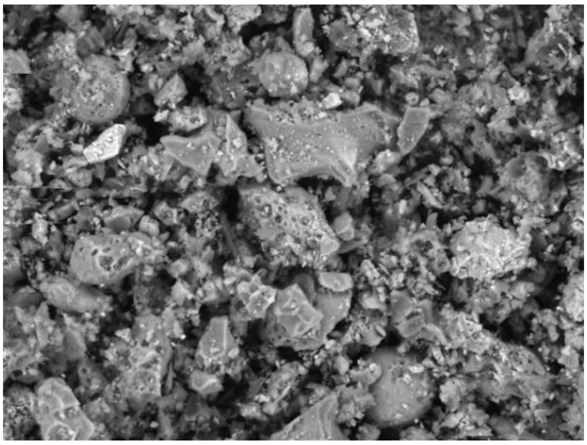

Fig 5 FESEM observation of RHA (Mag:5000X)

Table 3 Percentage of chemical composition

Chemical Composition	OPC (%)	POFA (%)	RHA (%)
Silicon dioxode	20.40	51.1	73.9
Aluminium oxide	5.20	1.39	0.99
Iron Oxide	4.19	4.56	11.50
Calcium Oxide	62.39	4.86	5.56
Magnesium oxide	1.55	1.88	1.53
Sodium oxide	0.75	0.0	0.0
Potasium oxide	0.005	8.23	5.56
Sulphur trioxide	2.11	1.34	0.90

The physical properties of including its specific gravity and median particle size for Cement, POFA and RHA used in this experimental program are tabulated in Table 4.

Table 4 Physical properties of Portland cement type I and pozzolanic materials

Materials	Specific gravity	Median particle size (µm)
Cement	3.15	14.6
POFA	2.33	12.6
RHA	2.15	8.88

3.3 Optimum percentage for POFA and RHA (Phase 1)

3.3.1 Workability

Fig. 6 shows the workability of concrete containing POFA and RHA. It can be observed that the workability of concrete containing POFA and RHA decreases as the percentage of POFA and RHA increases. Replacement of OPC with POFA and RHA showed an adverse effect on the workability. The decrease in slump value was observed for all replacement level starting from 10% to 30% for both materials. The lowest slump measured was at 30% of replacement for POFA and RHA. A low workability was observed for all replacements due to the high specific surface area and high-water absorption capacity of the material. Addition of supplementary cementitious material into concrete will densified the matrix by filling up the void and resulted a stiffer concrete [8].

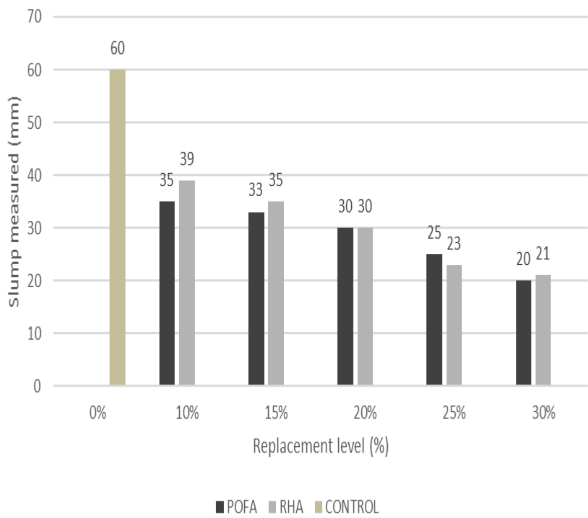

Fig 6 Slump measurements for POFA and RHA

3.3.2 Compressive strength

3.3.2.1 Palm Oil Fuel Ash (POFA)

Compressive test was conducted on concrete containing 10%, 15%, 20%, 25% and 30% of POFA from weight of cement. The results for the compressive strength are shown in Fig 7.

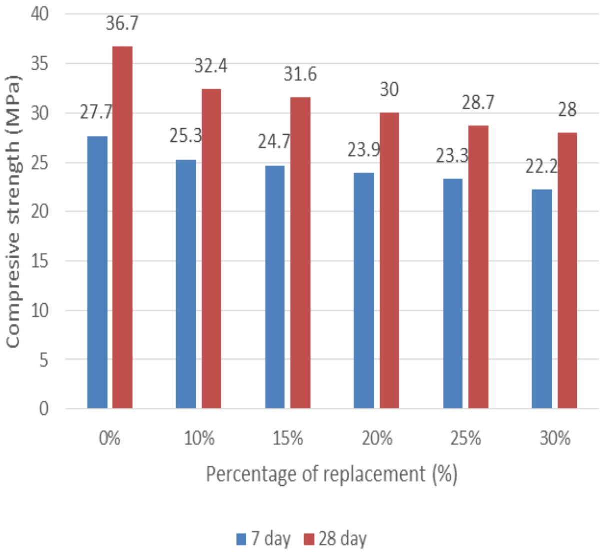

Fig 7 Compressive strength for POFA

Fig 7 shows the compressive strength of concrete containing POFA at 7 and 28 days, which clearly indicates strength reduction as the percentage of replacement was increased. The highest compressive strength recorded was observed when 10% of POFA produces a strength of 32.4 MPa at 28 days. This result was, however, still low by 13.7% in comparison to the controled specimen. Continuous reduction of strength was observed after 10% replacement level due to the excessive amount of POFA which resulted in the formation of voids in the concrete. The lower compressive strength of concrete with POFA was caused by slower pozzolanic reactivity of POFA due to lesser hydration product, namely calcium silicate hydrate in concrete. This result was parallel to Alsubari et al. [4] where a lower compressive strength for concrete containing POFA was recorded specifically at the early age of curing. However, the difference of strength between control and concrete containing POFA at 28 days was relatively small compare to 7 days due to the longer curing days resulting in prolonged pozzolanic reaction. Although the addition of POFA resulted in a lower compressive strength than control, but at 28 days the strength for 10%, 15% and 20% still achieved the targeted strength of 30MPa.

3.3.2.2 Rice Husk Ash (RHA)

Compressive test was conducted to concrete containing 10%, 15%, 20%, 25% and 30% of RHA from weight of cement. The result are shown in Fig 8.

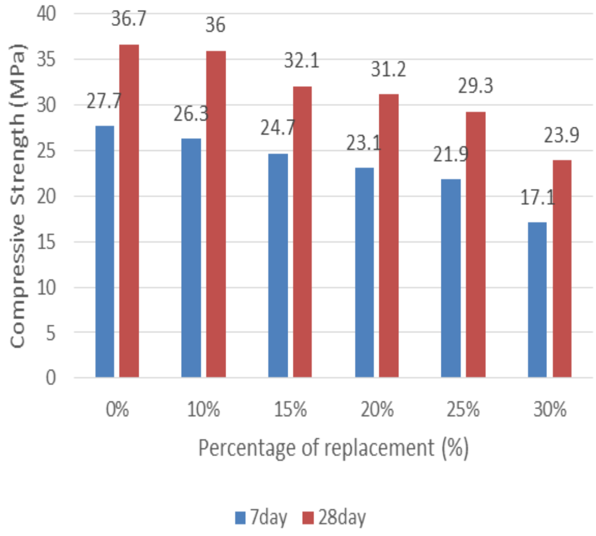

Fig 8 Compressive strength for RHA

Fig 8 shows the result in concrete containing RHA at 7 and 28 days. It can be observed that the result of concrete containing RHA at 7 and 28 days has nearly the same pattern as concrete containing POFA. The results also show that at 10% RHA replacement, a slightly lower strength with control at 28 days was achieved. However, further reduction in strength beyond 10% of RHA replacement was observed. This phenomenon in concrete occurred because of the excessive volume of voids created in the concrete. Similar findings were observed by Ephraim et al. [5]. In 28 days, only 10%, 15% and 20% of RHA replacement achieve the targeted strength of 30MPa. However, the differences in compressive strength between control and other specimens was less at 28 days compared to 7 days. This was due to the pozzolanic reaction started to occur at 28 days, which improves the concrete microstructure.

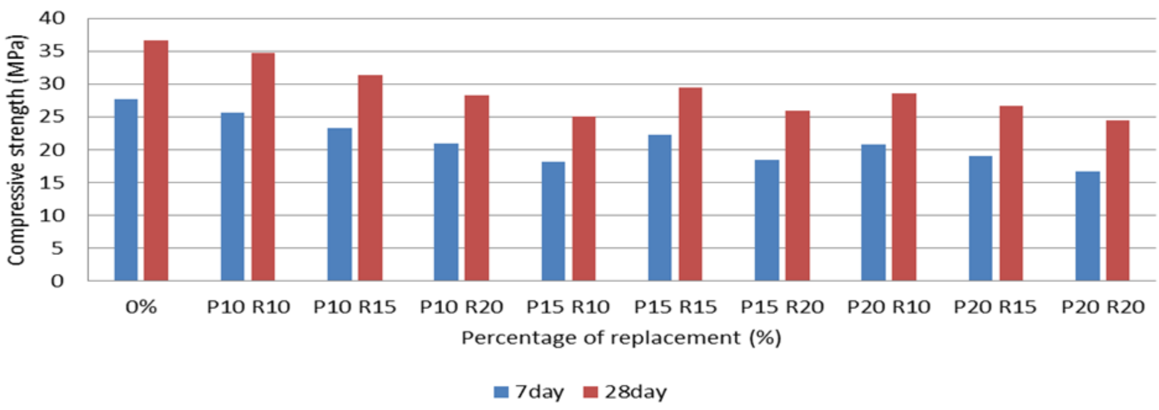

Fig 9 Concrete compressive strength with various combination of POFA and RHA

3.4 Optimum percentage for the combination of POFA and RHA (Phase 2)

In Phase 2, the experimental program to determine the optimum combined percentage of POFA and RHA to achieve the targeted strength of 30MPa was conducted. Based on the results obtained in Phase 1, 10%, 15%, and 20% replacement for either POFA or RHA was established. Hence, both POFA and RHA materials are combined accordingly to the percentage shown in Table 5. The results for its compressive strength at 7 and 28 days are shown in Fig 9**.**

Table 5 Various combination for POFA and RHA

Percentages (%)	Compressive Strength (MPa)	
	7 days	28 days
0	27.7	36.7
P10 R10	25.6	34.7
P10 R15	23.3	31.4
P10 R20	20.9	28.3
P15 R10	18.1	25.1
P15 R 15	22.2	29.4
P15 R20	18.4	25.9
P20 R10	20.8	28.6
P20 R15	19.1	26.6
P20 R 20	16.7	24.4

Note: P10R10 = POFA 10% + RHA 10%
P10R15 = POFA 10% + RHA 15%

Fig 9 shows the compressive strength result after combining POFA and RHA in one concrete mix. From the results shown it can be observed that the combination of 10% of POFA with 10% of RHA (P10R10) achieved the highest compressive strength compared to other percentage of combination at 28 days. For P10R10, the compressive strength at 28 days was 34.7MPa and was 5.7%, slightly lower than the controled specimen. By increasing the percentage of RHA from 15% to 20% and combined with 10% POFA causes a slight reduction in the compressive strength. This reduction is due to the different physical and chemical properties of both POFA and RHA materials that lead to the problem with particle packing and also lack of silica content that produces lower calcium silicate hydrate gel. However, only P10R10 and P10R15 showed a compressive strength of more than 30MPa at 28 days. Hence, based on the aims of the research, the optimum combination of POFA and RHA in concrete was selected at 10% POFA and 15% RHA

4. Conclusion

Utilizing POFA and RHA in concrete as a supplementary cementitious material has proven to improve the concrete compressive strength. Although the strength of concrete for both materials show a lower compressive strength than control specimen at 7 days, but the difference in strength was reduced at the later age. The strength increases after 28 days due to the pozzolanic reaction process that densified the concrete microstructure. Replacement of 10% RHA in concrete produces similar strength with control at 28 days compare to POFA. Higher replacement than 10% of both materials will reduce the strength due to the particle packing problem. However, 15%, and 20% replacement for both materials still achieved the targeted strength of 30MPa at 28 days. Workability of concrete will become lower as the replacement level of POFA and RHA increases. This is because both materials are porous and have a high water-absorption capacity. The addition of high dosage of superplasticizer was needed to improve concrete workability. Meanwhile, for the optimum combination of POFA and RHA in concrete, the optimum percentage recorded was at 10% POFA combined with 15% RHA. This percentage shows a higher utilization of waste and was able to achieve the targeted strength of 30MPa at 28 days. Hence, it can be concluded that concrete with a combination of two different pozzolan materials, especially POFA and RHA can be used to produce a concrete of grade M30.

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