Effect of Palm Oil Fuel Ash (POFA) on Strength Properties of Concrete

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Abstract - The utilization of pozzolanic materials in concrete construction is increasing, and this trend is expected to continue in the years ahead because of technological advancement and the desire for sustainable development. One of the latest additions to this is Palm oil fuel ash (POFA), a waste material obtained from burning of palm oil husk and palm kernel shell as fuel in palm oil mill boilers, which has been identified as a good pozzolanic material. Palm oil fuel ash which contains siliceous compositions produces a stronger and denser concrete. Effective consumption of POFA in concrete, would decrease the cost of concrete production, could reduce negative environmental effect, and also would solve the landfill problem for the disposal of these wastes.
In this study, the effectiveness of agro waste ash by-product namely palm oil fuel ash (POFA) was developed as an alternative material to replace OPC. POFA cement-based concrete is a concrete produced by integrating POFA as a pozzolan in concrete. This paper will discuss the strength properties of POFA concrete in different replacement level and also compares with control mixture. Concrete specimens containing 10%, 20%, 30% and 40% POFA were made at a water-cement ratio of 0.45. Strength properties such as Compressive strength, Flexural Strength and Split Tensile Strength were studied, and compared with that of concrete containing 100% OPC as control. It is revealed that POFA is an excellent pozzolanic material and can be used as an alternative cement replacement in concrete. It is recommended that the optimum replacement level of OPC by POFA is 20% for a good strength in compressive test.

Index Terms - Palm Oil Fuel Ash, Pozzolanic material, Compressive Strength

I. Introduction

It is known that there are several causes of global warming, including CO_2 from cement. Approximately 5% of total CO_2 emission is released to atmosphere, with about 0.7–1.1 ton of CO_2 being emitted for every ton of cement production. In order to reduce the amount of CO_2 emission, cement manufactures can help by improving production process. For concrete production, the reduction of cement content in concrete can be achieved by utilization of supplementary cementitious materials such as fly ash, blast-furnace slag, natural pozzolans, and biomass ash. Also, the generation of large quantities of industrial by-products every year by chemical and agricultural process industries has created environmental pollution as well as increasing the expenditure of the industry for disposing this waste. As a result, solid waste management has become one of the major environmental concerns in the world. With the increasing awareness about the environment, scarcity of land-fill space and due to its ever increasing cost, waste materials and by-products utilization has become an attractive alternative to disposal. Use of these materials not only helps in getting them utilized in cement, concrete, and other construction materials, it helps in reducing the cost of cement and concrete manufacturing, but also has numerous indirect benefits such as reduction in land-fill cost, saving in energy, and protecting the environment form possible pollution effects. Further, their utilization may improve the microstructure, mechanical properties of concrete, which are difficult to achieve by the use of only ordinary Portland cement.
One of the potential recycle materials from palm oil industry is palm oil fuel ash. Palm oil is extracted from the fruit and copra of the palm oil tree. After the extraction process, waste products such as palm oil fibers, shells, and empty fruit brunches are burnt as biomass fuel to boil water, which generates steam for electricity and the extraction process in palm oil mills. The result is palm oil fuel ash (POFA), which is about 5%, by weight, of solid waste product. The silica oxide content in POFA can react with calcium hydroxide ($Ca(OH)_2$) from the hydration process which is deteriorated to concrete and the pozzolanic reactions produce more calcium silicate hydrate (C-S-H) which is a gel compound as well as reducing the amount of calcium hydroxide. Thus, this contributes to the strength of the concrete thus produce stronger and denser concrete as well as enhanced the durability of the concrete.

II. Literature Review

During recent decades, many researches have been conducted for the use of agro waste ashes. Some of them are summarized below.
Karim et al., (2011) discovered that the concrete produced using a particular level of POFA replacement achieved same or more strength as compared to OPC concrete. No significant strength reduction of concrete is observed up to about 30% replacement of POFA. Awa1 et al., (2011) investigated that high volume palm oil fuel ash concrete, like concrete made with other pozzolanic materials, showed a slower gain in strength at early age. Safiuddin et al., (2010) reviewed that the use of POFA is limited to a partial replacement, ranging from 0-30% by weight of the total cementitious material in the production of concrete. Indeed, the partial

replacement has a beneficial effect on the general properties of concrete as well as cost. Sata et al., (2010) investigated that the strength development of POFA concretes with w/c ratios of 0.50, 0.55, and 0.60 tended to be in the same direction. At early ages, concretes containing POFA as a cement replacement of 10, 20, and 30% had lower strength development than control concretes while at later age 28 days, the replacement at rates of 10 and 20% yielded higher strength development. Mohammed Warid Hussin et al., (2009) studied concrete replaced with POFA with a water to binder ratio of 0.45, were seen to develop strength exceeding the design strength of almost 60MPa at 28-day. Hussin et al., (2008) discovered that inclusion of 20% POFA would produce concrete having highest strength as compared to any other replacement level. Ahmad et al., (2008) studied that one of the potential recycles material from palm oil industry is palm oil fuel ash which contains siliceous compositions and reacted as pozzolans to produce a stronger and denser concrete. Malhotra et al., (2005) investigated that a pozzolanic material has little or no cementing properties. However, when it has a fine particle size, in the presence of moisture it can react with calcium hydroxide at ordinary temperatures to provide the cementing property. Tangchirapat et al., (2003) reported that the chemical composition of POFA contains a large amount of silica and has high potential to be used as a cement replacement. Sukantapree et al., (2002) have found that POFA can be used in the construction industry, specifically as a supplementary cementitious material in concrete. Hussin et al., (1996) studied the compressive strength of concrete containing POFA. The results revealed that it was possible to replace at a level of 40% POFA without affecting compressive strength. The maximum compressive strength gain occurred at a replacement level of 30% by weight of binder. Tay et al., (1990) investigated that replacing 10–50% ash by weight of cementitious material in blended cement had no significant effect on segregation, shrinkage, water absorption, density, or soundness of concrete.

III. EXPERIMENTAL INVESTIGATIONS

A. Materials Used

A.1 Cement

Ordinary Portland Cement 53 grade conforming to IS: 8112-1939 was used. Its properties are shown in Table 1.

Table 1: Cement Test Results

Sl. No.	Characters	Experimental Value	As per IS:8112 - 1989
1.	Consistency of Cement	32%	-
2.	Specific Gravity	3.15	3.15
3.	Initial Setting Time	50 minutes	>30 minutes
4.	Final Setting Time	460 minutes	<600 minutes

A.2 Palm Oil Fuel Ash (POFA)

Palm Oil Fuel Ash is the product of burning palm oil husk and palm kernel shell in the palm oil mill. POFA obtained from Oil Palm India Limited, Kottayam in Kerala was used in the investigation. The specific gravity of Palm oil fuel ash was 1.65.The chemical composition of POFA was tested at **Department of Mining & Geology, Thiruvananthapuram** and the results is given in Table 2. Figure 2 and 3 shows the Palm Oil Residues and palm Oil Fuel Ash.

Figure 1: Palm Oil Residues

Figure 2: Palm Oil Fuel Ash (POFA)

Table 2: Chemical composition of POFA

Chemical composition	% in POFA
Silica	21.81
Aluminium	2.76
Iron	3.20
Calcium	5.70
Magnesium	3.978
Potassium	3.23
Sodium	0.76
Phosphorus	3.58
Chlorine	0.34
Sulphur	1.28
LOI	2.99

A.3 Fine Aggregate

Natural sand conforming to Zone II with specific gravity 2.62 was used as the fine aggregate. The maximum size of fine aggregate was taken to be 4.75 mm. The testing of sand was done as per Indian Standard Specifications IS: 383-1970. The sieve analysis result is shown in Figure 3.

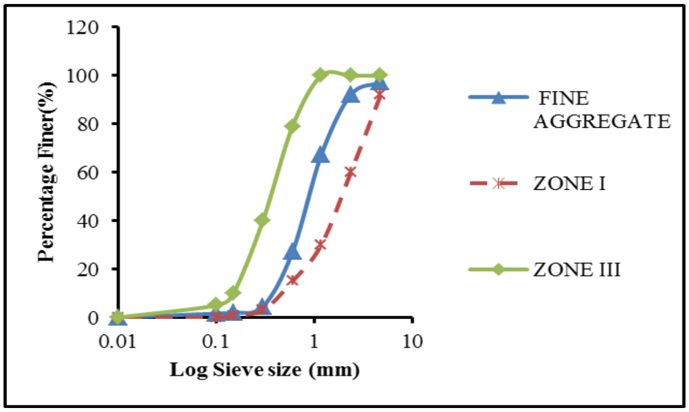

Figure 3: Particle size distribution of Fine Aggregate

A.4 Coarse Aggregate

Coarse aggregate was used with 12mm and 20mm nominal size and specific gravity 2.64, and were tested as per Indian Standard specifications IS: 383-1970 . The sieve analysis result is shown in Figure 4.

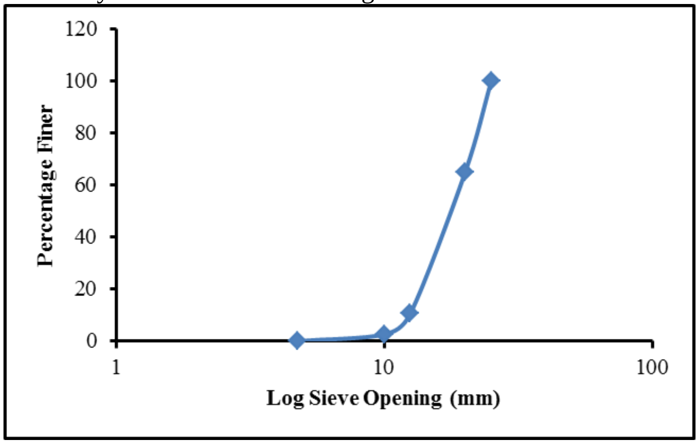

Figure 4: Particle size distribution of Coarse Aggregate

A.5 Water

Fresh potable water, which is free from acid and organic substance, was used for mixing the concrete.

B. Mix Proportion

The concrete mix is designed as per IS: 10262 – 2009 and IS 456-2000 for the normal concrete. The grade of concrete adopted is M30 with a water cement ratio of 0.45. Five mixture proportions were made. First was control mix (without palm oil fuel ash), and the other four mixes contained palm oil fuel ash. Cement was replaced with palm oil fuel ash by weight. The proportions of cement replaced ranged from 10% to 40%. Mix proportions are given in Table 3. The controls mix without palm oil fuel ash was proportioned as per Indian standard Specifications IS: 10262-1982, to obtain a 28-days cube compressive strength of 30 MPa. The ingredients of concrete were thoroughly mixed in a mixer machine till uniform consistency was achieved.

Table 3: Mix proportions

Mixture no.	**C**	**P_1**	**P_2**	**P_3**	**P_4**
Cement (kg/m^3)	437.78	394	350.22	306.45	262.67
Palm Oil fuel ash (%)	0	10	20	30	40
Palm Oil fuel ash (kg/m^3)	-	43.78	87.56	131.33	175.112
Water (lts)	197	197	197	197	197
Sand (kg/m^3)	643.68	643.68	643.68	643.68	643.68
Coarse aggregate (kg/m^3)	1104.36	1104.36	1104.36	1104.36	1104.36

C. Casting and Curing of Specimens.

The 150 mm size concrete cubes, concrete beams of size 100 mm x 100 mm x 500 mm and cylinders of 150 × 300 mm size were used as test specimens to determine the compressive strength and flexural strength and Splitting Tensile Strength respectively. After casting, all the test specimens were finished with a steel trowel. All the test specimens were stored at temperature of about 30^oC in the casting room and are demoulded after 24 hours for water-curing. When the test age is reached, they are tested for Compressive strength, Splitting tensile strength and Flexural Strength.

D. Test Procedure

The concrete properties such as Compressive strength Test, Splitting Tensile Strength Test and Flexural Strength Test were performed in accordance with the provisions of the Indian Standard Specification IS: 516-1959.

D.1 Compressive strength Test

This test will provide the breaking strength of the cube which is made particularly for the purpose of testing the compressed concrete compression strength. The compressive strength of the specimen is determined by dividing the maximum load carried by the specimen during the test by the average cross sectional area.

$$\text{Compressive strength} = \frac{Maximum\ load}{Cross\ sectional\ area}$$

D.2 Splitting Tensile Strength Test

This test method measures the splitting tensile strength of concrete by the application of a diametral compressive force on a cylindrical concrete specimen placed with its axis horizontal between the platens of a testing machine. The splitting tensile strength, T can be calculated as follows:

$$T = \frac{2P}{\pi dl}$$

where, P is maximum load at failure
d is average diameter of cylinder
l is the average length of the concrete specimen.

D.3 Flexural Strength Test

Modulus of rupture of concrete is determined by the Flexural Strength Test using a simple beam. The flexural tensile strength or modulus of rupture, f_b can be calculated as follows:

$$f_b = \frac{PL}{bd^2}$$

where, P is maximum applied load in kg,
b is average width of specimen at the point of fracture
d is average depth of specimen at the point of fracture.

IV. RESULTS AND DISCUSSIONS

The various aspects studied include the effect on compressive, flexural and splitting tensile strength using palm oil fuel ash in varying percentages as a partial replacement of cement. The results are given below:

A. Compressive Strength

Compressive strength of concrete mixes made with and without palm oil fuel ash was determined at 7 and 28 days. The test results are given in Table 4 and are represented in Figure 6. The compressive strength decreases as the percentage of ash increases. However, for 10% ash added, the compressive-strength development at 7 days was greater than the control samples, and the 28 day compressive strength was nearer to the control samples. As shown in Fig. 4.4, the 28-day compressive strengths for concrete cubes with 0, 10, 20, 30, and 40% replacement of cement with ash decrease from 36.89 MPa to 35.63 MPa, 32.7 MPa, 28.44 MPa, and 23.48 MPa, respectively. As per IS 456 : 2000, the specified characteristic Compressive strength of 150 mm cube at 28 days for a M30 grade concrete is 30N/mm^2. From the results it can be observed that upto 20% replacement of cement by POFA, a compressive strength of 30N/mm^2 can be obtained. When more than 20% is replacing, the compressive strength goes below than targeted strength of 30N/mm^2.

Table 4: Compression behaviour of Palm Oil Fuel Ash Concrete

Mix Type	Compressive Strength (N/mm^2)	
	7 days	28 days
C	28.07	36.89
P_1	29.41	35.63
P_2	27.71	32.7
P_3	23.04	28.44
P_4	18.59	23.48

Figure 5: Compression Test

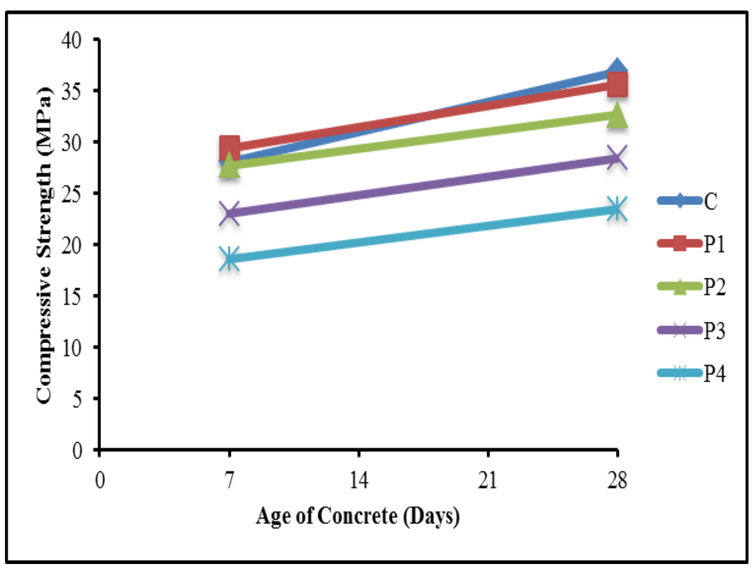

Figure 6: Variation of Compressive Strength with age

B. Splitting Tensile Strength

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The results of splitting tensile strength of concrete mixes with and without palm oil fuel ash measured at 28 days are given in Table 5. Test results.indicate that the tensile splitting strength increases as the percentage of the POFA increases from 0% to 10%. However, for 20% ash added, the tensile-strength development was the same as the control samples. When the replacement of POFA is increased to 30%, strength goes on decreasing. These results are represented graphically below in Figure 8. It is observed that mixes P1 and P2 containing 10% and 20% POFA respectively performed similar to control mixes. Also, it can be inferred that mix P1 contribute to the improvement of tensile splitting strength than others.

Table 5: Splitting tensile behaviour of Palm Oil Fuel Ash concrete

Mix Type	Splitting Tensile Strength (N/mm^2) at 28 days
C	2.62
P_1	2.69
P_2	2.62
P_3	2.33
P_4	1.99

Figure 7: Split Tensile Test

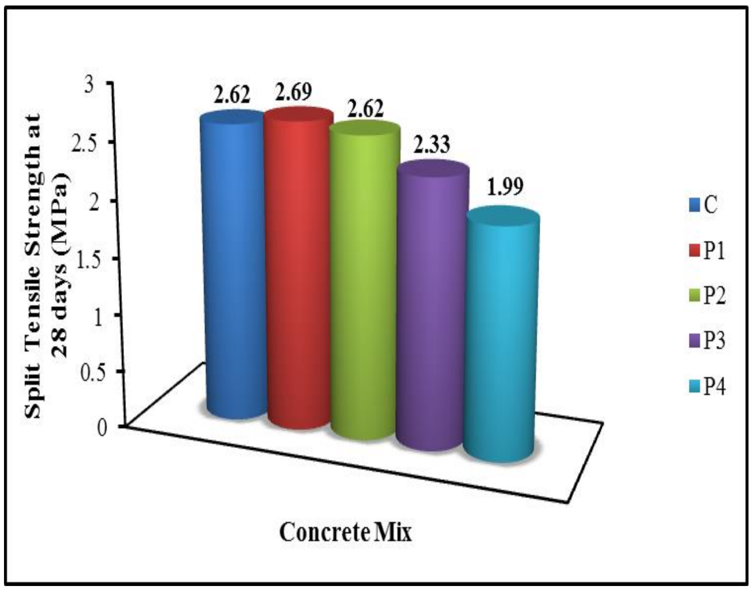

Figure 8: Variation of Split Tensile Strength

C. Flexural Strength

The flexural strength test results of palm oil fuel ash concrete are given in Table 6 and shown in Figure 10 respectively. From the results it is well understood that P_2 mix achieved the highest flexural strength. It is seen that 28 day flexural strength of 10% replacement of cement with POFA is similar to that of the control mix. When the replacement proportion is increased to 20%, the flexural strength also increases. But, further increase in proportion of POFA causes a reduction of Flexural Strength.

Table 6: Flexural behaviour of Palm Oil Fuel Ash concrete

Mix Type	Flexural Strength (N/mm^2) at 28 days
C	5.71
P_1	5.71
P_2	6.12

P_3	4.89
P_4	4.28

Figure 7: Flexural Strength Test

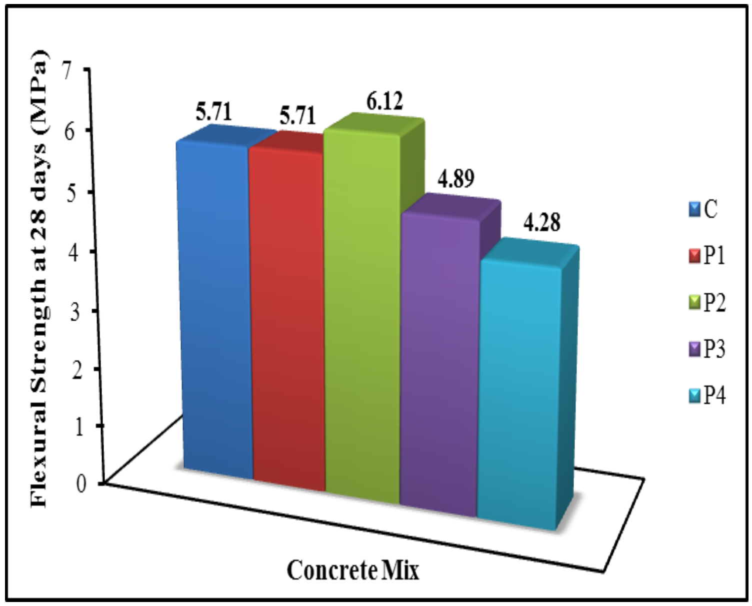

Figure 8: Variation of Flexural Strength

V. CONCLUSIONS

The following conclusions could be arrived at from the study:

- ❖ Compressive strength, Splitting tensile strength and Flexural strength of cement replaced palm oil fuel ash concrete specimens were found to be lower than those of normal OPC concrete.
- ❖ Results suggest that 20% replacement of POFA could be the optimum level for the production of concrete because strength of concrete reduced gradually beyond this replacement level.
- ❖ Palm Oil Fuel Ash used as Cement replacement enables the large utilization of waste product.
- ❖ Long-term studies on the development of strength as well as durability aspect of concrete containing POFA have been recommended for further investigation.

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