Evaluation of the effective mechanical properties of palm oil fuel ash based fiber reinforced concrete

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Abstract. Cement concrete is one of the utmost regularly used building materials next to water. But one tonne of cement produces 1.25 tonnes of CO₂ and pollutes the environment. To keep that in mind, in this study the cement is partially replaced with POFA up to 30% (5% equal intervals), and steel fibers are added to the volume of concrete by 0.5% apart from normal concrete. Generally, POFA is one of the Agro-Industrial garbage materials which is coming as of the palm oil industry, with the growing amount of waste produced from the different processes there has been an increasing the waste generation. Increasing intrust in the use of agro – Industrial waste to achieve the potential advantages. Comparing with cement, POFA contains a high silica content. specimens are cast with M40 grade of concrete. The prepared POFA based Fibre reinforced concrete (FRC) was tested for all types of mechanical properties, as compressive strength, split tensile strength, bending strength, and load-deflection curve. All these properties are compared with the nominal concrete.

Keywords: POFA, Steel Fibres, FRC, Mechanical properties, and Agro-Industrial waste

1. Introduction
Throughout the most recent quite a few years, more consideration has been paid to the proficient administration of numerous sorts of waste creation to guarantee maintainability in the building. One of the essential issues of waste administration procedures is the utilization of waste materials instead of sustainable assets. The vital advantages of reusing are diminishing ecological outflows, diminishing landfiling and garbage removal, and saving crude materials.

Accessibility of the two squanders locally, has started endeavors to consolidate these materials in solid creation. Consolidation of palm oil fuel debris as a halfway concrete substitution in oil palm shell lightweight total cement effectively improves the compressive strength of cement [1].The experiment results on the exhibition of POFA find out that it has a decent capability in diminishing the development because of soluble alkali-silica response [2].
The side effect of palm oil fuel debris would generally grow yearly, although the use of POFA continues exceptionally restricted. Palm oil is a necessary component of biodiesel fabrication. The majority of POFA is arranged as garbage in dumping ground along these lines, which initiates numerous natural difficulties. Silicon dioxide (SiO2) is the fundamental substance generation of palm oil fuel debris, and past studies have shown that POFA is not reasonable as a decent pozzolan in its unique size by its huge molecule and lofty perviousness[1]. POFA was presented in concrete as a pozzolanic material nearly all investigations POFA consists of concentrated cement's mechanical properties, for example, compressive-strength and modulus of elasticity concrete[3].

The principal substance structure of POFA debris is silica which is a fundamental element of imporous. Exploration shows that ground pofa debris can be utilized a pozzolan in ordinary and more strength concrete[4]. One promising pozzolan is palm oil fuel debris and is available in numerous parts of the globe. It is a result of a power plant that uses as fuel the palm fiber, shells, and void natural product packs and is sparked at 800-1000°C[5]. Albeit the porosity of the glue is expanded because of the consolidation of fly ash, the normal porous volume is diminished. These outcomes in a fewer penetrable glue[6]. The intermingling region of the boundary among total as well as the framework is additionally expanded because of the utilization of fly ash[7].

The expansion of steel-strands altogether improves a significant number of the designing properties of mortar and cement, extreme toughness, and durability. Flexural strength, fatigue strength, elasticity, and the capacity to oppose breaking and spalling are additionally upgraded. To plan and dissect structures utilizing steel-fiber fortified cement for strength, the stress-strain efficiency of the material in compression is crucial. While the compressive strength is manipulated instead of the strength estimation of the primary factors, the stress vs strain curve is expected near evaluate the material's durability instead of flexibility contemplation.

The expansion of steel fibers extraordinarily upgrades a significant number of the mortar and concrete designing properties, particularly durability and toughness. It likewise improves elasticity, flexural strength, fatigue strength, and spalling limit[8]. The utilization of steel fiber reinforced concrete (SFRC) is a form of concrete that is reinforced with steel fibers consistently expanded throughout the most recent years. Extensive advancements have occurred in SFRC. The contemporary disciplines of the utilization of SFRC incorporate roadway asphalts [9]. As indicated by crack mechanics of normal concrete, the disappointing conduct of concrete constructions will in general be more brittle with expanding size [10]. Subsequently, there happens a size impact on flexural and shear strength. Because of fiber-strengthened concrete, if the fiber volume content is sufficiently high (say over 3% for steel fiber) to deliver a flexible concrete, size impact most likely is irrelevant. But a low volume of "fiber content, the conduct may in any case display size impact.

In this current research, cement is switched out for POFA up to 30 percent (5% equal interval). In addition to the materials referred to above, 0.5 percent of steel fibers were applied to the concrete volume except for normal concrete. For this substitution, compression, split and bending strength tests were performed. We observe an optimal combination of those alternatives. Prepare a beam for this optimum combination and perform a load vs deflection curve compared to the normal concrete mix beam.

Note: POFA - palm oil fuel ash, OPC – Ordinary Portland cement, SFRC- Steel fiber reinforced concrete.

2. Materials Properties and Mix Proportions

2.1. Materials and Properties
2.1.1. Cement. Here the OPC Grade 53 was adapted from IS: 12269 – 2013 and applied to Chemical constituent of ordinary Portland cement as shown in Table 1.

**Table 1.** Chemical Constituent of OPC[11].

| Chemical Constituent | Content % |
|----------------------|-----------|
| CaO                  | 62.4      |
| Al₂O₃                | 5.2       |
| SiO₂                 | 20.4      |
| K₂O                  | 0.005     |
| Fe₂O₃                | 4.2       |
| MgO                  | 1.6       |
| SO₃                  | 2.1       |
| L.O.I                | 2.36      |

2.1.2. Fine aggregate. Aggregate is the granular material used for the manufacture of concrete or mortar, and it is considered fine aggregate because the granular material particles are so fine that they move through a 4.75 mm sieve. It is frequently exploited to expand the amount of concrete in the building industry. in this report, fine aggregate is adapting to IS 383 -2016.

2.1.3. Coarse aggregate. Coarse aggregate is additionally vital for strength, warm and flexible properties of concrete, dimensional steadiness, volume, and soundness. Remembering the full for the mix will handle the shrinkage level and forestall breaking. The size of coarse aggregate was used in this study is 20 mm.

2.1.4 Steel fibers. Steel fibers are employed in this study as shown in figure 1. Accumulation of steel fibers to the concrete there are several advantages with adding up steel fibers to the concrete can resist crack width and improve the flexure strength of concrete. Steel fibers can act as a secondary reinforcement. The Table 2. Shows the properties of steel fibers.

2.1.5. Palm Oil Fuel Ash. Environment pollution problems can happen diminished to a huge degree by utilizing POFA in cement. It tends to be utilized as a valuable solidifying material up to a specific substitution level of concrete without creating any unfavorable impact on the strength and different properties of cement. The gathered debris was broiler dried and gone through a 90micron strainer and utilized for concrete substitution. The value of specific gravity of POFA is has used towards 2.36
during this experimentation, the POFA and chemical compositions Samples are shown in figure 2 and Table 3.

![Figure 2. Palm oil fuel ash.](image)

| Chemical Component | Content % |
|--------------------|-----------|
| SiO$_2$            | 43.60     |
| Al$_2$O$_3$        | 8.50      |
| Fe$_2$O$_3$        | 10.10     |
| CaO                | 8.4       |
| MgO                | 4.80      |
| K$_2$O             | 3.50      |
| SO$_3$             | 2.8       |
| L.O.I              | 18.0      |

**Table 3. chemical configuration of POFA[11].**

2.1.6. **Water.** Normal water and New consumable water, which was liberated from a corrosive and natural substance, was utilized for blending the concrete. The synthetic response among water and concrete is vital to accomplish a solidifying property; subsequently, water utilized mustn’t be dirtied.

2.1.7. **Superplasticizer.** Superplasticizer is utilized to build its usefulness. Also, valuable establishing materials, for example, fly debris and silica smolder, are broadly utilized as pozzolanic materials in high-strength concrete. They have been regularly managed to make additional pozzolanic strength responses, to decrease the porousness, also, to develop the toughness of the concrete [12]. The reason for the superplasticizer is to influence the new solid properties by expanding the functionality in concrete. The type of superplasticizer utilized in this investigation is ECMAS.

2.2. **Mix Proportions**
In this investigation cement has been replaced with POFA 0 %, 5%, 10%, 15%, 20%, 25%, and 30 %.

The steel fibers are kept constant at 0.5 % to the total volume of concrete except for nominal concrete as shown in Table4. Mix design was prepared according to IS 10262-2019[13] and the water-cement ratio of 0.40 has been used in this study as shown in Table5.

| Mix ID | CEMENT (%) | POFA (%) | FINE AGGREGATE (%) | COARSE AGGREGATE (%) | STEEL FIBERS (%) |
|--------|------------|----------|--------------------|----------------------|------------------|
| S1     | 100        | 0        | 100                | 100                  | 0                |
| S2     | 95         | 5        | 100                | 100                  | 0.5              |
| S3     | 90         | 10       | 100                | 100                  | 0.5              |
| S4     | 85         | 15       | 100                | 100                  | 0.5              |
| S5     | 80         | 20       | 100                | 100                  | 0.5              |
| S6     | 75         | 25       | 100                | 100                  | 0.5              |
| S7     | 70         | 30       | 100                | 100                  | 0.5              |

Table 4. Replacement of POFA with cement

| Mix ID | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|--------|----|----|----|----|----|----|----|
| Cement | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| POFA   | 0  | 0.038 | 0.07 | 0.124 | 0.173 | 0.226 | 0.284 |
| Fine Aggregate | 1.54 | 1.6 | 1.666 | 1.728 | 1.79 | 1.87 | 1.95 |
| Coarse Aggregate | 3.22 | 3.33 | 3.46 | 3.59 | 3.741 | 3.9 | 4.07 |
| Water  | 0.4 | 0.415 | 0.431 | 0.444 | 0.469 | 0.49 | 0.513 |
| Super Plasticizer (%) | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| Steel Fibers (%) | 0  | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

Table 5. Mix proportions of palm oil fuel ash fiber reinforced concrete.

3. Experimental Investigation

3.1. Workability of Concrete

The slump has been reduced by the addition of steel fibers and replacement of POFA as shown in Fig3. The incorporation of supplementary cement materials as an exemplar POFA into the concrete blenddesire typically enlarge the atmosphere by satisfying up space in the concrete complex. Consequently, a related decrease in the operability of the concrete was induced by the tougher matrix.

Figure 3. Slump values (mm)
3.2. Compressive strength

One of the greatest widespread and useful assets of concrete is the compressive strength [14] of concrete. It is usually concluded by the examination of 150X150X150mm³ cubes performed in the laboratory as shown in figure 4. In contrast to that nominal concrete, POFA fiber reinforced concrete mixes found substantially superior strength values at 20 % substitution of POFA and the addition of steel fibers with 0.5 % achieved optimum compressive strength compared to all other replacements of POFA fibrous reinforced concrete compared with nominal concrete as shown in figure 5.

![Figure 4. (a.) cube specimens, (b.) Cube Compressive strength](image)

![Figure 5. Cube Compressive strength](image)
3.3. Split Tensile Strength

The tensile strengths of concrete samples comprising steel fibers were substantially superior to those of fiber-free nominal concrete. The steel fibers that joined the split sections of the specimens worked after the matrix to the fibers over the stress transfer and thus unhurriedly endorsed the maximum tensile stress. The moved stress increased the concrete matrix’s tensile strain potential and thus improved the POFA fibrous mixtures’ tensile strength over the non-fibrous concrete mixture complement. The mixture of POFA with steel fibers can be inferred from the results shown in the creation of concrete tensile strength as shown in figure 7. It is important to mention that the accumulation of POFA to fibrous combinations influenced constructively tensile strength growth. But, due to the pozzolanic nature of POFA, the rate of power growth was poor at an initial curing period. For an instance, the accumulation of POFA to the fiber-reinforced concrete mixtures improved the tensile strength associated with the mix without any POFA and steel fibers. The tensile strength was performed in the laboratory for the cylindrical specimens as shown in figure 6. Among all replacements of POFA fibrous reinforced concrete, tensile strength has been achieved optimally at 20 percent substitution of POFA with the addition of steel fibers with 0.5% fiber reinforced concrete relative to nominal concrete.

(a.)

(b.)

Figure 6. (a.) Cylinder specimens (b.) Split tensile strength of Cylinders

![Figure 6](image1.png)

![Figure 7](image2.png)

Figure 7. Split tensile strength of Cylinders
3.4. Bending Strength

It is calculated by the testing of 100X100X500 mm³ specimens performed in laboratory. The bending strength measure (IS 516) [14] is designed to provide the bending strength of tensile concrete. The described flexural strengths of prismatic beams are demonstrated. The results attained by combining the 0.5% steel fiber precedes to enhanced bending strength efficiency and increased concrete bending strength. The combined effects of POFA and steel Fiber were exposed, and bending strength was increased at 20% of POFA with 0.5 percent steel fiber reinforced concrete compared with the nominal concrete mix as shown in figure 9. The bending strength of PCC was obtained by performing the laboratory test on the specimen by using ASTM Machine as shown in figure 8. Therefore the strength of fiber-reinforced concrete is expanded by the removal of cracks. The connecting action of fibers may be responsible for improving the flexural act of concrete containing steel fibers.

![Figure 8. (a.) Prism specimens (b.) Bending strength](image8.png)

![Figure 9. Bending strength](image9.png)
3.5. Behaviour of load-deflection

In this study, the behavior of load-deflection was calculated by performing the flexure test to the beam having a size of 150mmx150mmx700mm. One normal reinforced concrete beam(S1) and one POFA fiber reinforced concrete beam (S5) with reinforced which is taking as optimum are compared. The test was performed in the UTM after curing of 28days. The first crack was at 74.62 KN for the beam S5, and for the normal RCC, the beam is 58.56 KN.

![Figure 10. Load vs deflection curve for nominal RCC beam (S1)](image1)

![Figure 11. Load vs deflection curve for S5 beam](image2)

The final ultimate load is 97.5 KN for normal RCC beam, for the S5 beam maximum load is 125.6 KN. The maximum deflection is 7.26mm for the normal RCC beam(S1) as shown in figure 10. And 3.76mm for POFA fiber reinforced concrete beam (S5) as shown in figure 11. From the experimental observations finding the following points are the flexural cracks are forming in the beam below the neutral axis, shear cracks are formed. When compared to the normal RCC beam(S1), the POFA steel fiber beam(S5) is showing the best performance and having the low deflection. The crack transmission of normal RCC beam (S1) and POFA fiber reinforced concrete beam (S5) are shown in figure 12 & 13.

![Figure 12. Crack transmission of normal RCC beam (S1)](image3)

![Figure 13. Crack transmission of palm oil fuel ash fiber reinforced concrete beam (S5)](image4)

4. Conclusion

The following result is obtained with careful experiments on M40 concrete with a changing percentage of POFA from 5-30 percent with 0.5 % of steel fibers are kept constant are compared with plain concrete by performing assessments for instances lump, compressive strength, split tensile strength test, bending strength and load-deflection curve.
1. The substitution of cement in concrete with POFA induces differences in strength.
2. The compressive strength raises the replacement by up to 20 percent and then begins to decrease. At 20 percent cement substituted with POFA and 0.5% addition of steel fibers with, the optimum strength is shown.
3. The results of split tensile strength indicate that strength increases steadily and then decreases at 20 percent replacement palm oil fuel ash and addition of 0.5 % steel fibers.
4. Bending strength indicates that strength increases steadily and then declines at 20% of the replacement and adding up 0.5 % of steel fibers.
5. In comparison to the normal reinforced concrete beam, the S5 beam has a higher load-bearing capacity and has less deflection.

References

[1] Tangchirapat W, Saeting T, Jaturapitakkul C, Kiattikomol K and Siripanichgorn A 2007 Use of waste ash from palm oil industry in concrete Waste Management.27 pp 81–88
[2] Yusuf M O, Johari M A M, Ahmad Z A and Maslehuddin M 2014 Performance of different grades of palm oil fuel ash with ground slag as base materials in the synthesis of alkaline activated mortar Journal of Advanced Concrete Technology.12 pp 378–387
[3] Tay J H and Show K Y 1995 Use of ash derived from oil-palm waste incineration as a cement replacement material Resources Conservation and Recycl.13 pp 27–36
[4] Sata V, Jaturapitakkul C and Kiattikomol K 2007 Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete Construction and Building Materials.21 pp1589–1598
[5] Chindaprasirt P and Rukzon S 2008 Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar Construction and Building Materials.22 pp1601–1606
[6] Poon C S, Wong Y L and Lam L 1997 The influence of different curing conditions on the pore structure and related properties of fly-ash cement pastes and mortars Construction and Building Materials.11 pp 383–393
[7] Wong Y L, Lam L, Poon C S and Zhou F P 1999 Properties of fly ash-modified cement mortar-aggregate interfaces Cement and Concrete Research.29 pp 1905–1913
[8] Gao J, Sun W and Morino K 1997 Mechanical properties of steel fiber-reinforced, high-strength, lightweight concrete Cement and Concrete Composites.19 pp 307–313
[9] Nataraja M C 1999 CCCv.21 pp.383-390.1999.pdf 21
[10] Hillerborg A, Modéer M and Petersson P E 1976 Analysis of crack formation and crack growth in concrete by means of fracture mechanics and finite elements Cement and Concrete Research.6 pp773–781
[11] Alsubari B, Shafigh P, Jumaat M Z and Alengaram U J 2014 Palm Oil Fuel Ash as a Partial Cement Replacement for Producing Durable Self-consolidating High-Strength Concrete Arab. Journal for Science and Engineering.39 pp 8507–8516
[12] Steven H. Kosmatka, Beatrix Kerkhoff and W C P 2008 Design and Control of concrete mixtures (Vol.5420, pp. 6077-1083). Skokie, IL: Portland Cement Association
[13] Standard I 2019 OAOhV fej vuqikru ekxZn ’ khZ fl%kar 02
[14] IS 516:2014 2004 Method of Tests for Strength of Concrete IS 516 - 1959 (Reaffirmed 2004) New Delhi, India