Influence of Palm Oil Fuel Ash on Strength Properties of Concrete

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ABSTRACT. Cement which is highly responsible for hydration enthalpy and also the cost of cement which makes it uneconomical. The only way to deal with this kind of challenge is by introducing different products to replace certain amount of cement. An environmental friendly waste product produced from agricultural industries known as POFA (Palm-oil-fuel-ash) can be replaced with certain percentage of cement replacement in concrete and still attain similar strength such as conventional concrete. This paper intention is to focus changes on mechanical, strength properties of M30 grade concrete by using (POFA) palm-oil-fuel-ash. It is very much efficient in reducing cement expenses and also enhances the strength when engineered in technical aspects. When this agro waste palm oil ash is added, very less quantity of co2 emission takes place with reduction in liberation of heat from concrete. With the incorporation of palm oil fuel ash in various incremental order of (0, 10, 20, 30, 40) % replacement by cement in concrete, certain amount of change in behavior in concrete strength parameters namely compression strength, split tensile strength, and flexure strength is noted. M30 grade of concrete is considered while performing tests and analyzing, it shows that 10% replacement of cement by palm oil ash (POFA) gave high strength compared to conventional concrete. All the result generated are compared against control mix which gave an impression of improvement in (mechanical, strength) parameters of concrete in a positive way which helps balance the environment and also achieve sustainability of the concrete.

Keywords: Palm Oil Fuel Ash; Mechanical Properties; Cementitious Replacement; Strength Parameters; CO₂ emission; Concrete Sustainability.

1. INTRODUCTION

The CO₂ which is produced during the emissions through the generation of Ordinary Portland Cement (OPC) greenhouse gases mainly effected our environment. On the other hand unused industrial by products are polluting surrounding water and air [1]. These emissions has a great impact entire ecological system. The estimated manufacturing of cement around the world is approximately in tons is (4.1 billions) [2]. Every ton of cement manufacturing process produces an approximate quantity of 900 kilograms of carbon emission and eventually this CO₂ will be due to its habit pollutes the air of atmosphere by penetrating in to the environment [3]. It was estimated that production of the cement in
2019 was incredibly increasing in billions of tons in quantity [4]. Recent facts strongly communicate that many industrial waste products or by products are dumped in open field which leads deterioration of land and nearby streams of ground water. Most of the unutilized products are mainly rice husk ash (RHA), fly ash (FA), palm oil ash fuel(POFA), palm oil (clinker powder) (POCP), oil palm shell (OPS), palm oil clinker (POC), steel slag, incinerated bottom ash aggregates (IBAA) could be utilized as substitutes in concrete[5]. The POFA with Geo-polymer has very limited research and due to abundant availability of POFA in South East Asia, the research on pozzolonic materials should be widely spread [6]. The strengthening of structural elements by incorporating palm oil ash (POFA) as bond for replacement in epoxy has seen satisfying results with flexure performance of the member compared to control specimen, which will be seen economic point of view [7]. Waste materials as a replacement for binders and conventional aggregates is very much in demand as the growing waste land is affecting the environmental ecosystem. Metakaolin, Palm ash fuel oil (POFA), ground granulated blast furnace slag must have to be used as binders, while palm oil clinker (POC) and oil palm shell (OPS) used as coarse aggregate in producing geopolymer concrete [8]. The only importance at present must be given to sustainability of environment by reducing the emission of CO2 and also various other extensive researches should be done on the how to replace the cement quantities with high percentages [9]. Pezzoli’s, when added to Portland cement it enhances the mechanical strength properties of concrete, also increases its durability. The reduction in the size of grains of pozzolonic reaction pozzolonic effect, voids and pores obstruction is the cause for it [10]. Recent developments in the research has been improving to reverse the damage done due to emission of CO2 and billions of tons of concrete waste which are increasing in the modern construction methods, recycled materials such as waste products recycled aggregate are the only way to restore the balance[11]. The usage of POFA at 30% has seen lesser generation of heat of hydration which significantly is an improvement and it also delayed the thermal centigrade increment at peak scale, the thermal resistance against cracking increased with addition of POFA [12]. This material has high silica content which acts as a pozzolonic material and forms C-H-S gel compound such a material partially or fully replacement of cement, the reduction in expansion of mortar bars is seen [13]. The pozzolans reduces permeability of the concrete which means the concrete deterioration and damage rate of concrete will be less [14]. High volume of POFA replacement by cement which was a concept to make UPOFA has seen resulting in a less strength and it resulted that from incremented % of POFA the strength reduces significantly [15]. The main aspect of the concrete is durability and it includes resistance to chloride and acid attacks, POFA reduces permeability and also the void volume resulting from it and also the sorptivity of cement paste with POFA as cement replacement is reduced [16]. The micro structure is main criteria when bonding is required and when POFA is treated with heat and making it used as a Nano particle the strength of Nano POFA incorporated mortar showed higher strength than OPC mortar, further increasing % of palm oil ash of Nano size can be used to increase the strength in concrete [17].

2. MATERIALS AND PROPERTIES

2.1 Materials

2.1.1 Cement
Cement is a substance used for binding and hardening other material. Ordinary Portland cement OPC 53 grade is used. Cement Chemical composition and properties are shown in Table 1 and Table 2 respectively.

2.1.2 Palm oil fuel ash (POFA)
It is a waste product of the palm oil industry, the raw POFA obtained from NBL palm industry of oil manufacturing west Godavari. POFA was sieved for removal of the large particles. Then with the help of Los Angeles machine was used to obtain fine particles. The palm oil ash POFA sample can be seen in Figure 1. The chemical constituents of the palm oil ash POFA is shown in Table 1.
2.1.3 Fine aggregate
Locally available sand from river has been procured. Many procedures were carried out to meet the experimental requirements and sand used was with a specific gravity of 2.79. The properties of fine aggregate are shown in Table 3.

2.1.4 Coarse aggregate
The coarse aggregate which is used is angular in nature and also size of aggregate used was 20 mm and below with specific gravity of 2.68. The properties of coarse aggregate are shown in Table 3.

2.1.5 Super-plasticizer
The purpose of super plasticizer is to alleviate the water percentage and increase the earlier strength of concrete also to increase workability. In this study conplast sp430 is used. Normal dosage rate is 0.5 to 2% of cement/cementitious content. The color of SP is dark brown liquid with the specific gravity of 1.16.

2.1.6 Water
From the nearby tap fresh water was procured. The $\text{pH}$ value was also considered, as it plays a crucial role when added to concrete. $\text{pH}$ value according to IS 456-2000 can be less than are equal to 6.0, water used for mixing and curing should be contained against injurious amounts of harmful chemicals and other acidic substances and other organic debris that can lead to deterioration of concrete or steel.

2.2 Properties of materials
Chemical constituents of material Table 1:

| Composition | OPC   | Palm oil fuel ash(POFA) |
|-------------|-------|-------------------------|
| $\text{SiO}_2$ | 9.81  | 50.3                    |
| $\text{Al}_2\text{O}_3$ | 2.76  | 4.74                    |
| $\text{Fe}_2\text{O}_3$ | 4.38  | 8.08                    |
| $\text{CaO}$ | 64.0  | 5.19                    |
| $\text{MgO}$ | 0.92  | 3.22                    |
| $\text{SO}_3$ | 2.30  | 1.40                    |
| $\text{K}_2\text{O}$ | 0.74  | 11.8                    |
| $\text{Na}_2\text{O}$ | 0.44  | 0.10                    |
| $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ | -     | 56.77                   |
| L.O.I     | 1.10  | 8                       |
Physical properties of cement are shown in Table 2:

| Test                  | Value |
|-----------------------|-------|
| 1. Specific gravity   | 3.10  |
| 2. Fineness test      | 3%    |
| 3. Consistency        | 33%   |
| 4. Initial setting time | 30min |

Properties of aggregate shown in Table 3:

| Materials        | Test                | Value |
|------------------|---------------------|-------|
| Fine aggregate   | 1. Specific Gravity | 2.79  |
|                  | 2. Fineness Modulus | 3.82  |
| Coarse aggregate | 1. Specific Gravity | 2.68  |
|                  | 2. Water Absorption | 0.20% |

3. DESIGN MIX PROPORTIONING

The mix proportioning of concrete is done as per is 10262:2019. The target compressive strength is 38.25 N/mm² and required number of samples and required number of proportions were prepared, in which one of them 0% (control mix) with no palm oil ash in it. Cement is then replaced by POFA in numbers of 10, 20, 30, 40, and 15 %. The mix proportion ratio of each one is given in Table 4.

Mix1= 100% Cement + 0% POFA, Mix2= 90% Cement + 10% POFA, Mix3= 80% Cement + 20 % POFA, Mix4= 70% Cement + 30 % POFA, Mix5= 60% Cement + 40% POFA, Mix6= 85% Cement + 15% POFA. Fine Aggregate = 100%, Coarse Aggregate = 100%, Superplasticizer = 1%
4. EXPERIMENTAL INVESTIGATION

4.1 Slump test

The type of test conducted to know the consistency or wetness of the concrete sample and also to know the degree of workability of concrete is known slump test and it is shown in the Figure 2.

![Figure 2. Slump Test](image)

4.2 Compressive strength test

Compressive tests were done on cubes 150mmx150mmx150mm size for curing period 7 days, 14 days and 28 days as shown in the Figure 3.

![Figure 3. Cube Compression Testing machine.](image)
4.3 Split tensile strength

The spilt tensile test on cylinders of 150x300mm has been carried out, the experimental setup can be seen in Figure 4.

![Split Tensile Testing](image)

Figure 4. Split Tensile Testing

4.4 Flexural strength

Flexure strength of concrete is determined by prisms of dimensions 100mm, 100mm, and 500mm of size with curing period of 7 days, 28 days. The Experimental setup is shown in the Figure 5.

![Flexure/bending testing](image)

Figure 5. Flexure/bending testing
4.5 Water absorption test

Water absorption test was performed, the specimens were oven kept for 1050 centigrade for 24 h, later weigh the sample and consider it as dry weight \( w_1 \). Further, the samples are immersed in water to take the sample’s wet weight \( w_2 \) after wiping the surface dry. Eq. (1) can be used for calculation of % of water absorption.

\[
\% \text{ of water absorption} = \frac{w_2 - w_1}{w_1} \times 100
\]  

(1)

5. RESULTS AND DISCUSSION

5.1 Slump test

This method is commonly used methods to find concrete workability. The apparatus is set on a flat surface either on ground or table and the cone is filled by placing concrete mix in three layers one by one and is compacted after each layer for 25 times with the tamping rod. The mould removed slowly by rotating in the vertical direction so as to allow the concrete to get stability and this allows the concrete inside the mould to subside. My testing slump is shear slump as per IS-7320(1974) and investigative findings can be seen in Table 5 and also in Figure 6.

| Palm oil fuel ash % | Slump value (mm) |
|---------------------|------------------|
| Control mix-0%      | 95               |
| 10                  | 140              |
| 15                  | 145              |
| 20                  | 150              |
| 30                  | 145              |
| 40                  | 140              |

Table 5. Slump value with various % of (POFA - Palm oil fuel ash).

![Figure 6. Column chart for slump value (mm) versus % Replacement of palm oil ash (POFA)](image)
5.2 Compressive strength

Compressive strength of concrete specimens was determined by casting of cube having dimensions standards according to Indian standard which is 150x150x150(mm). After casting POFA concrete they were left undercuring condition for 7 days, 14 days and 28 days. The procedure carried out was as per IS 516:1959. Cube specimens were placed in the test machine in such a way that the specimen is placed centrally on bottom plate of the test machine, and movable part is adjusted so that it touches the top surface of cube.

Application of load was without any shock and was gradual, the load application was continued until the specimen was failed. The load at which the specimen was failed is noted and this process was done for every % mix. For good results a minimum of 3 cubes were casted for every % mix and the average load value was taken as compressive strength. This test was done on 7 days, 14 days and 28 days and results are shown in Figure 7.

![Figure 7: Column chart for % (POFA-Palm oil ash) versus compressive strength](image_url)

**Note:** from the above graph it is observed maximum value compressive strength 10% replacement.

5.3 Split tensile test

There was no direct method for knowing the tensile strength of concrete, for determining the tensile strength of POFA cylinder were cast of height 300mm and 150 mm diameter. The test specimens were placed under compression test machine with specimen longitudinal axis parallel to horizontal direction. The load was applied gradually until cylinder splits in two parts.

Number of specimens tested for accurate results was 3, failure load was taken as split tensile strength after testing all the 3 specimen as average for every mix percentage replacement of palm oil ash. The test was performed as per is 5816:1999 and results shown in the Figure 8 are for 7days and 28 days strength.
Figure 8. Column chart for % (POFA-Palm oil ash) versus splitting tensile strength

Note: The following results shows that maximum value for split tensile test is 10% replacement of palm oil fuel ash.

5.4 Flexural / bending test

The test performed for flexure/ bending strength of concrete was performed with prisms with dimensions 100 x 100 x 500 mm for 7 days and 28 days strength. This test was performed as per IS 516:1959 code. In this the test two supports of testing machine on which prisms were placed and the load application known as two point loads was applied. The test setup for flexural strength was shown in Figure 9. The load where failure of the specimen occurred was noted.

Figure 9. Column chart for Palm oil fuel ash % versus flexural strength

Note: The above results shows that maximum value of flexure strength is for 10% replacement of POFA-Palm oil fuel ash.
5.5 Water absorption test

The Test results shown in Table 6 are for water absorption test which implies that the rate of absorption of water rising higher with increase in the percentage of palm oil fuel ash. Also Obtained results are graphically shown in Figure 10.

| S.no | POFA% | Water absorption % |
|------|-------|---------------------|
| 1.   | 0     | 0.88                |
| 2.   | 10    | 1.42                |
| 3.   | 15    | 2.78                |
| 4.   | 20    | 3.10                |
| 5.   | 30    | 3.33                |
| 6.   | 40    | 5.05                |

**Figure 10.** % POFA-Palm oil fuel ash versus % Absorption of water at 28 days.
6. CONCLUSION

The Experimental Analysis in this study done on Palm oil ash replaced in concrete where cementitious replacement has been done is completed and following conclusion can be made,

1. The study shows that a significant change in strength parameters of concrete when palm oil fuel ash is being added which leads to overall cost reduction of concrete compared to conventional one and making it less harmful by reducing the emission of CO₂ and the heat of hydration.
2. Compressive strength is increased maximum at 10% addition of POFA mix proportion.
3. A maximum of 10% Palm oil fuel ash (POFA) replacement was ideal for attaining the peak compressive strength of concrete 'compared with 0% replacement which is control mix.
4. The Split tensile test also showed higher strength at 10% POFA replacement.
5. The Flexure/Bending test showed maximum strength at 10 % replacement of POFA in M30 concrete.
6. Usage of POFA increases the utilization of waste products which is suitable for environmental aspects and increases the reduction in agro-waste.
7. The Rate of Absorption of water and Workability increased with higher % of POFA palm oil fuel ash.

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