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Strength of Concrete Containing POFA and Fine Recycle Concrete as Partial Cement Replacement

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Abstract: Construction and industrial waste consumption has increased rapidly over the world in recent years, resulting in significant amounts of waste. It reflected the issue of a limited number of landfills due to the massive amount of waste created. One option is to recycle the waste and turn it into a useful product that will help to reduce landfill waste. As a result, the goal of this research is to study into the density, slump, compressive strength, and splitting tensile testing of concrete incorporating palm oil fuel ash (POFA) and fine recycled concrete aggregate (FRCA). Concrete was designed at 30 MPa, water cement ratio was 0.50 and containing 5%, 10% and 15% for both POFA and fine recycled concrete materials. At 7 and 28 days, compressive strength and density were tested, while splitting tensile strength was determined only at 28 days. The concrete containing 10% POFA and 10% FRCA was the ideally appropriate mix proportion to replace cement in concrete. In comparison to specimens that did not include POFA as a cement replacement, the addition of 10% POFA as a cement replacement increased the compressive strength and split tensile strength of concrete.

Keywords: Palm Oil Fuel Ash, Fine Recycle Concrete Aggregate, Cement Replacement

1. Introduction

Concrete, which is made up of cement, sand, and aggregate, is the most used building material. Its popularity arises from its strength, durable, and low cost. Globally, around 10 billion tonnes of concrete are produced each year [1]. Since coarse aggregate adds to concrete's toughness and strength, it is the most significant component. The manufacturing of concrete necessitates the use of a large amount of aggregate. However, everything in the world has a limit, and concrete ingredients are no exception. There is a necessity to think about the options [2].

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As it is one of the major components in concrete, cement is one of the most commonly utilized materials in the world [3]. Many countries around the world have had a high need for construction materials. As a result, finding a less expensive and more accessible alternative to traditional building materials has become a critical issue [4]. Many researchers, like Barbuta et al. [5] , Yahya et al. [6] , and Sandanayake et al. [7] , are interested in utilizing pozzolanic materials, plastic, fibre, food waste and polystyrene, as substitutes for coarse aggregate, fine aggregate, cement and sand. This is due to an increase in the processing of toxic waste and non-biodegradable materials like plastic and polystyrene in recent years, which has resulted in a slew of environmental issues.

In comparison to consumer costs, concrete, on the other hand, is highly expensive. Many researchers are trying to figure out how to make concrete more cost-effective by lowering its cost. Substituting less expensive materials like agricultural or ceramic waste for concrete is one of the most effective methods. Companies are being pressured to provide environmentally friendly products and materials as public awareness of the environment grows [8].

The purpose of this research is to see whether POFA can be used to substitute cement in concrete. Slump, density, compressive strength and splitting tensile of concrete produced with POFA and fine recycled concrete aggregate are compared. The compressive strength of POFA and fine recycled concrete aggregate was analyzed if it is equal to or better than that of ordinary concrete in a strength test. As a result, it is demonstrated in the study that POFA and fine recycled concrete aggregate have good potential in settling issues.

2. Utilization of POFA and Fine Recycle Concrete as Partial Cement Replacement

Cement is one of the most significant materials in the production of concrete. As the construction industry's demand develops, resources will unavoidably be depleted. As a result, greater research into the usage of cement in concrete is needed, with the purpose of replacing cement with POFA and fine recycled concrete aggregate in the future. In terms of concrete production, the best options are POFA and FRCA. In fact, the homogeneous aggregate mixture is made from concrete and is not combined with any other elements. As a result, RCA created from concrete waste has proven to be even more efficient than RCA made from waste materials [9]. According to Safiuddin et al. [10], the splitting tensile strength of recycle concrete aggregate concrete was higher than that of natural coarse aggregate (NCA) concrete.

When compared to normal cement, the usage of POFA makes concrete stronger and more durable. POFA is a material that contains a lot of silicon dioxide and can be used as an alternative to cement. Another study found that concrete made with a specific level of POFA substitution had the same or greater strength than Ordinary Portland Cement (OPC). The mechanical properties of concrete are improved when cement is replaced with POFA, such as peak temperature, elastic modulus, and strength. By replacing a lower percentage of POFA for cement, concrete strength can be enhanced [11]. According to recent study, finely ground POFA is an effective pozzolanic material which can be used in concrete with other pozzolans such as fly ash and silica fume [12] , POFA has been found to have good pozzolanic characteristics, making it suitable for use as a cement alternative in mortar and concrete mixtures [13]. Figure 1 shows the process of making POFA.

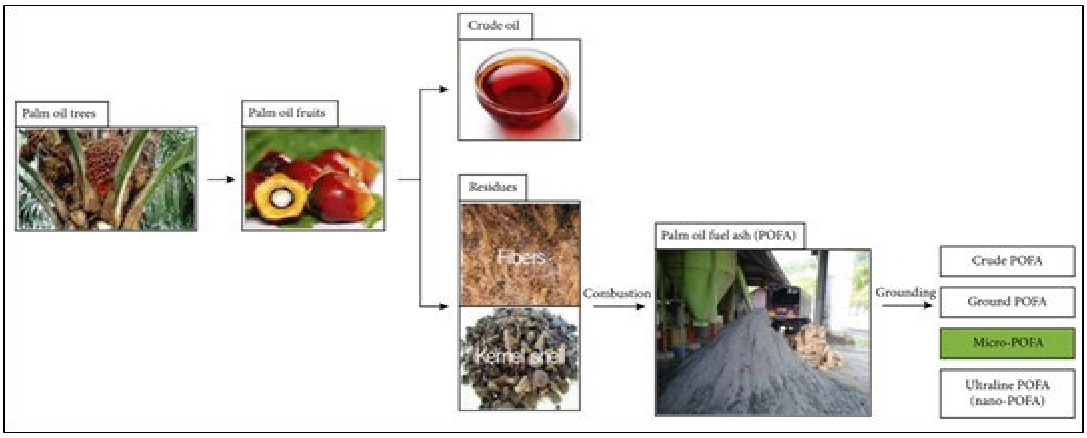

Figure 1: Process of making palm oil fuel ash [14]

2. Materials and Methods

The materials that were used in this study were cement, sand, coarse aggregate, palm oil fuel ash, fine recycled concrete aggregate, and water.

i) Cement

The concrete mix design, which corresponds to ASTM 150M – 12, was made with ordinary Portland Cement (OPC).

ii) Sand

The sand for this study came from a local factory close to Universiti Tun Hussein Onn Malaysia (UTHM). The texture of sand was as fine aggregates such as natural white sand and it must be dried under sunlight before used it.

iii) Coarse Aggregate

To avoid aggregate blockage, the maximum aggregate size used was 12 mm. The maximum aggregate is determined by the amount of 12 mm that passes through the sieve pan. The coarse aggregate was normal and heavy, and it met ASTM C33/ C33M requirements. The coarse aggregate was dried naturally in the sun.

iv) Palm Oil Fuel Ash

The palm oil fuel ash was taken from an oil palm plantation in Parit Sulong, Johor. Most of the POFA was collected in a damp and high humidity state. Before it can be utilized in concrete mixture, the material must be air-dried for a specified amount of time. The POFA percentage in the mix design are 5%, 10%, and 15%, respectively.

v) Fine Recycle Concrete Aggregate

In this study, the FRCA was collected from test crushing normal concrete cubes. FRCA was obtained by crushing the concrete aggregates cubes in the Structural and Material Laboratory in UTHM, Batu Pahat, Johor. The size of waste concrete cube was 150 mm x 150 mm x 150 mm. The strength of concrete cubes was designed in the range of C30 to C35. The crushing process were done by the crushing machine. The FRCA was then produced using a sieve process with a maximum size of 5 mm and added to the mixture in various percentages. The FRCA percentage in the mix design are 5%, 10%, and 15%, respectively.

vi) Water

Water is a significant component of concrete mixtures in this study. The water for this concrete mix comes from Syarikat Air Johor's direct supply of fresh water. This water had been treated and is free of organic matter, chemicals, sludge, clay, oil, and any other potentially hazardous substance. The concrete can be harmed by using contaminated or untreated water.

2.2 Methods

Concrete was design at 30 MPa and containing 5%, 10% and 15% for both POFA and FRCA materials. Aside from that, the water cement ratio in this study is 0.5. There are four testing that need to carry out to achieve the objective of this study. It is also to determine the workability of the materials used in this study. The type of tests was slump, density, compressive strength and splitting tensile tests. The testing for compressive strength and splitting tensile test was measured at 7 and 28 days.

In order to conduct compressive strength and splitting tensile test, sample preparation is important to be carried out. The concrete cube sample was used in compressive strength test while concrete cylinder sample was used in splitting tensile test. The size of cube was 100 mm x 100 mm x 100 mm was made for compressive strength test and size of cylinder was 100 mm X 150 mm was made for splitting tensile test. The number of specimens for compressive strength test was 60 sample while 30 sample for splitting tensile test. Both samples were undergone curing process before starting the test. Table 1 shows the number of specimens for this study.

3. Results and Discussion

The findings of this study were based on laboratory tests and experimental findings. This section discusses the density, slump, compressive strength, and splitting tensile test results.

3.1 Slump Test

The slump reading for normal concrete was 72.1 mm. The data shown that all of the sample was in the medium range and in true slump condition. All of the concrete containing POFA and FRCA had a lower slump reading compared to normal concrete. According to Lu et al. [15], RCA has a greater water absorption capacity than virgin aggregates. The higher the RCA's water absorption rate, the less workable the concrete is during mixing [16]. From the graph, the highest value of slump reading was concrete containing 5% POFA and 10% FRCA which is 69.4 mm while the lowest value of slump reading was concrete containing 15% POFA and 15% FRCA which is 61.1 mm. In short, the larger the percentage of POFA in concrete, the worse the workability of the concrete. Table 1 and Figure 2 shows the graph of slump test of concrete containing POFA and FRCA.

Table 1: Slump test of concrete containing POFA and FRCA

Mix Designation	Slump Reading (mm)
Normal	72.1
POFA 5% - FRCA 5%	69.3
POFA 5% - FRCA 10%	69.4
POFA 5% - FRCA 15%	68.2
POFA 10% - FRCA 5%	66.5
POFA 10% - FRCA 10%	67.1
POFA 10% - FRCA 15%	66.4
POFA 15% - FRCA 5%	63.1
POFA 15% - FRCA 10%	62.2
POFA 15% - FRCA 15%	61.1

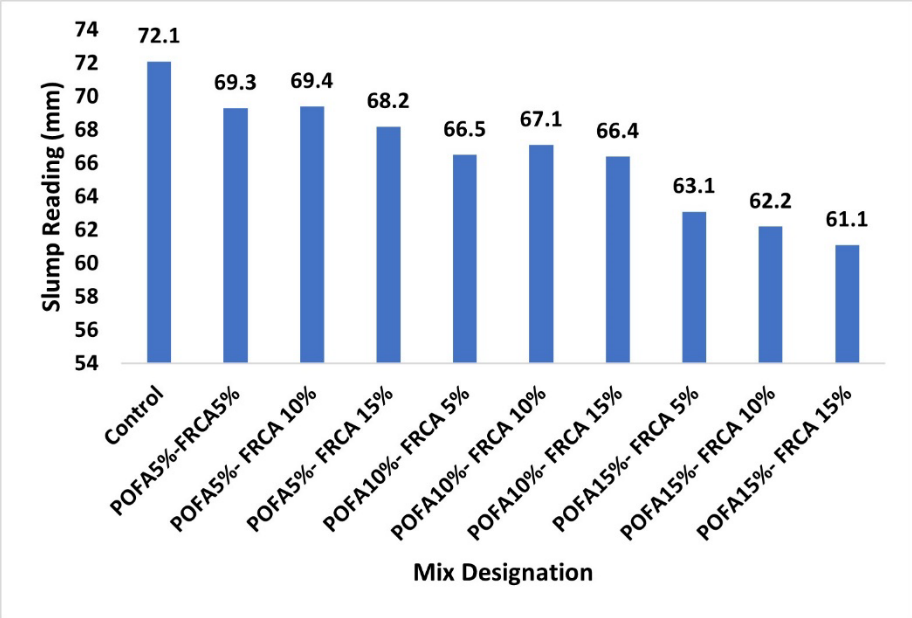

Figure 2: Graph of slump test of concrete containing POFA and FRCA

3.2 Density Test

The variation of mix designation of POFA and FRCA may lead the concrete to become more porous, while the density of the concrete decreases as a result of the additional material. However, these modifications are not that dissimilar from normal concrete. The flakiness and texture of the RCA, which limit compaction and hence reduce the bulk density of concrete [17], are also possible explanations for why over 80% of the sample had a lower density than normal concrete. Overall, the findings indicate that a concrete mix containing 5% POFA and 10% FRCA was the optimum percentage mix for a 7-day curing age. Since the best percentage of concrete mix was a normal concrete mix, there was no optimum percentage mix designation for 28 days of curing age. Table 2 and Figure 3 shows the density of concrete containing POFA and FRCA.

Table 2: Density of concrete containing POFA and FRCA

Mix Designation	Density (kg/m^3)	
	7 days	28 days
Normal	2612	2431
POFA 5% - FRCA 5%	2645	2411
POFA 5% - FRCA 10%	2656	2312
POFA 5% - FRCA 15%	2641	2334
POFA 10% - FRCA 5%	2600	2332
POFA 10% - FRCA 10%	2607	2306
POFA 10% - FRCA 15%	2589	2293
POFA 15% - FRCA 5%	2580	2203
POFA 15% - FRCA 10%	2603	2285
POFA 15% - FRCA 15%	2581	2289

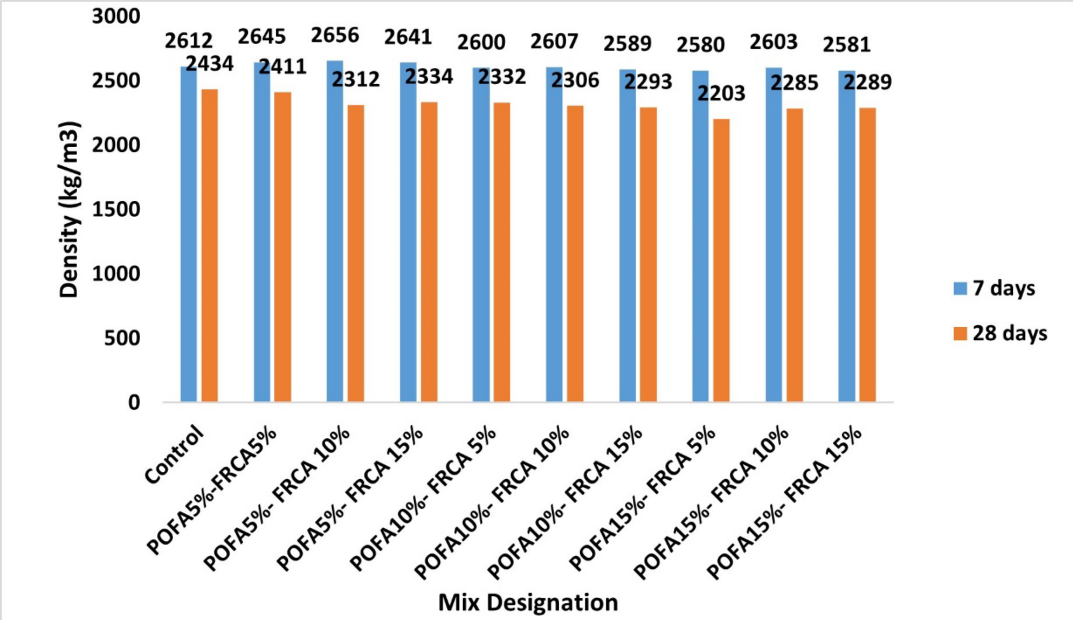

Figure 3: Density of concrete containing POFA and FRCA

3.3 Compressive Strength Test

Concrete with 10% POFA has the maximum compressive strength, whereas concrete with 5% POFA has the lowest. The results support the claims of Aiswarya et al. [4] that the greatest value of compressive strength is reached with a 10% percent substitution and for a 10% replacement of POFA, the maximum strength is attained. This study supports up the findings of Adnan et al. [18], who found that concrete with a 10% POFA substitution has the maximum concrete strength. The study also discovered a correlation between concrete's compressive strength and its age. It's reasonable to suppose that as concrete ages, so does its compressive strength [16]. From this compressive strength test, it also can be concluded that the age factor increases the strength of normal concrete. Overall, the results show that adding the correct quantity of POFA and FRCA to concrete can improve its compressive strength. The findings indicate that a concrete mix containing 10% POFA and 15% FRCA was the best percentage mix for a 7-day curing age. The ideal percentage mix designation of concrete for 28 days of curing age was 10% POFA and 10% FRCA. Table 3 and Figure 4 shows the compressive strength of concrete containing POFA and FRCA.

Table 3: Compressive strength of concrete containing POFA and FRCA

Mix Designation	Compressive Strength (MPa)	
	7 days	28 days
Normal	21.0	32.3
POFA 5% - FRCA 5%	21.9	31.9
POFA 5% - FRCA 10%	21.6	32.7
POFA 5% - FRCA 15%	22.6	33.0
POFA 10% - FRCA 5%	22.4	33.8
POFA 10% - FRCA 10%	22.9	34.6
POFA 10% - FRCA 15%	23.9	33.2
POFA 15% - FRCA 5%	23.5	33.0
POFA 15% - FRCA 10%	22.6	33.1
POFA 15% - FRCA 15%	23.3	32.0

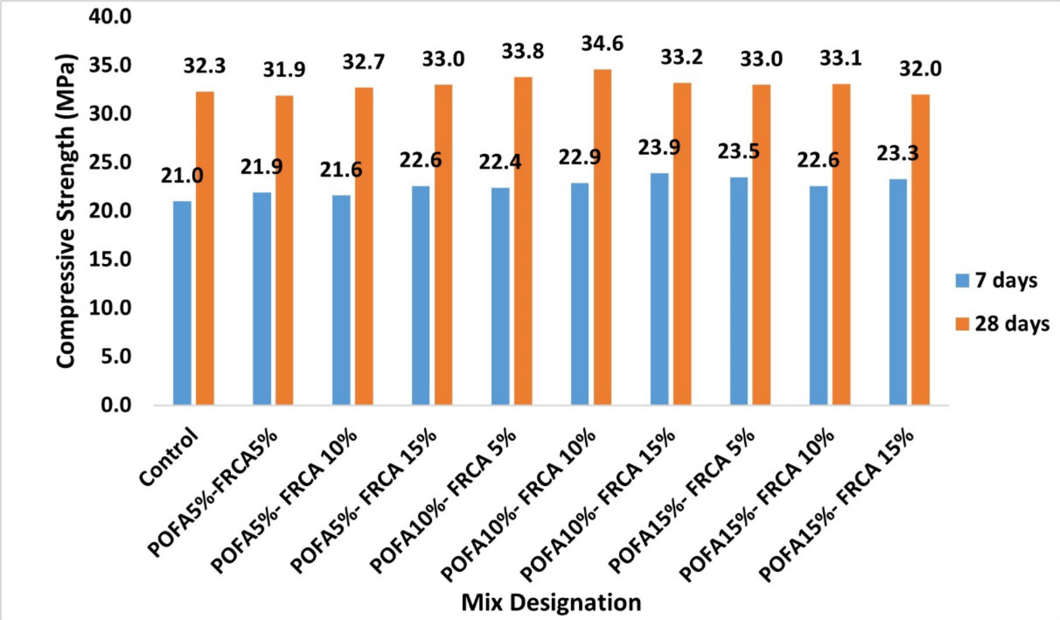

Figure 4: Compressive strength of concrete containing POFA and FRCA

3.4 Splitting Tensile Test

The trend from current study result is similar like studied by Safiuddin et al. [10]. Author claimed that splitting tensile strength of recycle concrete aggregate was higher compared to normal concrete aggregate. It can be proven with concrete containing 10% POFA and 10% FRCA have higher tensile strength which is 3.34 MPa than normal concrete which is only 3.28 MPa. It can be concluded that concrete tensile splitting strength has been observed to increase when cement is partially replaced with POFA. This analysis was supported by Hamada et al. [19]. According to Aiswarya et al [4], the greatest strength is achieved with a 10% substitution of POFA. In short, the optimum percentage mix designation of concrete for 28 days of curing age was 10% POFA and 10% FRCA. Table 4 and Figure 5 shows the splitting tensile strength of concrete containing POFA and FRCA.

Table 4: Splitting tensile strength of concrete containing POFA and FRCA

Mix Designation	Splitting Tensile Strength (MPa)
	28 days
Normal	3.28
POFA 5% - FRCA 5%	3.26
POFA 5% - FRCA 10%	3.31
POFA 5% - FRCA 15%	3.31
POFA 10% - FRCA 5%	3.31
POFA 10% - FRCA 10%	3.34
POFA 10% - FRCA 15%	3.32
POFA 15% - FRCA 5%	3.29
POFA 15% - FRCA 10%	3.30
POFA 15% - FRCA 15%	3.24

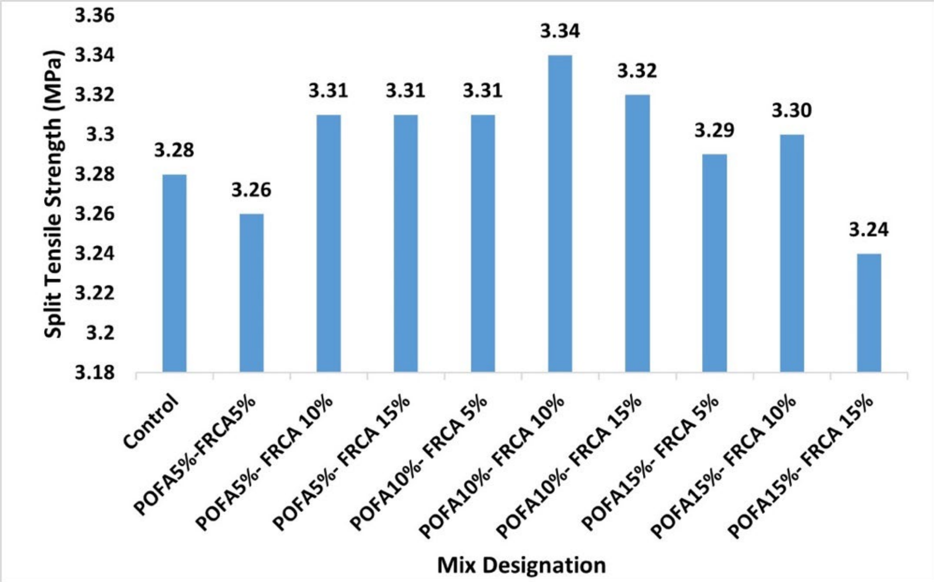

Figure 5: Splitting tensile strength of concrete containing POFA and FRCA

4. Conclusion

As a result, concrete strength varies when cement is partially replaced with palm oil fuel ash and fine recycled concrete aggregate. Based on the compressive strength and splitting tensile results, it can be determined that a concrete mix containing 10% POFA and 10% FRCA is the best mix proportion for replacing cement in concrete. The concrete has a 34.6 MPa compressive strength and a 3.34 MPa tensile strength. In comparison to specimens that did not include POFA as a cement replacement, the addition of 10% POFA as a cement replacement increased the compressive strength and split tensile strength of concrete. Furthermore, POFA has been shown to be a pozzolanic material with the potential to be used as a partial cement substitute while also contributing to the long-term sustainability of construction materials.

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