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Experimental Study on Sustainable Light Weight Concrete Incorporating with Oil Palm Industrial Waste

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Abstract

In present days a very huge number of raw materials are used by the construction sector which releases very large amount of harmful gases such as carbon dioxide (CO_2) into the environment. To avoid such problems research should be focused on sustainable materials, among which Oil Palm industrial waste that can be used in concrete. The main purpose of this research is to utilize the palm oil fuel ash (POFA) as a replacement of cement and replacing fine aggregate with Oil Palm clinker (OPC) with different proportions. The test results for workability of concrete, Mechanical properties, durability properties, Micro structural analysis and Flexural behavior of beams are carried to produce sustainable light weight concrete for 7, 28 & 56 days of curing period. The results obtained and observations made clearly demonstrate that the replacement of cement and fine aggregates by Oil Palm waste is advantageous, partially for mass concrete.

Keywords: Mechanical and Durability properties, Oil Palm Clinker, Palm Oil Fuel Ash, Sustainable Light Weight Concrete, HI-FORZA 369

INTRODUCTION

The construction sector is consuming numerous environmental resources, releasing CO2 into the environment, causing pollution. To address this issue, research should focus on sustainable materials and alternative construction resources like palm oil industrial waste. This approach can help protect the environment and promote a safer and healthier environment [1]. Nearly two million tons of waste, including Oil palm shells, Palm fibers and empty fruit bunches, are releases annually during the oil extraction process. Disposal of POFA in landfills can also cause environmental problems [2]. Palm oil waste presents a substantial challenge in the agro-industry of countries such as Malaysia, Thailand, Nigeria, and India. This waste includes solid materials that are utilized in the production of biofuel. The residual byproduct from this process is subsequently burned to generate steam, which is then used to produce electricity [3]. POFA constitutes up to 5% of the total weight of solid waste generated during the combustion of palm oil waste [4].

The increase in palm oil production has led to a rise in Palm Oil Fuel Ash (POFA), which has pozzolanic properties and could be a viable cement replacement. However, its natural form limits its pozzolanic properties when mixed with concrete, and its larger particle size and unburned carbon contribute to higher loss on ignition (LOI) in high-strength concrete [5].

POFA has a significant quantity of silica, making it a promising ingredient for replacing cement [6]. The fuel ash produced from burning palm oil has various particle sizes. But when it gets crushed, it

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transforms into a consistent grey colour with homogeneous sized particles. This crushed POFA is an excellent replacement of cement because of its cement-setting properties when combined with cement [7]. The inclusion of POFA in concrete results in an increase of both the initial and final setting time. The amount of POFA replaced, and the corresponding fineness defined the duration of the delay [8]. When subjected to acid and sulphate attacks, the specimens with higher POFA quantity showed lower surface water absorption and greater strength in comparison to conventional concrete [9].

Malaysia, the second-largest palm oil producer globally, is increasing the amount of oil palm shells (OPC), a by-product generated by palm oil mills, which results in approximately four million tons of solid waste [10]. Being a by-product of producing palm oil, the oil pam shells have characteristics that make it appropriate for use in different kinds of light weight constructions. It can be utilized as a material filler and aggregate replacement, and it also serves as an absorbing material for industrial water treatment [11]. OPC can serve as a cool material for pavements which improves the development of cool pavement technology [12].

Research on Date Palm Leaf Fiber (DPLF) reinforced composites has shown improvements in tensile strength, impact resistance, and flexural strength compared to ordinary epoxy. The composites also showed improved performance when bent, demonstrating improved impact resistance and flexural strength. The study also found that DPLF reinforced composites have a favorable coefficient of thermal expansion, good thermal conductivity, and great thermal stability, making them suitable for high-heat applications in automotive and aerospace sectors [13]

The OPC recycling process can reduce the effects of residues while generating a cleaner atmosphere. When OPC is added in higher quantity which is replacement of natural aggregates, the total density and strength of light weight concrete decreases gradually. As the quantity of OPC increases then the amount of water absorption of light weight concrete gradually increased [14].

In Nigeria, around 2.5 million tons of OPC are collected annually and dumped into the landfills. It is found that when there is an increase in OPC content in concrete mix then there is a decrease in workability, density and mechanical properties but reduce in the landfills [15]. The study aims to improve the durability of Self-Compacting Concrete (SCC) by using ultra-fine natural steatite powder and fly ash as filler materials. This could reduce atmospheric pollution from cement manufacturing. SCC has shown resistance to various factors, including chloride diffusion, oxygen permeability, mercury porosity, water absorption, carbonation, and ammonium nitrate leaching. Previous research has explored using admixtures to enhance bond and durability properties in normal concrete [16]

Basalt fiber and metakaolin are two commonly used materials in the production of High-Performance Concrete (HPC) due to their favorable properties. Basalt fiber, a type of mineral fiber derived from fine basalt rock, possesses excellent mechanical properties, including high tensile strength, good resistance to alkaline environments, and high durability. These characteristics make basalt fiber an ideal reinforcement material for concrete, enhancing its strength and crack resistance [17]

For the OPS aggregates used in the concrete mixes, all three saturated conditions-sun dry (SD), air dry (AD), and Saturated-surface-dry (SSD) are suitable. The OPS aggregates were soaked in clean water to obtain the SSD condition. Subsequently, the aggregates undergo drying to remove any remaining moisture from the OPS aggregate surfaces. After this, the aggregates will be ready to be mixed into the concrete and will be in an SSD condition. OPC aggregates are air-dried in a controlled laboratory environment until their moisture content falls between 2% to 6%. The SD condition aggregates were left in the sun for around two weeks in order to reduce their moisture content to less than 2% [18]. When OPC is used as coarse aggregate in lightweight concrete, 25 MPa of compressive strength can be achieved [19].

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MATERIALS AND MATERIAL PROPERTIES

To perform this experiment on POFA and OPC replacements the following materials are required for the concrete mixing.

Materials

The materials used in this research are Cement, POFA, fine aggregate, OPC, coarse aggregate, superplasticizer. Ordinary Portland cement grade 53 was used for all the concrete mixes. The POFA utilized in this research was obtained from a palm oil industry located in Andhra Pradesh, India. The POFA was sieved through of 150µ.The Physical parameters of cement and POFA are presented in Table 1, while the chemical properties are presented in Table 2. Zone-II fine aggregate was used in this research. Two different sizes of coarse aggregate are used in this research. 20 mm down and 12.5 mm down aggregates. OPC were near Gannavaram oil palm and industry, Andhra Pradesh, India. 4.5 mm down shells were used in this research as a clinker. Physical properties of OPC and aggregates are presented in Table 3. Super plasticizer HI-FORZA 369 PC based with specific gravity 1.2 is used in this research. The OPC and Palm oil industrial waste is used for the fuel for boilers. The ash which is generated from the boilers is POFA.

Table 1. Physical properties of Binding Materials.

S.N.	Property	Cement	POFA
1	Specific gravity	3.14	2.2
2	Setting time of cement • Initial setting time • Final setting time	50 min 480 min	-
3	Normal consistency	34%	-
4	Bulk density (kg/m^3)	1865	963
5	Surface area (m^2/kg)	355	975

Table 2. Chemical Properties of Binding Materials.

Chemical Compositions	Cement	POFA
Silicon dioxide (SiO_2) [2]	20.9	22.1
Aluminum Oxide (Al_2O_3) [20]	4.7	3.5
Iron Oxide (Fe_2O_3) [2]	3.4	5.5
Calcium Oxide (Cao) [8]	64.2	8.4
Magnesium Oxide (MgO) [20]	1.2	4.8
Phosphorous Oxide (P_2O_5) [21]	0.28	3.75
Potassium Oxide (K_2O) [22]	0.005	7.5
Sodium Oxide (Na_2O) [21]	0.75	0.39
Sulfur trioxide (SO_3) [22]	2.11	0.33
Titanium Oxide (TiO_2) [23]	0.22	0.24
Manganese Oxide (MNO) [24]	0.09	0.07
Loss of Ignition (LOI) [25]	0.9	10.1

Table 3. Physical properties of Aggregates.

S.N.	Property	OPC	FA	CA
1	Specific gravity	2.17 (SSD)	2.71	2.73
2	Bulk density (kg/m^3)	640	-	-
3	Fineness modulus	-	3.17	7.94
4	Size (mm)	4.75 (Down)	4.75	20

Mix Proportions

In this research four concrete mixes were prepared with M30 grade for all the concrete mixes. The mix proportions of all the prepared concrete mixes were tabulated in table 4. The first mix was conventional concrete with a w/c ratio of 0.45. The super plasticizer used is 0.7% of the weight of the binder. Details for mix ratio for 1 cu.m of concrete 1 : 1.9 : 3.3. Substituting cement with POFA for different proportions with w/c ratio 0.45. In this research POFA is limited to 30%, which was passed through 150µ sieve is used in this mix and up to 1% of super plasticizer was used. It is observed from the workability results, increasing the POFA content the slump values are decreasing simultaneously. Replacement of fine aggregate with OPC with different proportions with water-cement ratio 0.45. Admixture was used up-to 1%. The Clinker was used is 4.5 mm down. After evaluating all the material properties 10 mixes are proposed and designed as per Indian standards (IS:10262-2019 and IS:456-2000) and the same was presented in Table 4. All the replaced mixes were compared with conventional mix, and from the experimental results the optimum mix is drawn and presented in Table 4.

Table 4. Mix Concrete Proportions.

Mix ID	Concrete mix Matrix	Proportions (C: POFA: FA: OPC: CA)
CC	Conventional concrete	1: 0: 1.9: 0: 3.3
M1	Conventional concrete + 10% POFA	1: 0.1: 1.8: 0: 3.1
M2	Conventional concrete + 20% POFA	1: 0.25: 1.8: 0: 3.1
M3	Conventional concrete + 30% POFA	1: 0.4: 1.8: 0: 3.1
M4	Conventional concrete + 10% OPC	1: 0: 1.6: 0.15: 3.17
M5	Conventional concrete + 20% OPC	1: 0: 1.4: 0.3: 3.17
M6	Conventional concrete + 30% OPC	1: 0: 1.2: 0.4: 3.17
M7	Conventional concrete + 40% OPC	1: 0: 1.1: 0.6: 3.17
M8	Conventional concrete + 50% OPC	1: 0: 0.92: 0.75: 3.17
M9	Conventional concrete+20% POFA + 10% OPC	1: 0.25: 1.6: 0.14: 3.13

Experimental Program

To know the behavior of OPC and POFA replaced concretes the following mechanical properties, are performed. They are compressive strength, Split tensile strength, Flexural strength. The specimen sizes are 150 mm × 150 mm × 150 mm cubes and 300 mm height 150 mm diameter cylinder specimens and 500 mm length, 100 mm width and depth beams are considered as per Indian standards. The palm oil clinker having high water absorption ratio, to avoid all the OPC are used in the research at SSD condition. By using proposed mix proportions all the mechanical properties were calculated for the curing period of 7, 28, & 56 days for all eight mixes (M1 to M8) and those are compared with CC mix. From the Results the optimum mix was drawn. To know all parameters for the optimum, mix the workability, mechanical properties, durability properties, and flexural behavior of beams tests were performed. The detailed experimental investigation is presented in results and discussion.

RESULTS AND DISCUSSIONS

This present research mainly focuses on POFA and OPC. The comprehensive strength studies of Mechanical properties such as compressive strength, split tensile strength, Flexural strength are plot and are described below.

Workability of Concrete

The following observations are noticed during the workability experimentation.

- Replacement of F.A with 10% OPC with mix ratio of 1:1.7:0.19:3.39 (C: FA: OPC: CA) without SSD condition. Super plasticizer is used 1% by weight of binder with 20% water-reduction in the mix. The slump obtained for this mix is a true slump i.e. it doesn’t have any workability.
- Replacement of F.A with 10% OPC with 1:1.65:0.15:3.17 (C: FA: OPC: CA) ratio without SSD condition. Super plasticizer is used 1% by weight of binder and 15% water reduction is used in this mix. Slump obtained is a true slump.

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- Replacement of F.A with 10% OPC with 1:1.2:0.14:2.46 (C: FA: OPC: CA) ratio with SSD condition. No super plasticizer is used in this mix. The slump obtained in this is 20 mm initially after addition of super plasticizer i.e., 10 ml to the concrete mix the final slump is 140 mm.
- Finally, 10% clinker are replaced with F.A. The mix ratios 1 : 1.65 : 0.15 : 3.17 (C: FA: OPC: CA) with SSD condition. Super plasticizer is used 1% by weight of binder with 15% water reduction in the mix. The slump obtained is 140 mm i.e., it is a shear slump. This mix proportion is adopted in this research.

The slump value for conventional M30 grade concrete is 110 mm as shown in Figure 1. The slump values for replacing cement with POFA and replacing fine aggregate with OPC are shown in Figure 1. As the proportion of POFA increases the workability of concrete decreases. The slump value for M1, is 110 mm which is same as conventional concrete. The workability of concrete decreases gradually as the quantity of clinkers in concrete increases. For 10% replacement of OPC i.e. M4 the slump value 140 mm is higher than conventional concrete. Replacement of both POFA and OPC the slump value is 90 which is less than the conventional concrete. All the slump values for the concrete mixes are shown in Figure 1.

Compressive Strength

The compressive strength is the major parameter which influences other properties of concrete such as flexural strength, split tensile strength and modulus of elasticity. The development of compressive strength was found to indicate the contribution of OPC and POFA when replaced with fine aggregates and cement respectively. The replacement of cement and fine aggregate compressive strength are computed separately. After examining the replacements optimum mix was identified and for optimum mix compressive strength also computed. All the compressive strengths are compared with conventional mix and presented in Figures 2,3&4 respectively. All the compressive strengths are computed for the curing period of 7, 28, & 56 days. The compressive strength for all the mixes is increasing with curing period. The compressive strength of POFA replaced mixes (M1 to M3), till the 20% replacements the strength is increasing and then from 30% strength is decreasing due to less cement content. The formed hydration products that are essential to form the calcium silicate hydrated gel are less than those of controlled concrete. The progressive increase in compressive strength shows that the palm oil clinker doesn't undergo deterioration once it has been imbanded in concrete. The compressive strength at each age decreases with increasing the clinker percentage. The bond between the particles is to a large extent dependent on surface texture, cement paste bonds more adequately with rough surface. However, smooth surface on the interior part of the clinker in addition to the presence of water will determine adhesive bonding between the aggregates, which leads to reduction in bonding strength. As clinker replacement increases, surface contact expands, necessitating more cement for adhesion. However, with constant cement levels insufficient bonding results in decreased compressive strength.

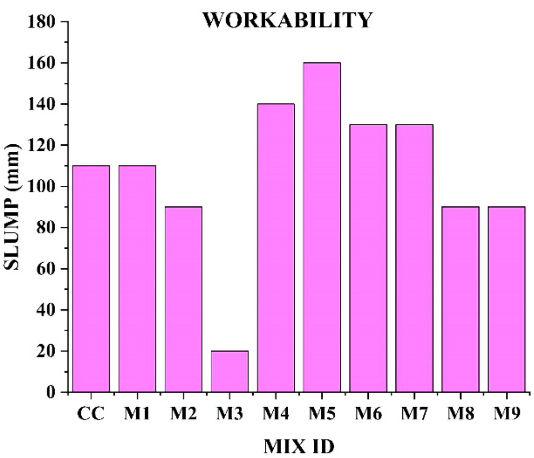

Figure 1. Workability of concrete mixes.

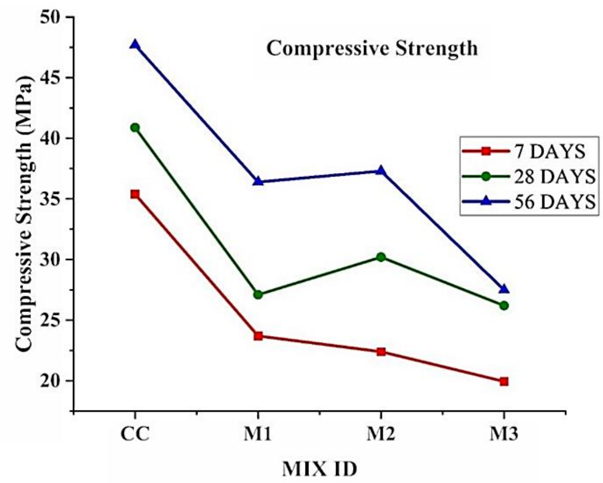

Figure 2. Compressive strength for conventional concrete and POFA.

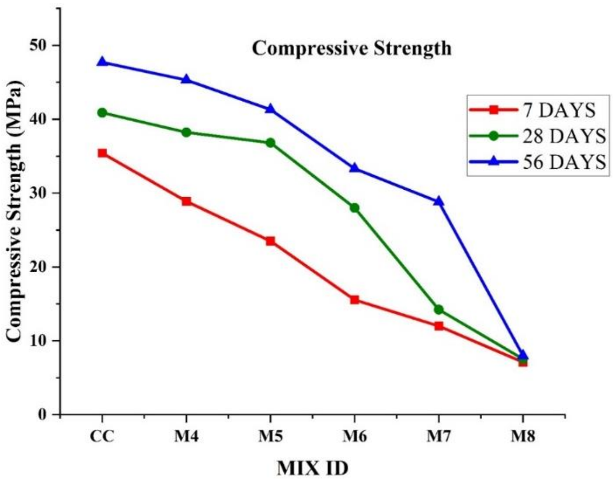

Figure 3. Compressive strength for conventional concrete and OPC.

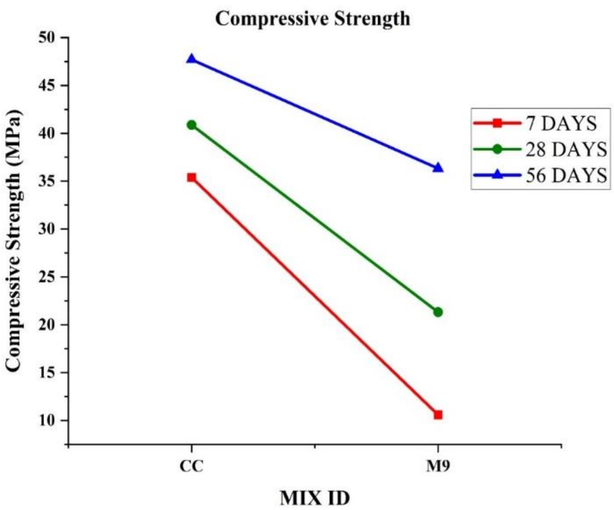

Figure 4. Compressive strength for replacement materials.

Split Tensile Strength

Split tensile strength serves as a crucial measure for assessing concrete's resistance to cracking. This strength is closely linked to the curing duration. Effective curing enhances the bond between the CSH gel and aggregate while reducing the occurrence of microcracks, which directly influences split tensile strength. As the replacement level of OPC increases, both the compressive strength and split tensile strength of OPC decreases, leading to early crack development under load. For all the mixes the split tensile strength is compared with conventional mix are presented in Figures 5,6 & 7. From the figures it is observed that the split tensile strength is increasing with curing age. When increasing the replacement with POFA and OPC content, the strength increases up to 20% and then it is decreasing.

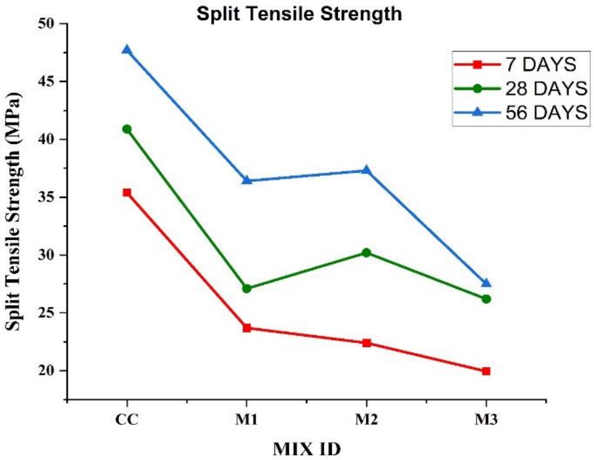

Figure 5. Split tensile strength for Conventional concrete & POFA.

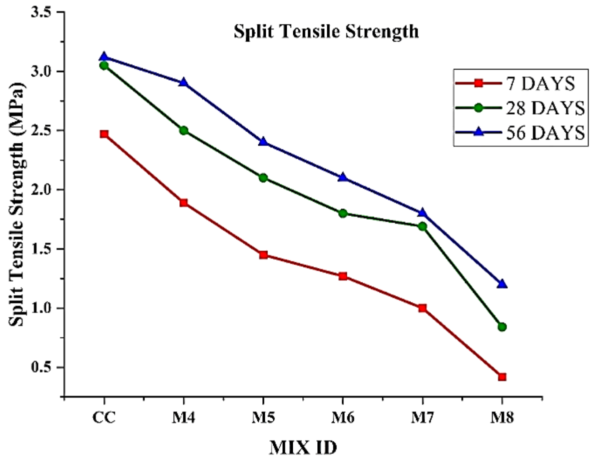

Figure 6. Split tensile strength for Conventional concrete & OPC.

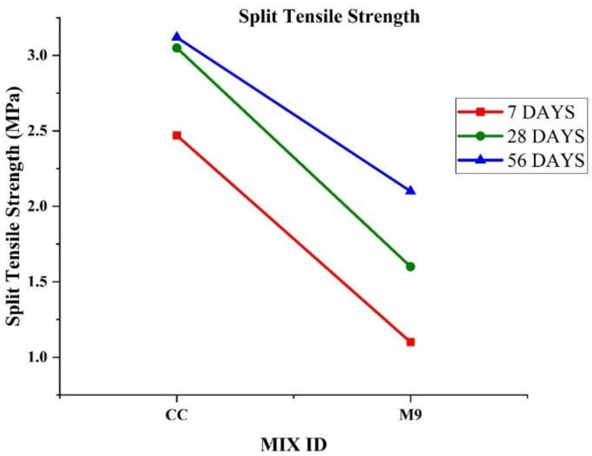

Figure 7. Split tensile strength for replacement materials.

Flexural Strength

Flexural strength, also known as modulus of rupture, gauges a material's ability to withstand bending stresses, particularly in beams. In the case of Ordinary Portland Cement, its flexural strength typically follows a similar pattern to its compressive and split tensile strengths, as evidenced by experimental results. It's noted that the flexural strength of OPC tends to decrease with higher percentages of OPC in the mix. Furthermore, the flexural strength of concrete is influenced by factors such as aggregate content and the uniformity of moisture distribution within the concrete. The flexural strength of all the mixes is presented in Figures 8,9, and 10. From the figures it is observed that the strengths are increasing with curing periods, and then decreasing with increasing the OPC and POFA content.

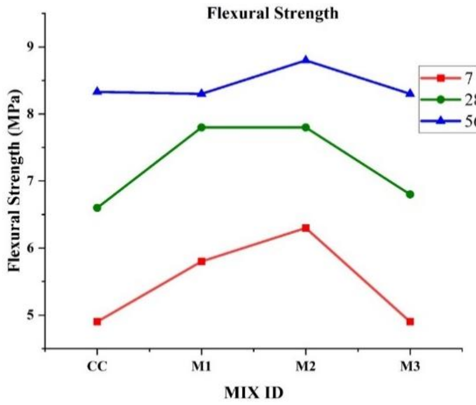

Figure 8. Flexural strength for Conventional concrete and POFA.

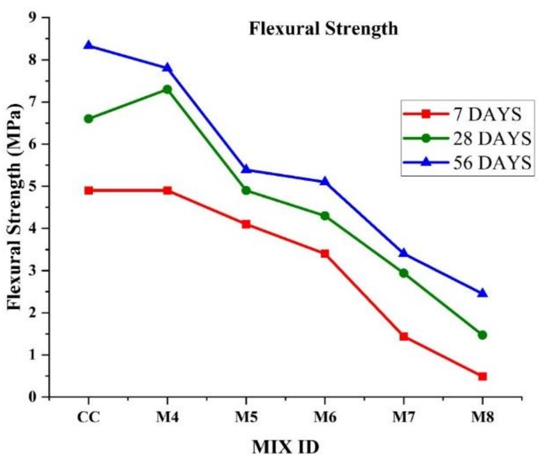

Figure 9. Flexural strength for Conventional concrete and OPC.

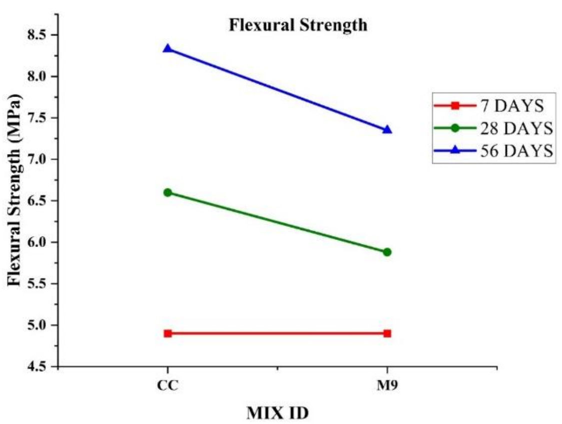

Figure 10. Flexural strength for replacement materials.

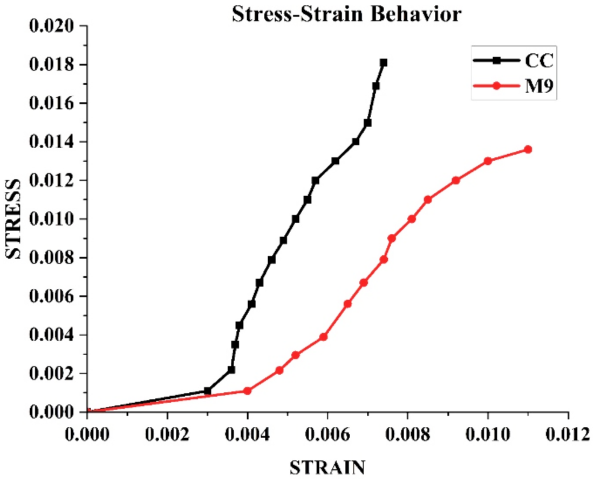

Figure 11. Stress-Strain Behavior.

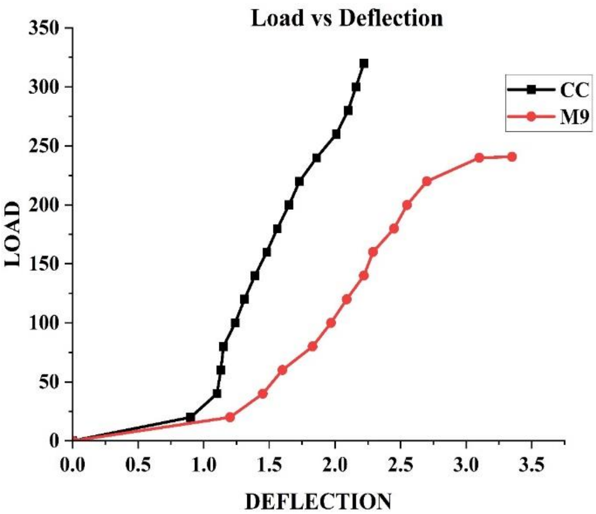

Figure 12. Load vs deflection.

Stress-Strain Behavior

The mechanical model depicting stress-strain behavior elucidates how materials respond to external stresses, offering valuable insights particularly for brittle substances such as concrete. These metric gauges a material's ability to withstand deformation when subjected to stress. factors like moisture distribution within specimens and the presence of large particles profoundly influence this behavior. An experiment was conducted on optimized specimens, featuring 20% POFA replacement and 10% OPC replacement over a 28-day period. The test results, showcasing stress-strain behavior and load vs. deflection, are presented in Figures 11 and 12. From Figure 11 it is observed the maximum stress for CC-Mix and M9 mix are X, Y respectively and the corresponding strains are X and Y. And from Figure 12 it is observed that the maximum ultimate load with corresponding deflections is X, Y for CC and M9 mixes.

DURABILITY PROPERTIES

For this research on POFA and OPC materials the durability properties of the concrete are crucial. The following durability properties are evaluated.

Water Absorption

Water absorption plays a pivotal role in determining the porosity of concrete, thereby influencing both its durability and resistance to weathering. This parameter is employed to assess the water absorption capacity of concrete under specific conditions. Concrete cubes measuring 150 mm × 150 mm × 150 mm were subjected to testing at 28 days of age to ascertain their saturated water absorption rate. Initially, the weight of the specimen, noted as W1, is recorded before full immersion in water at room temperature for a specified duration, commonly 24 hours or more. Subsequently, after the immersion period, specimens are removed from the water and allowed to dry on the surface to eliminate any excess water. The weight of the dried specimens is then recorded as W2. The Figure 13 illustrates that cube specimens absorb 2.9% of water. The inclusion of POFA typically extends the hydration process and enhances water absorption. The test results for water absorption in both Conventional concrete and the M9 mix are presented in Figure 13. From Figure 13 it is observed that the water absorption for the M9 mix is less than the conventional concrete. The water absorption of concrete is governed by the pozzolanic property of the added alternative cementitious materials. The additional CSH gel produced because of pozzolanic reaction helps in filling the pores, reducing permeability, and thereby reducing water absorption.

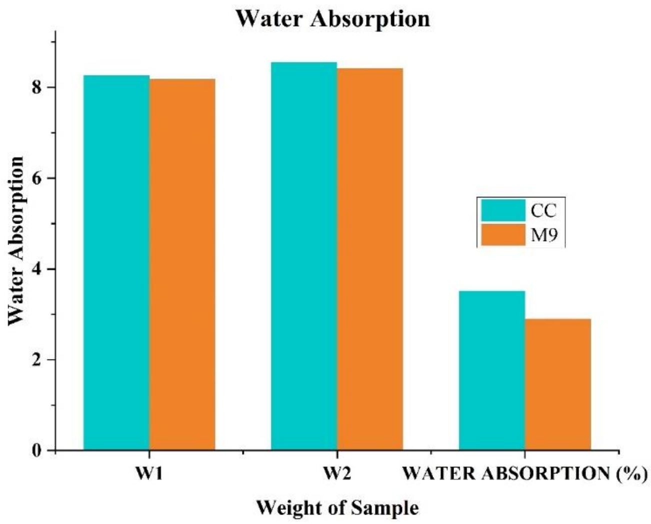

Figure 13. Water absorption of Samples.

Water permeability

One of the most significant tests for assessing concrete's ability to withstand water under specific conditions is the water permeability test. This test aids in evaluating the strength and longevity of concrete structures, as excessive water penetration can cause deterioration and structural damage over time. Species with cubes of 150 mm are typically utilized for this test. These specimens undergo exposure to continuous water pressure for a predetermined duration, often 72 hours. Throughout this exposure period, the water passing through the specimen is measured and recorded at regular intervals.

Darcy’s law is employed to calculate the permeability coefficient, which quantifies the concrete’s resistance to water penetration. The water permeability test furnishes valuable insights into concrete quality and its suitability for various applications. The test setup for water permeability is depicted in Figure 14, and the test results for both Conventional concrete and the M9 mix are detailed in Table 5. The result showed that the higher fineness of POFA resulted in lower water permeability values. The low water permeability of CC mix was affected by the pozzolanic reaction and packing effect of small particles, which produced concrete with a denser matrix and low permeation.

Table 5. Water Permeability.

MIX ID	Water Permeability (m/s) 28 days
CC	1.98×10^{-12}

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M9	1.52×10^{-12}

Figure 14. Water Permeability Apparatus.

Acid Attack (H_2SO_4)

Sulfuric acid, H_2SO_4, is a strong oxidizing agent. When this acid reacts with concrete, calcium sulfuric will be produced. When concrete undergoes curing in an acidic environment, both its compressive strength and density decrease. Acid corrosion is particularly prominent in exposed aggregates, exacerbating degradation. Submerging concrete cubes in an acidic solution notably reduces their compressive strength compared to curing them under normal conditions. The deleterious effects of acid attacks on concrete intensify with a higher proportion of cement relative to the total volume. This is because the acid targets hydrated lime, leading to the formation of soluble salts. The disclosure particles occur due to the breakdown of bonds between cementitious aggregates. As these particles lose mass, the concrete becomes less functional, and experiences accelerated mass loss. Tests were conducted using 100 mm size cubes after 28 days of curing. Before immersing them in water mixed with 4% sulfuric acid by weight, specimens were weighed. Tests were conducted at 28 and 56-day intervals. The test results for compressive strength under sulfuric acid attack are illustrated in Figure 15.

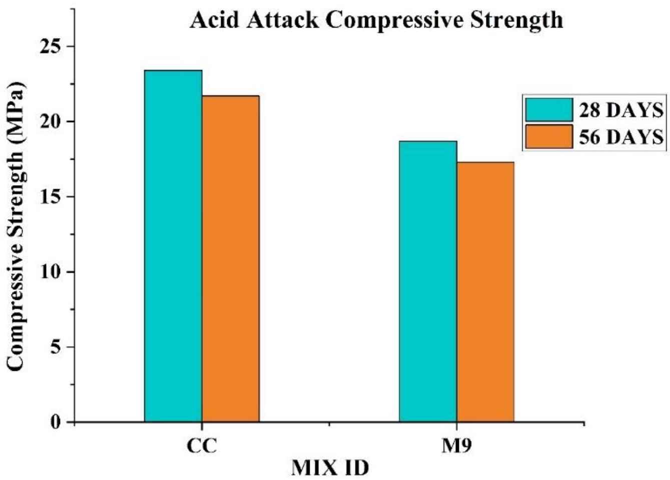


Figure 15. Compressive Strength of Sulfuric Acid Attack.

When concrete meets acid, the acid reacts with calcium hydroxide, a byproduct of hydration, to produce calcium salt ($Ca(OH)_2$), which is largely soluble in water. This calcium salt leaches out from the concrete, weakening the structure of the concrete paste. This weakening process is termed deterioration. Conversely, insoluble salt, a minor product of the acid reaction, remains within the concrete layers, forming a thin protective layer that can impede the deterioration process.

$$HX\ (acid) + Ca(OH_2) = Ca\ X + H_2O$$

Sulfate Attack ($MgSO_4$)

External sulfate attack occurs when surrounding water dissolves sulfates and infiltrates concrete. POFA, possessing numerous advantages in concrete construction, enhances concrete properties to resist sulfate attacks. POFA exhibits better resistance to sulfate attacks (RSA) than OPC due to its alternative low-toxicity coating material. Generally, the expansion of concrete due to sulfate attack decreases with increasing POFA content. Fineness affects the sulfate resistance of concrete; coarser POFA results in greater concrete expansion from sulfate attack. Sulfates penetrate concrete and chemically react with Calcium-silicate-hydrate (C-S-H) gel, crucial for concrete cohesion, initiating paste disintegration and concrete damage. Ettringite, a new crystal, forms as sulfates dry and undergo chemical changes, exerting pressure on surrounding paste and causing cracks, further compromising structural integrity. Concrete undergoes significant physical and chemical transformations due to sulfate attack, gradually losing strength. All concrete specimens exhibited damage after exposure to magnesium sulfate ($MgSO_4$) solution. Tests used 100 mm cubes after 28 days of curing, immersed in 5% sodium sulfate solution for 28 and 56 days. Compressive strength test results for sulfate attack are shown in Figure 16.

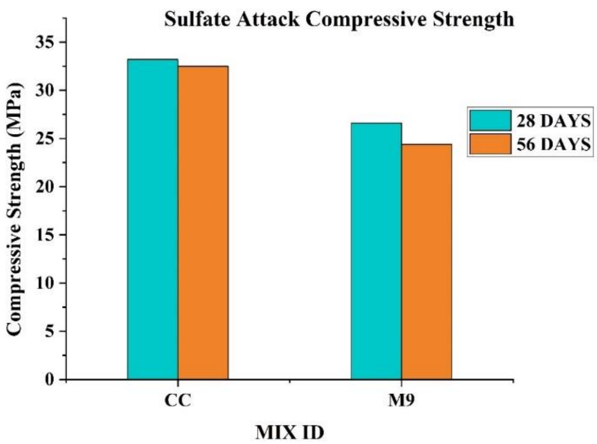


Figure 16. Compressive Strength of Sulfate Attack.

Chloride Attack (NaCl)

Concrete deterioration resulting from chloride penetration has led to safety and performance concerns in various large structures such as dams and bridges in coastal regions. Surprisingly, in many instances of concrete structure failures, the actual cause was the failure of concrete to shield steel against corrosive elements like chlorides, rather than design flaws. Tests were conducted using 100 mm cubes after 28 days of curing, immersed in a 3.5% NaCl solution for 28 and 56 days. Compressive strength test results for chloride attack are depicted in Figure 17.

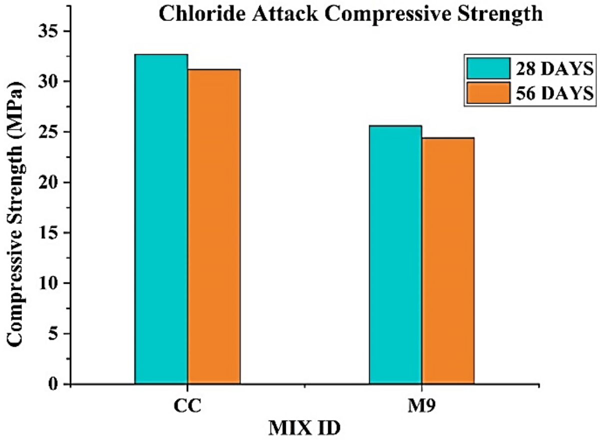


Figure 17. Compressive Strength of Chloride Attack.

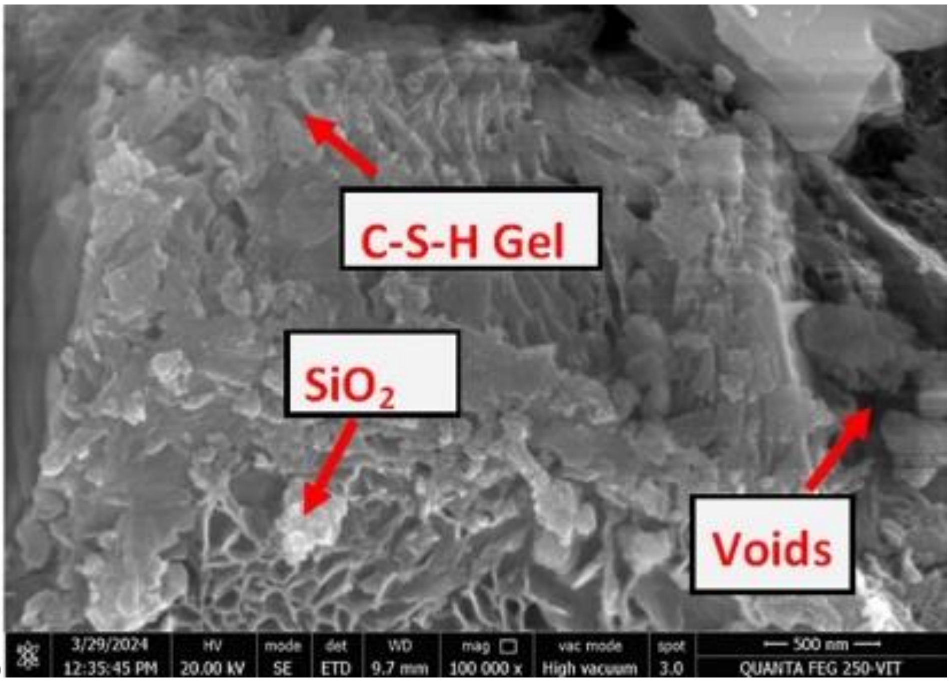
Microstructure Analysis

Microstructure analysis of POFA and OPC involves examining the internal structure of the concrete at a microscopic level. This helps to understand the interaction between the POFA and OPC materials. For this research the following techniques are employed.

Scanning Electron Microscopy (SEM)

An extremely efficient imaging method, scanning electron microscopy (SEM) allows for the high-resolution, in-depth study of surface topography and morphology of various substances. In contrast to optical microscopy, scanning electron microscopy (SEM) studies at the surface of a sample using a concentrated electron beam rather than visible light. Images are generated by visible signals created by unique electron-sample collisions, such as secondary electrons, backscattered electrons, and typical X-rays.

One major benefit of scanning electron microscopy (SEM) is the high resolution and magnification it provides, enabling the analysis of surface characteristics below to the nanoscale with tremendous details. Metals, ceramics, Polymers, composites, as well as biological specimens may have the microscopic compositions investigated with this feature's help. Using energy-dispersive X-ray spectroscopy (EDS) or wavelength-dispersive X-ray spectroscopy (WDS), scanning electron microscopy (SEM) is capable of elemental analysis in addition to imaging. By analyzing the distinct X-ray produced by a specimen when it is struck with an electron beam, these methods make it possible to discover and trace the components within the materials. Microstructure analysis of SEM for optimum mix is shown in the Figure 18.

(a)


(b)


Figure 18. SEM image. (a) SEM image at 20 kv, 100000 x (b) SEM image at 20 kv, 50000 x.

X-Ray Diffraction (XRD)

One useful analytical tool for studying material's microscopic structure is XRD. A materials crystalline lattice can be investigated by examining the X-ray scattering pattern. Several fields make extensive use of this technique, including biology, geology, materials science, and chemistry. Crystal structure, phase composition, and crystalline material location can all be properly evaluated with this tool. XRD is a quite effective procedure for identifying a very small number of crystalline phases in a sample. To do this, they can compare the sample's diffraction pattern to reference patterns; this will allow them to identify the crystalline phases present and quantify them to a certain degree.

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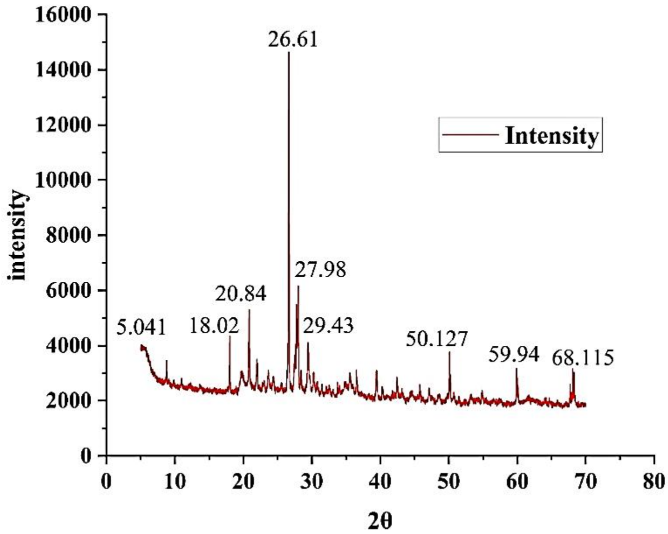

Figure 19. XRD Analysis.

Other than identifying phases, XRD may inform you the way a polycrystalline substance's crystallites are oriented, how big they are on average, some lattice characteristics, and whether there are any crystal defects like vacancies or dislocations. To better understand materials and their physical and chemical properties and improve their efficiency in different applications, this data is crucial. Microstructure analysis of XRD for optimum mix is shown in the Figure 19.

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform infrared Spectroscopy (FTIR) is a method used to examine the chemical composition of substances by analyzing how they absorb infrared light. The types and concentrations of chemical bonds present in the material are connected to this absorption. Whenever it comes to analyzing the molecular structures of both organic and inorganic molecules, FTIR is a highly effective method for identifying functional groups. It is utilized for both qualitative and quantitative examination in a variety of industries, including forensic science, polymers, medicines, and environmental monitoring. FTIR is a frequently used methos in domains such as analytical chemical and materials studies because of its highly valued characteristics of sensitivity, rapid, and non-destructiveness. Microstructure analysis of FTIR for optimum mix is shown in the Figure 20.

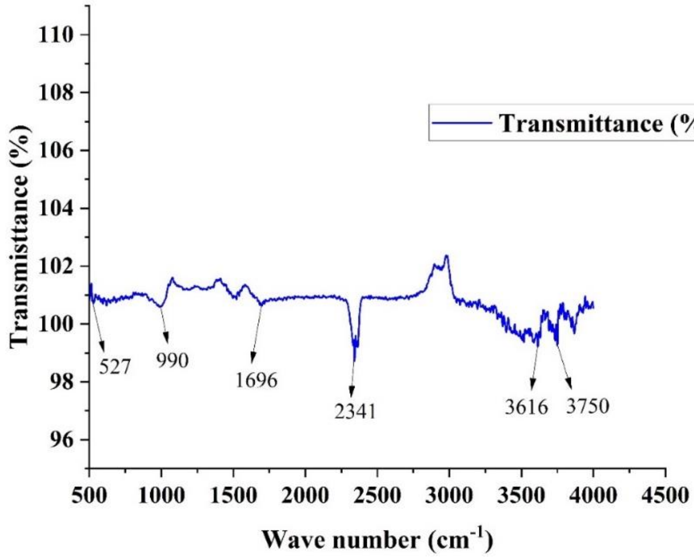

Figure 20. FTIR Analysis.

FLEXURAL BEHAVIOR OF R.C. BEAMS

In this experiment, a simply supported reinforced concrete (RCC) beam is tested using both conventional concrete and concrete made with POFA and OPC in place of cement and fine aggregate. To evaluate the beam, 1.5 m × 0.15 m × 0.15 m cross sections are used. After 28-days curing period, the beams were tested using a loading frame with a capacity of 200 tons. Testing of beams and details of the reinforcement are shown in Figure 21. Each end of the support is attached tightly, and the beam is grid-marked so that the distance between the cracks can be measured properly. Figures 22&23 shows the beam testing for Conventional concrete and M9 mix. Test results for CC and M9 mix are shown Figure 24.

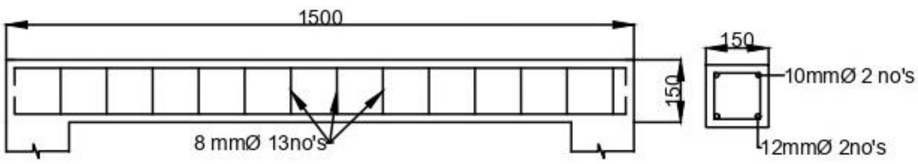

Figure 21. Detailing of Beams.

Figure 22. Beam testing for Conventional concrete.

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Figure 23. Beam testing for Replacement of POFA and OPC.

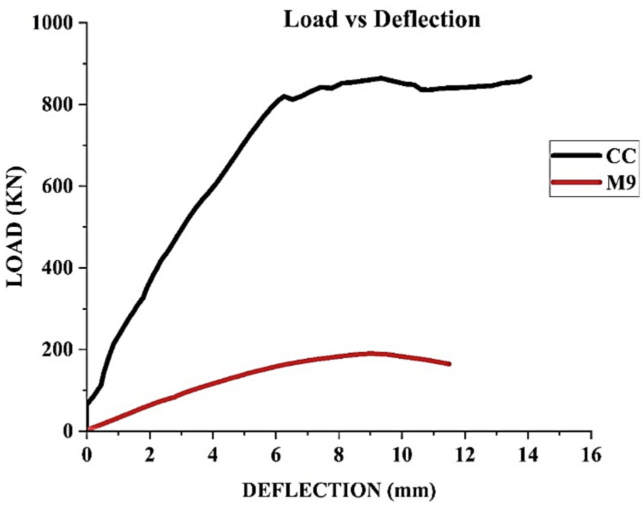

Figure 24. Load vs deflection for Beams.

Conventional concrete and M9 mix beams i.e., optimum replacement mix beams are cast with same cross section (1.5 m × 0.15 m × 0.15 m) as shown in above Fig.22&23. The curves for load vs deflection exhibit identical behavior. The concrete in the tensioned area resisted the stretching pressure when the main force was applied to the beams, keeping its maximum flexural strength until it reaches the beam's bottom. In addition to gaze tests, the rise in deflection rate was employed to identify the starting point of beam bending. Upon looking at the curve it is clear that load vs deflection relationship is initially linear and elastic. Eventually, the beams get failed because of the non-linearity after the elastic phase.

CONCLUSION

The impacts of OPC and POFA on mechanical and durability qualities, microstructural analysis, and structural applications are studied in this study by assessing the results. The following are the test findings from this current study. Using POFA as a partial replacement for cement is feasible up to a maximum of 20% due to the presence of residual carbon in the material.

- Increasing the proportion of POFA in the concrete mix reduces its workability and flexibility.
- POFA-based concrete has lower compressive and split tensile strength than conventional concrete but exhibits higher flexural strength.
- Optimized OPC concrete has better workability than conventional concrete, but as the shell content increases, workability decreases.
- Concrete with 10% OPC, the optimized percentage, has lower compressive strength than conventional concrete but still meets the required target strength.
- Partial replacement of cement and fine aggregate with 20% POFA and 10% OPC results in concrete with inferior mechanical properties compared to conventional concrete.

This study analyzed the replacement of sustainable materials in concrete mixes. It will help to reduce waste generation in the world. The researchers aim to develop sustainable concrete to reduce pollution and create a healthy environment. Research on waste materials was conducted to determine whether it can be useful to humans in accordance with sustainability ideals.

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