

An Experimental Investigation on Partial Replacement of Oil Palm Shell as Coarse Aggregate and M Sand as Fine Aggregate with Elevated Temperature

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Abstract: Concrete plays a pivotal role in construction, and the quest to enhance its performance and sustainability is ongoing. Aggregates, comprising 70-80% of concrete, are traditionally made of crushed rocks as coarse aggregates and river sand as fine aggregates. However, increasing demand for these natural resources due to growing construction activities has escalated costs and raised environmental concerns. This study investigates the potential of using Oil Palm Shell (OPS) as a partial replacement for coarse aggregates and Manufactured Sand (M Sand) as a substitute for fine aggregates in M30 grade concrete. Furthermore, the study examines how these replacements affect the concrete's properties when exposed to elevated temperatures. Various tests were conducted to evaluate slump, split tensile strength, compressive strength, and flexural strength of concrete specimens after 7, 14, and 28 days of curing. Concrete samples were prepared with varying proportions of OPS (5%, 10%, and 15%) and M Sand (10%, 20%, and 30%), along with combinations of both. The results indicated that the inclusion of OPS and M Sand improved the concrete's strength properties, with certain mixtures outperforming conventional concrete. The analysis of these outcomes underscores the factors contributing to the enhanced strength, demonstrating the potential of OPS and M Sand in boosting the durability and sustainability of concrete structures. Adopting these materials not only reduces construction costs but also promotes environmentally sustainable practices within the construction industry.

Keywords: Acid Curing, Flexural Strength, M Sand, Oil Palm Shells, Substitution for Aggregates.

1 INTRODUCTION

Concrete is one of the most widely used construction materials across infrastructure, residential, and commercial projects. It typically consists of cement, fine and coarse aggregates, and water. Traditionally, crushed gravel serves as the coarse aggregate, while river sand functions as the fine aggregate. Although these natural materials are generally abundant and cost-effective, their excessive use has raised concerns about resource depletion and environmental sustainability. The increasing demand for concrete has led to the realization that these natural resources may not remain readily available in the future.

To address these issues, the construction industry is actively exploring sustainable alternatives to conventional concrete materials. Researchers are focusing on incorporating industrial by-products and natural waste materials to minimize environmental impacts. One promising approach involves replacing coarse aggregates with oil palm shells (a natural waste product) and substituting river sand with manufactured sand (M-Sand). These alternatives not only help conserve natural resources but also present eco-friendly solutions for concrete production, maintaining strength and performance.

The extraction of palm oil and palm kernels from palm fruit generates several by-products, including empty fruit bunches, palm oil fibres, palm oil mill effluent, and OPS. Improper management of these waste materials can result in significant environmental challenges. OPS, a solid by-product, is produced during the processing of palm fruit for oil extraction. The fruit comprises an outer exocarp, a mesocarp layer containing palm oil, and a hard shell called the endocarp, or OPS, which encases the palm kernel.

A practical solution for managing this waste is to convert OPS into lightweight aggregates suitable for concrete and other construction materials. This approach not only mitigates the environmental impact of palm oil production but also promotes sustainable construction by utilizing eco-friendly materials. To prepare OPS for construction purposes, the shells are collected from palm oil mills. The fruit has three main parts: the mesocarp, which is processed for oil extraction; the kernel, used in various products; and the endocarp (OPS), which can be used as coarse aggregate.

Before utilizing OPS as a construction material, the shells must be thoroughly cleaned with water to eliminate impurities. Since OPS has a high water absorption capacity, it is treated with sodium silicate to reduce this tendency. This treatment enhances the performance of OPS as a construction aggregate, making it more durable and suitable for a range of building applications.

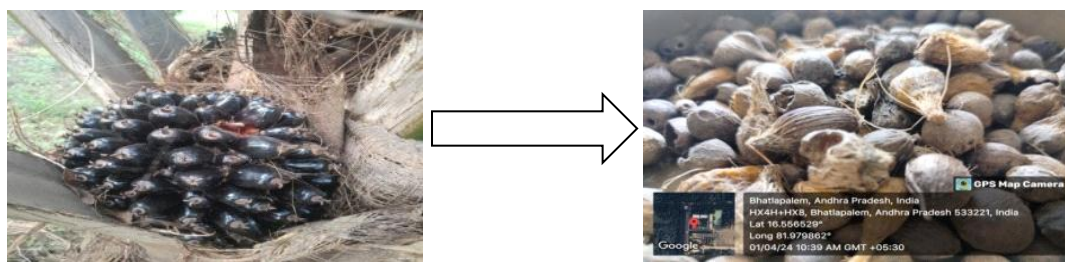


Fig. 1 Conversion of Oil Palm Fruit to Oil Palm Shell

Manufactured sand, commonly referred to as M-Sand, is produced by crushing rocks and stones into sand-sized particles. It serves as a viable replacement for natural river sand in concrete production and plastering activities. The manufacturing process involves crushing, screening, and washing to achieve the desired particle size and texture. M-Sand offers a sustainable and cost-effective alternative to natural sand, particularly in areas where river sand is scarce. Materials such as granite dust, copper slag, and iron dust are often used in M-Sand production, making it a versatile solution for various construction applications.

2 LITERATURE SURVEY

The literature on utilizing alternative materials in concrete production highlights the importance of incorporating sustainable materials, particularly agricultural by-products, to improve environmental performance. Yew et al. [1] explored the impact of different species of OPS as coarse aggregates in high-strength lightweight concrete, demonstrating significant improvements in both compressive strength and workability, especially when using 10–15-year-old crushed dura OPS. Similarly, Foong et al. [2] investigated the use of rice husk ash (RHA) and manufactured sand (M-sand) in lightweight OPS concrete, finding that a combination of 15% RHA and 100% M-sand enhanced mechanical properties, including compressive and flexural strength. In a related study, Itam et al. [3] examined palm kernel shell (PKS) as a coarse aggregate replacement in lightweight concrete, concluding that while PKS increases water absorption and reduces workability, it remains a viable option for lightweight construction applications due to its acceptable performance.

Research into the use of PKS in concrete extends to its application in structural and road construction. Azunna [4] demonstrated that PKS could partially replace coarse aggregates in concrete, yielding compressive strengths sufficient for non-structural applications. Samuel [5] further expanded this concept by investigating PKS in highway pavements, determining that up to 20% PKS could replace conventional aggregates in asphalt concrete without compromising performance. Ezeanokwasa [6] found that incorporating PKS into concrete mixtures enhanced flexural and compressive strength at low replacement levels but warned against exceeding 4% PKS content due to the material's limited strength. Muomaife [7] echoed these findings, recommending PKS as a partial replacement for coarse aggregates in lightweight concrete, though noting reduced performance when used as a fine aggregate.

The use of advanced modifications, such as nanocoating, has also been explored to improve the mechanical properties of OPS concrete. Nadh et al. [8] demonstrated that nanocoated OPS aggregates performed similarly to conventional aggregates, with nano silane coatings enhancing the bond between cement paste and aggregates, resulting in improved compressive strength. Kareem et al. [9] reviewed the broader environmental benefits of using OPS, highlighting its potential to reduce greenhouse gas emissions and promote sustainability in concrete production. Additionally, innovative approaches to concrete mix design were explored by Rao et al. [10], who investigated the effects of adding quartz and eggshell powders to concrete, finding enhanced strength characteristics.

Further studies have focused on enhancing the durability and performance of concrete using alternative materials. Anitha et al. [11] examined the inclusion of Alccofine 1203 in M35 grade concrete, showing improvements in both strength and durability. Rajesh et al. [12] explored ceramic insulator waste as a partial replacement for coarse aggregate in concrete, reporting favourable results in terms of mechanical properties, which supported the potential for waste materials to be repurposed in construction applications. Together, these studies underscore the growing interest in sustainable and innovative materials for concrete, with promising results for both structural performance and environmental impact.

3 MATERIALS AND METHODOLOGY

This study investigates the feasibility and performance of using OPS and manufactured sand (M-Sand) as partial replacements for coarse and fine aggregates in concrete subjected to elevated temperatures. Laboratory experiments were conducted to assess various concrete mix designs and analyze their mechanical properties. The materials used in this research include:

- **Oil Palm Shells (OPS):** Collected, cleaned, and treated to serve as a substitute for coarse aggregates.
- **Manufactured Sand (M-Sand):** Sourced from crushed rock to replace natural river sand.
- **Ordinary Portland Cement (OPC):** Used as the primary binding agent in concrete.
- **Water:** Used for mixing and curing processes.
- **Admixtures:** Added, if necessary, to modify or enhance the concrete mix properties.

The methodology involves preparing different concrete mix designs, performing mechanical tests, and analyzing the results to determine the most effective proportions of OPS and M-Sand for structural applications.

3.1 Cement

Cement is the key binding material in concrete, providing strength and cohesiveness. This study uses 53-grade Ordinary Portland Cement (OPC), sourced from UltraTech Cement, to ensure high-quality binding in the concrete mix. Table 1 presents the properties of cement.

Table 1. Properties of Cement

S.No.	Property	Test Results
1	Specific gravity	3.14
2	Normal Consistency	29%
3	Initial setting time	36 min
4	Final setting time	320 min
5	Fineness (%)	5%

3.2 Fine Aggregate

Fine aggregates fill the gaps between coarse aggregates, enhancing the density and strength of concrete. In this study, river sand from Godavari Sand Suppliers, Ravulapalem, East Godavari District, was selected as the fine aggregate. The properties of fine aggregate are given in Table 2.

Table 2. Properties of Fine Aggregate

S. No.	Property	Test Results
1	Type	River Sand
2	Zone	Zone-II
3	Specific Gravity	2.56
4	Grading Size	4.75mm-0.075mm
5	Fineness Modulus	2.70
6	Water absorption	0.6%
7	Bulk Density	In loose state 1378.82 kg/m ³ In compacted state 1544.67Kg/m ³

3.3 Coarse Aggregate

Coarse aggregates contribute to the bulk and stability of concrete. Crushed granite with a maximum size of 20 mm was used as the coarse aggregate in this study. The properties of coarse aggregate are given in Table 3.

Table 3. Properties of Coarse Aggregate

S. No.	Particulars	Results
1	Type	Crushed stone
2	Specific gravity	2.66
3	Maximum size	20mm
4	Water absorption	0.55%
5	Fineness modulus	3.9
6	Bulk density	1628 kg/m ³

3.4 Oil Palm Shell

OPS, a by-product of palm oil extraction, can be repurposed as a lightweight construction aggregate. To improve its performance in concrete, the OPS used in this study was soaked in a sodium silicate solution (100 g/liter) for two hours to reduce water absorption and enhance bonding with the cement paste. The properties of oil palm shells are given in Table 4.

3.5 M SAND

Manufactured sand (M-Sand) is produced by crushing rocks into sand-sized particles. It is used as a substitute for natural river sand in concrete and plastering applications. The properties of M sand are given in Table 5.

Table 4. Properties of Oil Palm Shell

S. No.	Properties	Results
1	Shell Thickness	3.2mm
2	Maximum Shell Size	12mm
3	Fitness Modulus	3.07
4	Bulk Density (Loose) (Compacted)	380Kg/m ³ 435 Kg/m ³
5	Specific Gravity	1.23
6	Absorption Rate	22.9%

Table 5. Properties of M sand

S. No.	Property	Test Results
1	Specific gravity	2.60
2	Water absorption	0.27%
3	Fineness modulus	3%

4 RESULTS AND DISCUSSIONS

This research study investigates the use of OPS and Manufactured Sand (M-Sand) as partial replacements for cement in M30-grade concrete. The study follows the procedures outlined in IS 10262-2009, including mix design, batching, mixing, specimen casting, and testing. The following tests were performed to assess the properties of the concrete: slump test, compressive strength test, split tensile strength test, flexural strength test, thermal durability, acid curing, and water absorption.

4.1 Slump Test

The slump test is a standard method for measuring the consistency and workability of fresh concrete. The test apparatus consists of a metallic cone with the following internal dimensions: bottom diameter (20 cm), top diameter (10 cm), and height (30 cm). A 16 mm steel tamping rod is used for compacting the concrete. After filling the mold, the cone is lifted, and the resulting slump is measured. This provides insight into the workability of the mix.

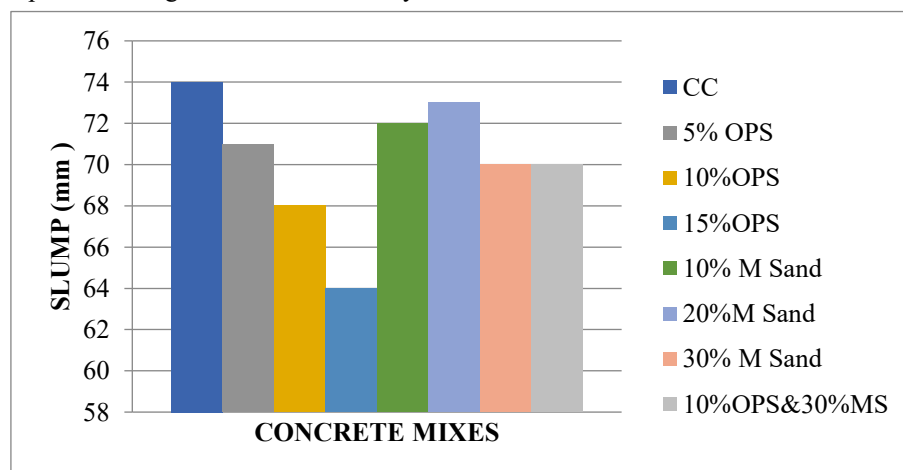


Fig. 2 Slump Test Results

4.2 Compressive Strength Test

Compressive strength tests were performed on the concrete samples after 7 and 28 days of curing. The results showed a reduction in compressive strength when OPS and M-Sand were incorporated as partial replacements for cement, with strength decreasing as the percentage of these materials increased.

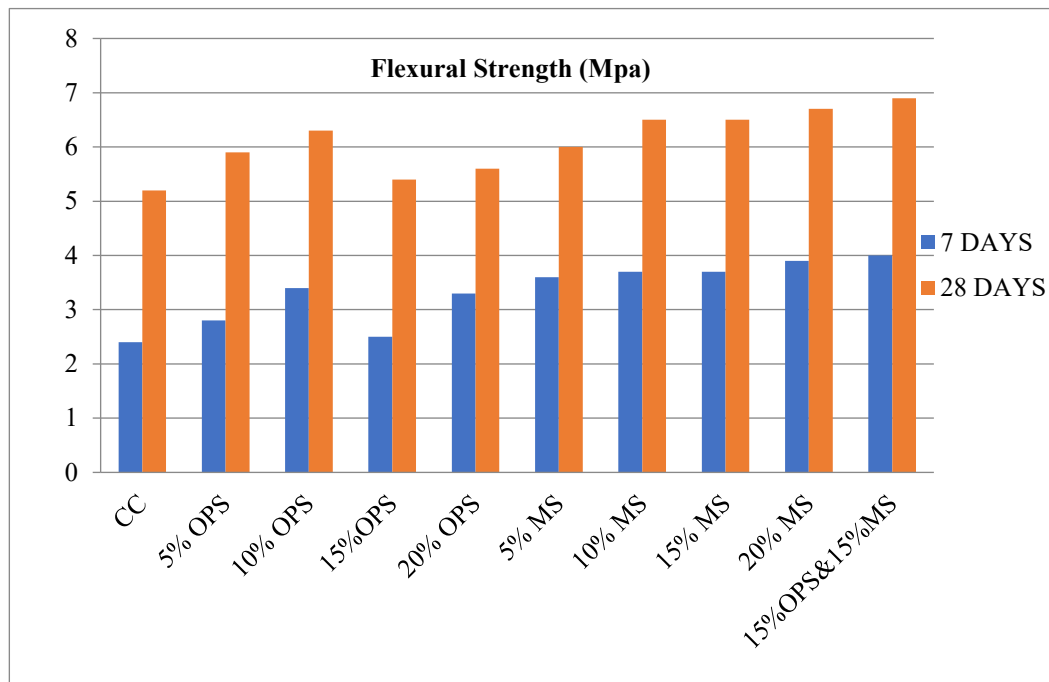


Fig. 3 Compressive Strength for Partial Replacement of OPS & M sand

4.3 Split Tensile Strength

Concrete has limited tensile strength due to its brittleness, making it susceptible to cracking under tensile loads. The split tensile strength test was conducted to assess the tensile behaviour of the concrete samples. This test provides insights into the material's durability and structural integrity.

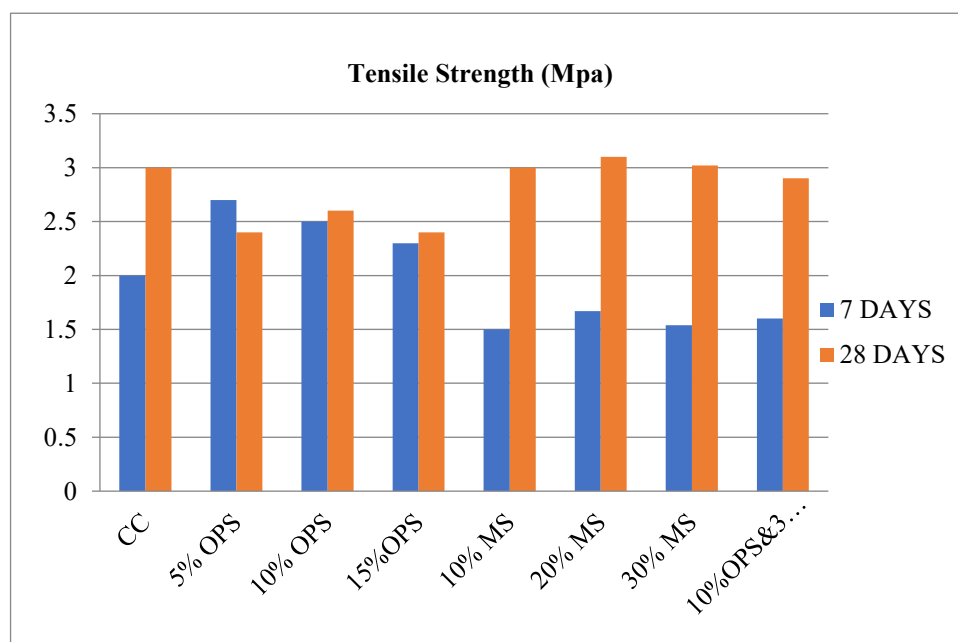


Fig. 4 Split Tensile Test Results

4.4 Flexural Strength Test

Flexural strength, or the modulus of rupture, measures a material's resistance to bending stresses before failure. It is crucial for assessing concrete's behaviour under flexural loads, especially in applications such as beams and slabs.

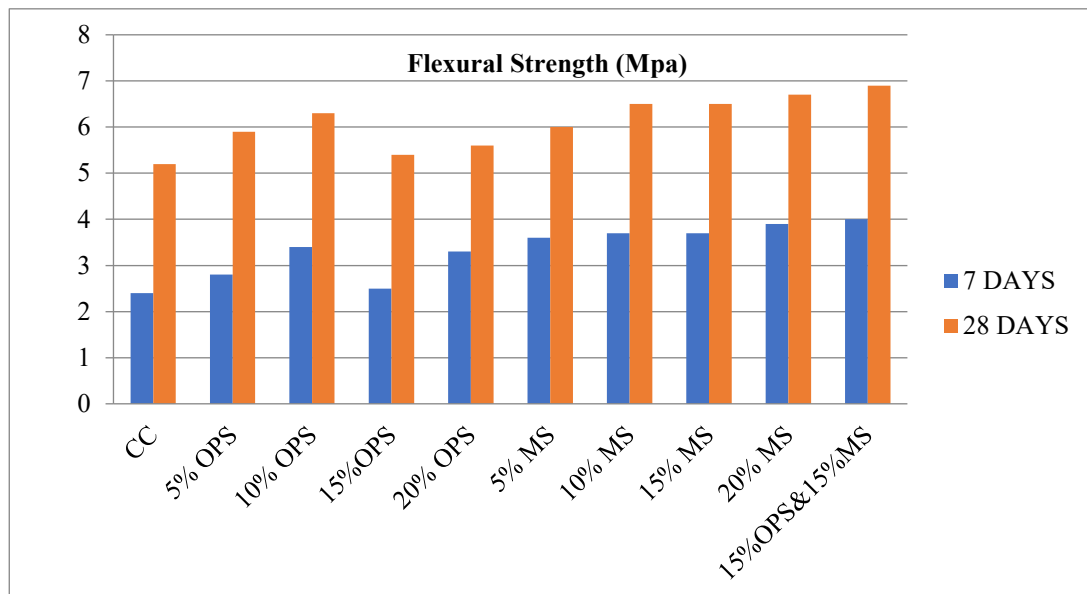


Fig. 5 Flexural Strength Results

4.5 Thermal Durability Test

To examine the impact of elevated temperatures, concrete cubes were subjected to a thermal durability test after 28 days of curing. The cubes were dried and heated in an oven, with temperatures gradually increasing from 150°C to 350°C. The compressive strength was measured after cooling.

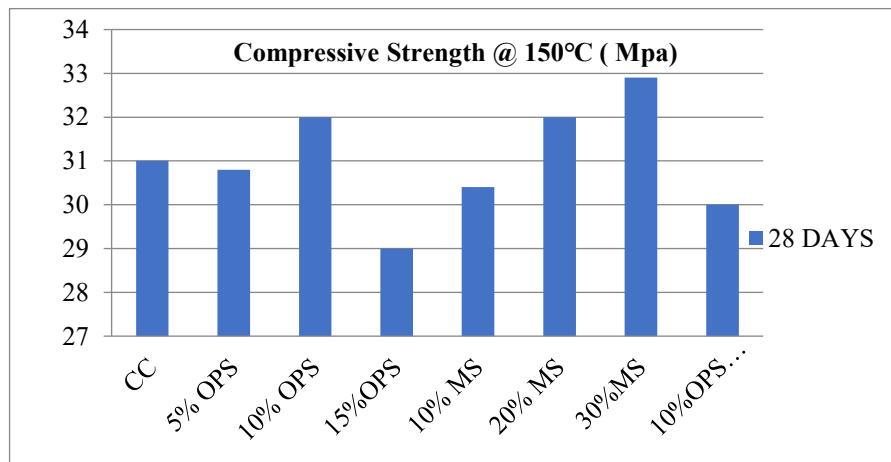


Fig. 6 Compressive Strength Results At 150°C

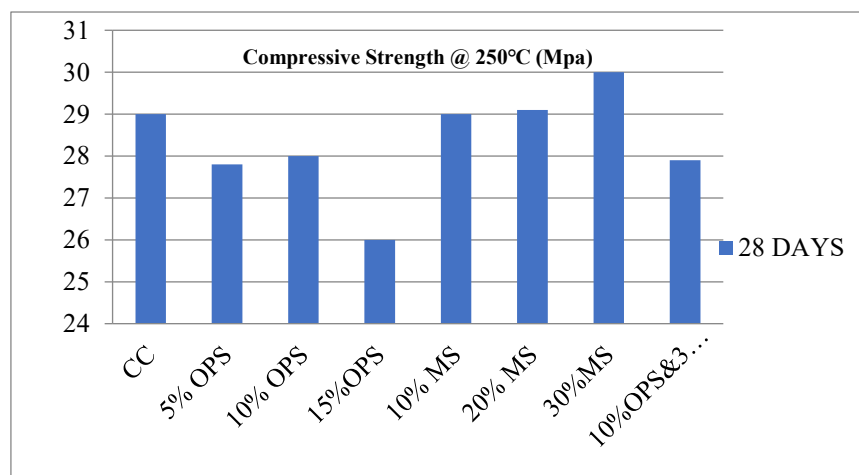


Fig. 7: Compressive Strength Results At 250°C

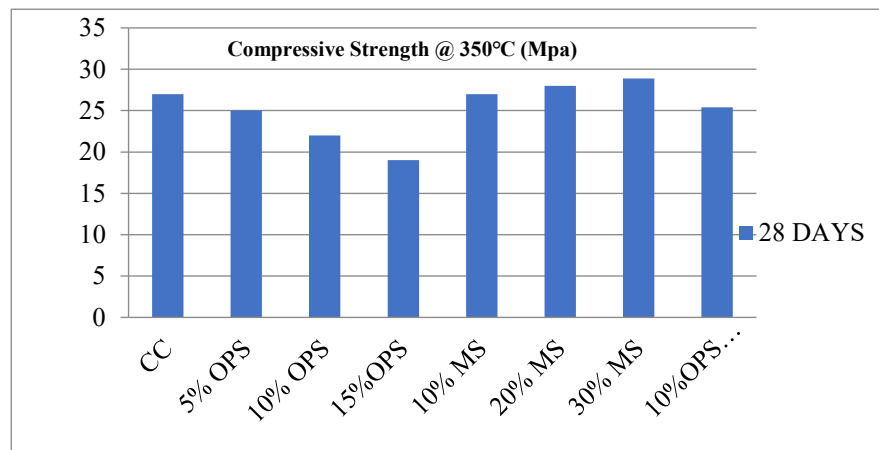


Fig 8: Compressive Strength Results at 350°C

4.6 Acid Curing

The acid curing test assesses concrete durability by immersing concrete cubes in a sulfuric acid solution (5 mg/L of water). After curing, the cubes are dried at 27°C, and the mass loss is measured. This test evaluates the concrete's resistance to acid attacks, which is crucial for structures exposed to acidic environments.

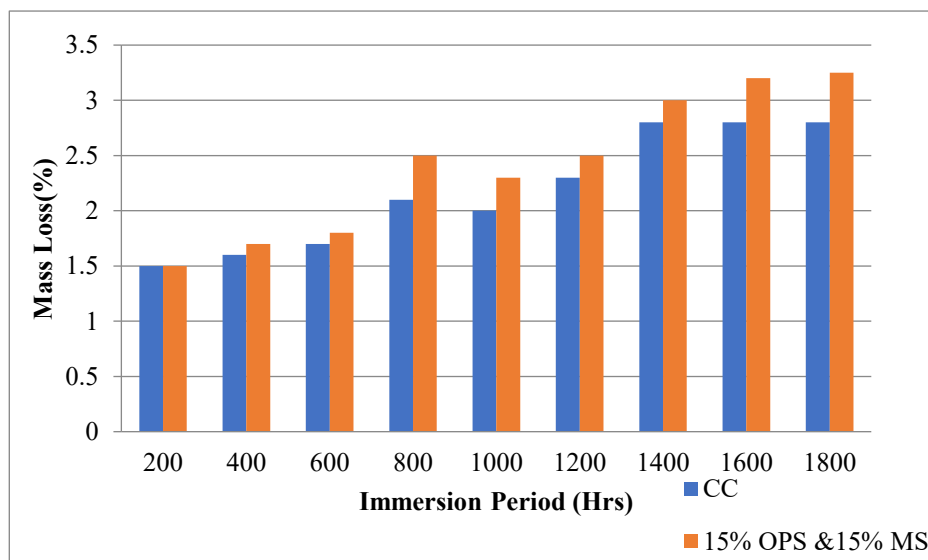


Fig. 9 Acid Curing Results

4.7 Water Absorption

Water absorption tests measure the concrete's ability to absorb water, which is essential for determining its durability and performance under different environmental conditions. This test helps predict the long-term water resistance of the concrete, ensuring its suitability for specific applications.

4.8 Environmental Approach

The use of OPS and M-Sand as partial replacements in concrete offers several environmental benefits, promoting sustainability in construction. OPS, a by-product of palm oil production, reduces waste disposal issues and lowers the carbon footprint associated with traditional aggregates. M-Sand serves as an eco-friendly alternative to natural river sand, helping conserve natural sand resources and mitigate habitat destruction in river ecosystems. By incorporating these materials, the construction industry can enhance resource efficiency, reduce reliance on non-renewable materials, and support a circular economy. Moreover, improved durability and strength in concrete mixtures containing OPS and M-Sand can lead to longer-lasting structures, reducing maintenance needs and lowering the overall environmental impact.

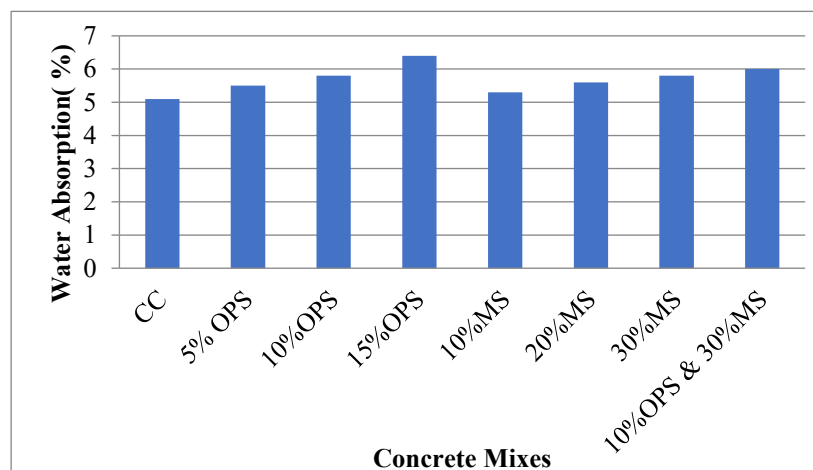


Fig. 10 Water Absorption

5 CONCLUSIONS

This experimental study offers valuable insights into the performance of concrete incorporating OPS and Manufactured Sand (M-Sand) as partial replacements for traditional aggregates. Key properties such as slump, split tensile strength, compressive strength, and flexural strength were evaluated over curing periods of 7 and 28 days, and at elevated temperatures of 150°C, 250°C, and 350°C. The results demonstrate a positive correlation between the inclusion of OPS and M-Sand and the enhancement of compressive strength, confirming their potential as effective components in concrete formulations. Notably, a 10% substitution of OPS provided strength results comparable to a 30% substitution of M-Sand. Durability tests were conducted on concrete samples, specifically examining the effects of a 10% replacement of coarse aggregates with OPS and a 30% replacement of fine aggregates with M-Sand. The Acid Curing Test revealed that prolonged exposure led to increased mass loss, indicating greater susceptibility to acidic environments.

The Thermal Durability Test showed that while strength generally decreased at higher temperatures, the concrete demonstrated improved durability. However, substantial strength loss was noted at temperatures exceeding 250°C. The Water Absorption Test indicated a rise in water absorption as the percentage of OPS increased, with a similar trend observed for M-Sand. From an environmental perspective, the use of OPS and M-Sand brings significant benefits. OPS, a by-product of the palm oil industry, addresses waste management issues by reducing landfill waste and promoting the recycling of agricultural by-products. This approach not only minimizes pollution but also lowers the carbon footprint associated with the extraction and processing of traditional aggregates. Similarly, M-Sand serves as a sustainable alternative to natural river sand, helping to preserve river ecosystems and mitigate the environmental damage caused by excessive sand mining. Additionally, the enhanced durability and strength of concrete incorporating these materials contribute to longer-lasting structures.

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ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

STATEMENT OF CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study.

LICENSING

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