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Performance Analysis Of Concrete With Partial Replacement Of Cement Using She-Oak (*Casuarina Equisetifolia*) Leaf Ash

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ABSTRACT

The rapid growth of the construction industry has increased the demand for cement, resulting in higher carbon dioxide emissions and environmental concerns. To promote sustainable construction practices, this study investigates the use of She-Oak (Casuarina equisetifolia) leaf ash as a partial replacement for cement in M20 grade concrete. The She-Oak leaves were collected, cleaned, burnt under controlled conditions, and sieved through a 90-micron sieve to obtain fine ash suitable for concrete production, with an ash yield of nearly 20% from dry leaves. Concrete mixes were prepared with 0%, 5%, and 10% replacement of cement using She-Oak ash, and experimental investigations were carried out to evaluate workability, compressive strength, split tensile strength, water absorption, acid resistance, sulphate resistance, and crack behaviors. The slump test results showed a reduction in workability from 78 mm for conventional concrete to 71 mm and 64 mm for 5% and 10% replacement respectively, while still maintaining medium workability suitable for RCC applications. The compressive strength increased from 20.3 MPa for conventional concrete to 22.7 MPa and 23.9 MPa for 5% and 10% replacement, indicating improvements of about 11.8% and 17.7%. Similarly, split tensile strength improved from 2.34 MPa to 2.52 MPa and 2.66 MPa for 5% and 10% replacement respectively. Durability tests also showed favorable results, with lower water absorption, reduced acid attack loss, and improved sulphate resistance for the She-Oak ash mixes compared to conventional concrete. Crack pattern analysis revealed narrower and more uniformly distributed cracks in the 5% replacement mix, indicating improved bonding and stress distribution within the concrete matrix. Overall, the study concludes that the incorporation of 5–10% She-Oak leaf ash enhances both the mechanical and durability properties of concrete while reducing cement consumption and promoting effective utilization of biomass waste for eco-friendly construction applications.

Keywords : She-Oak leaf ash, Casuarina equisetifolia, sustainable concrete, supplementary cementitious material, compressive strength

GRAPHICAL ABSTRACT & METHODOLOGY

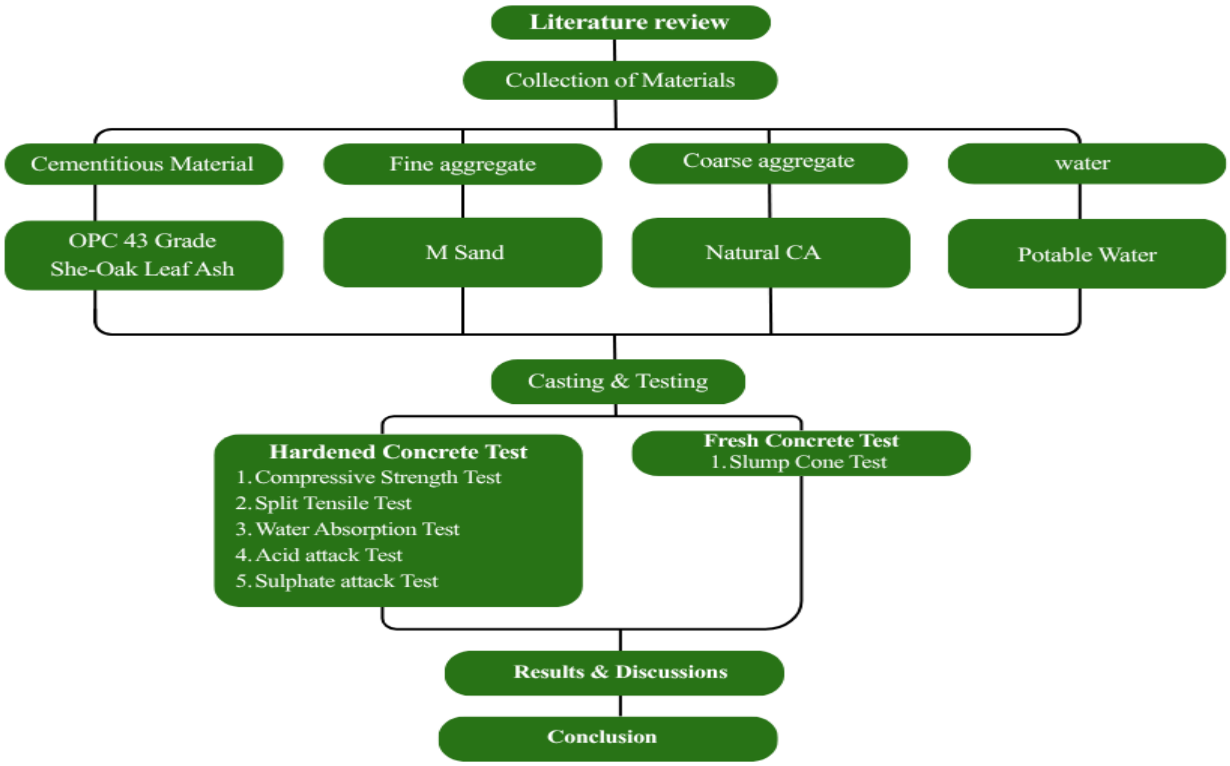


Fig.1. Methodology Flow Chart

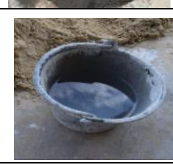
1 INTRODUCTION

The extensive growth of the construction industry has significantly increased the demand for cement-based materials worldwide. Concrete remains the most widely used construction material because of its strength, durability, and versatility. However, the production of cement is highly energy-intensive and is responsible for considerable carbon dioxide emissions, contributing to environmental degradation and climate change. In recent years, the search for sustainable and eco-friendly alternatives to conventional cement has become an important area of research in civil engineering. One of the effective approaches to reducing the environmental impact of concrete is the utilization of supplementary cementitious materials derived from industrial and agricultural waste. Biomass ashes obtained from organic waste materials have shown promising potential in improving concrete properties while simultaneously reducing cement consumption. Materials such as rice husk ash, fly ash, bamboo leaf ash, and groundnut shell ash have already been studied for their pozzolanic behaviours and their contribution to sustainable construction practices. She-Oak (Casuarina equisetifolia), commonly cultivated in coastal and dry regions of Tamil Nadu, generates a large quantity of leaf waste throughout the year. These leaves are often discarded or burnt in open areas, leading to environmental pollution and inefficient waste management. Since the ash obtained from biomass materials contains reactive silica and other mineral compounds, it can potentially act as a supplementary cementitious material in concrete production. However, only limited research has been carried out on the use of She-Oak leaf ash as a partial replacement for cement, particularly with respect to strength and durability characteristics. The present study investigates the performance of M20 grade concrete incorporating She-Oak leaf ash as a partial replacement for cement. The research mainly focuses on evaluating workability, compressive strength, split tensile strength, water absorption, acid resistance, and sulphate resistance at different replacement levels. The study also aims to identify the optimum percentage of replacement that provides satisfactory mechanical and durability performance without affecting the quality of concrete. By utilizing locally available biomass waste in concrete production, this research contributes toward sustainable construction practices, reduction of cement consumption, and effective waste management. The findings of this study may help promote the development of environmentally responsible construction materials for future infrastructure applications.

2 MATERIALS USED IN THIS INVESTIGATION

The materials used in this study were Ordinary Portland Cement (OPC) 43 grade, M-sand, 12.5 mm coarse aggregate, water, and She-Oak (Casuarina equisetifolia) leaf ash. The She-Oak leaves were collected, cleaned, burnt under controlled conditions, and sieved through a 90-micron sieve before being used as 5–10% partial replacement for cement in M20 concrete. Table 1 shows the materials which is used in this investigation.

TABLE 1 Materials used in this Investigation

S.No.	MATERIAL	DESCRIPTION	IMAGE
1	Ordinary Portland Cement (OPC 43 Grade)	Used as a primary binding material in concrete preparation	
2	M sand (Manufactured Sand)	Manufactured sand obtained by crushing hard stones used as fine aggregate in place of river sand.	
3	Coarse Aggregate	To provide bulk and strength of the concrete	
4	She-Oak (Casuarina Eqisetifolia) Leaf ash	Used as partial replacement of cement at 5% and 10%	
5	Water	Used for mixing and hydration in concrete	

3 STEP BY STEP PRODUCTION PROCESS OF SHE-OAK ASH

Dry She-oak (Casuarina equisetifolia) leaves were collected from local sources and carefully cleaned to remove dust, soil, and other impurities to ensure purity of the raw material. The cleaned leaves were then subjected to controlled burning under regulated conditions to produce ash with consistent properties. During this process, approximately 200 g of ash was obtained from 1 kg of dry leaves, indicating a yield of about 20%. The resulting ash was further processed by passing it through a 90-micron sieve to obtain a fine and uniform particle size suitable for use as a supplementary cementitious material. Finally, the processed She-oak ash was stored in dry, airtight containers to prevent moisture absorption and maintain its quality for concrete preparation.

Fig.2. Flow Chart for the Production Process of She-oak Ash

4 MIX DESIGN FOR M20 GRADE CONCRETE WITH SHE-OAK LEAF ASH

The mix design for M20 grade concrete was prepared using standard proportions with partial replacement of cement by She-Oak (*Casuarina equisetifolia*) leaf ash at 5% and 10% levels. The concrete mix consisted of OPC 43 grade cement, M-sand, coarse aggregate, water, and processed She-Oak leaf ash. The mix proportions were maintained to achieve the required strength, workability, and durability characteristics for experimental evaluation. Table.2 shows the mix design of the current investigation.

TABLE 2 Mix Design

S.NO	CEMENT (Kg/m^3)	SHE-OAK LEAF ASH (g/m^3)	SHE-OAK LEAF ASH in (%)	M SAND (Kg/m^3))	COARSE AGGREGATE (Kg/m^3))	WATER	Water – Cement Ratio
1	1.36	0	0	2.27	4.25	0.68	0.27
2	1.29	70	5	2.27	4.25	0.68	0.27
3	1.22	140	10	2.27	4.25	0.68	0.27

5 EXPERIMENTAL INVESTIGATIONS

5.1 SLUMP CONE TEST

The slump cone test was carried out to determine the workability of fresh concrete mixes containing She-Oak leaf ash. The slump cone was placed on a smooth non-absorbent surface and filled with fresh concrete in three equal layers, with each layer compacted using 25 tamping strokes. After filling, the cone was lifted vertically, and the reduction in height of the concrete was measured as the slump value in millimeters. The slump values decreased from 78 mm for conventional concrete to 71 mm at 5% replacement and 64 mm at 10% replacement due to the finer particle size and higher water absorption capacity of the She-Oak ash, which reduced the free water available in the concrete mix. The increased ash content also increased internal friction between particles, resulting in lower workability. However, all the concrete mixes exhibited medium workability and were found suitable for RCC applications. Table 3 shows the slump cone test results.

TABLE 3 Slump Cone Test Values

S.NO	% OF ASH	SLUMP LEVEL (mm)
1	0	78
2	5	71
3	10	64

5.2 COMPRESSIVE STRENGTH TEST

The compressive strength test was conducted to determine the load-carrying capacity of concrete containing She-Oak (Casuarina equisetifolia) leaf ash as partial replacement for cement. Concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast and cured for 28 days under normal water curing conditions. After 28 days of curing, the specimens were placed in a Compression Testing Machine (CTM) and subjected to gradual compressive loading until failure occurred. The maximum load carried by each specimen was recorded, and the compressive strength was calculated in Mpa. The compressive strength test results after 28 days of curing showed that the incorporation of She-Oak leaf ash improved the compressive strength of concrete compared to conventional concrete. The conventional concrete achieved a compressive strength of 20.3 MPa, whereas the mixes containing 5% and 10% She-Oak ash attained strengths of 22.7 MPa and 23.9 MPa respectively. The 10% replacement mix exhibited the highest compressive strength, indicating improved bonding and densification of the concrete matrix due to the pozzolanic reaction between the reactive silica present in the She-Oak ash and calcium hydroxide released during cement hydration. The fine ash particles also contributed to better particle packing and reduced micro voids, thereby enhancing the overall strength characteristics of the concrete. Table 4 shows the compressive strength test results. Fig.3. shows the compressive strength test results.

TABLE 4 Compressive Strength Results

S.NO	SHE-OAK LEAF ASH REPLACEMENT (%)	COMPRESSIVE STRENGTH AFTER 28 DAYS (Mpa)
1	0	20.3
2	5	22.7
3	10	23.9

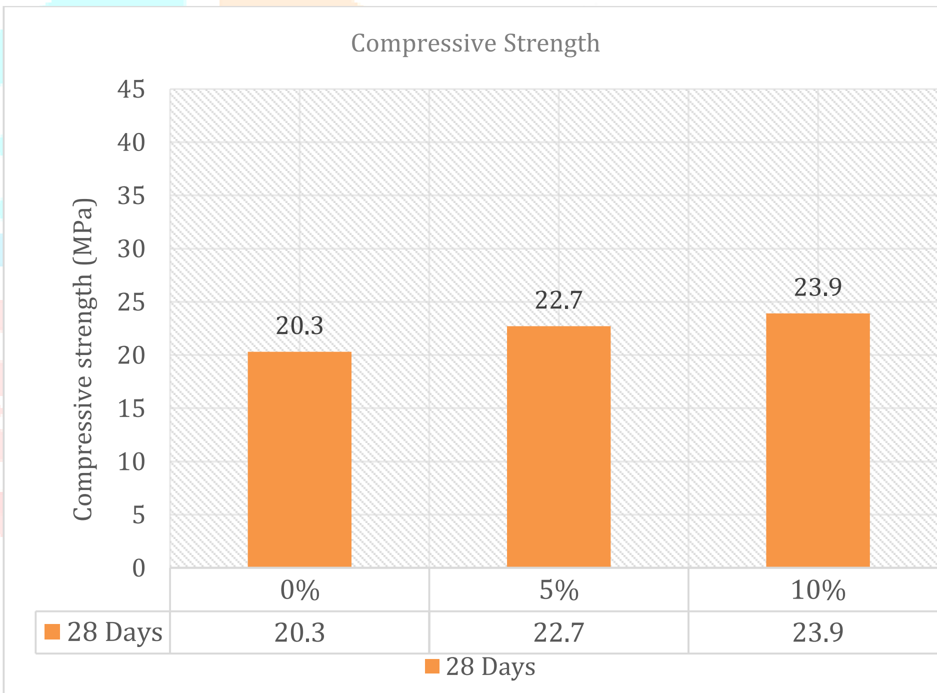


Fig 3. Compressive Strength Results for M20 Concrete with She-oak Leaf Ash

5.3 SPLIT TENSILE TEST

The split tensile strength test was conducted to determine the tensile behavior of concrete containing She-Oak (Casuarina equisetifolia) leaf ash as partial replacement for cement. Cylindrical concrete specimens were cast and cured for 28 days under normal water curing conditions. After 28 days of curing, the specimens were placed horizontally in a Compression Testing Machine (CTM) and subjected to diametrical loading until failure occurred. The maximum load applied on the specimen was recorded, and the split tensile strength was calculated in MPa. The split tensile strength test results after 28 days of curing showed that the incorporation of She-Oak leaf ash improved the tensile strength characteristics of concrete compared to conventional concrete. The conventional concrete exhibited a split tensile strength of 2.34 MPa, whereas the mixes containing 5% and 10% She-Oak ash attained strengths of 2.52 MPa and 2.66 MPa respectively. The 10% replacement mix showed the highest tensile strength due to improved particle packing, better bonding between cement pastes and aggregates, and the pozzolanic action of the She-Oak ash. The fine ash particles helped in reducing internal micro voids and enhancing the density of the concrete matrix, thereby improving the tensile performance of concrete. Table.5. shows the split tensile strength test values. Fig.4. shows the split tensile strength test.

TABLE 5 Split tensile test Results

S. No	SHE-OAK LEAF ASH REPLACEMENT (%)	FAILURE LOAD (KN)	SPLIT TENSILE STRENGTH AFTER 28 DAYS (MPa)
1	0%	165	2.34
2	5%	178	2.52
3	10%	188	2.66

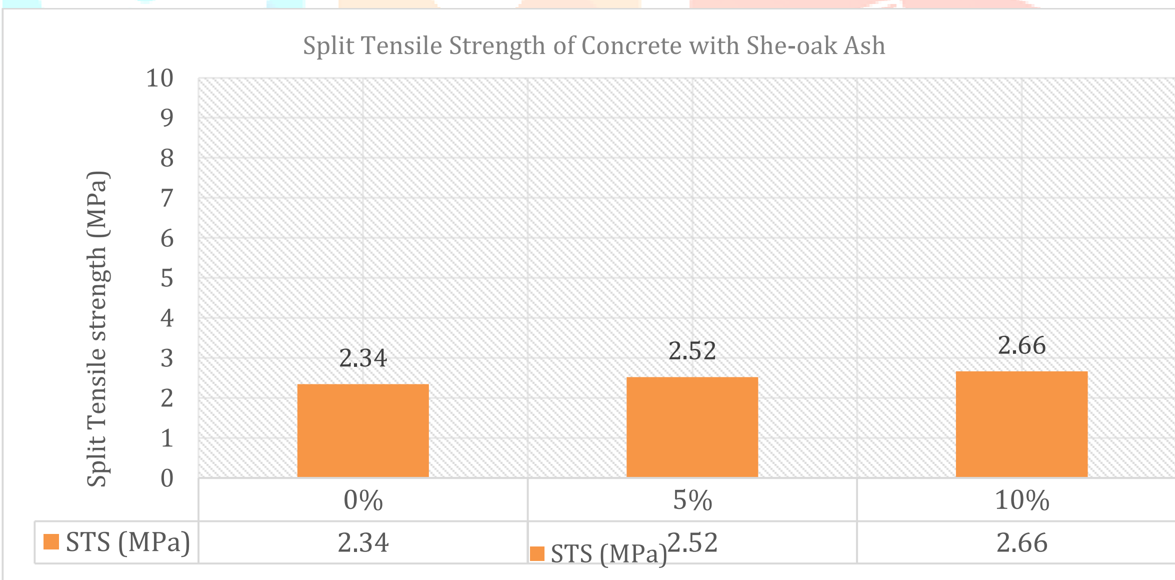


Fig 4 Split tensile test Results for M20 Concrete with She-oak Leaf Ash

5.4 WATER ABSORPTION TEST

The water absorption test was conducted to determine the porosity and durability characteristics of concrete containing She-Oak (Casuarina equisetifolia) leaf ash as partial replacement for cement. After 28 days of curing, the concrete specimens were oven dried at a standard temperature until a constant weight was achieved and the dry weight was recorded. The water absorption test results showed that the incorporation of She-Oak ash reduced the water absorption capacity of concrete compared to conventional concrete. The conventional concrete exhibited a water absorption value of 5.2%, whereas the mixes containing 5% and

10% She-Oak ash showed lower absorption values of 3.1% and 3.3% respectively. The 5% replacement mix demonstrated the least water absorption, indicating reduced porosity and improved durability. Although the 10% replacement mix showed a slight increase compared to the 5% mix, it still performed better than conventional concrete due to the denser concrete matrix formed by the filler effect and pozzolanic reaction of the fine She-Oak ash particles. Fig.5. shows the water absorption test setup. Fig.6. shows the water absorption test results.

Fig 5 Water Absorption Test Setup

TABLE 6 WATER ABSORPTION TEST VALUES

S. No	SHE-OAK LEAF ASH REPLACEMENT (%)	WATER ABSORPTION (%)
1	0	5.2
2	5	3.1
3	10	3.3

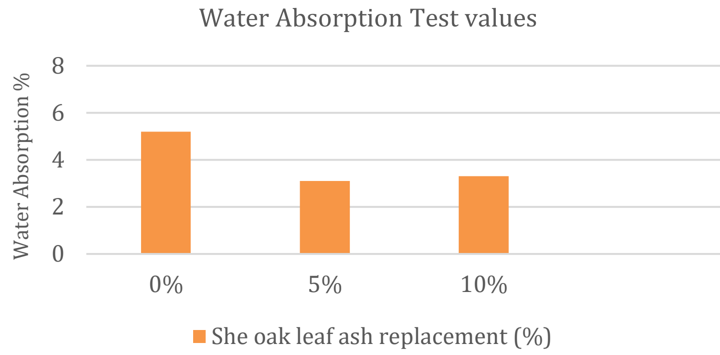


Fig.6. Water Absorption Test

5.5 ACID ATTACK TEST

The acid attack test was conducted to evaluate the durability and chemical resistance of concrete containing She-Oak (Casuarina equisetifolia) leaf ash as partial replacement for cement. After 28 days of curing, the concrete cube specimens were oven dried and their initial weights were recorded. The specimens were then immersed in a 1% hydrochloric acid (HCl) solution for 28 days. The acid attack test results indicate that concrete containing 10% She-Oak ash exhibited satisfactory resistance against acidic conditions. Although the percentage loss slightly increased from 4.4% at 5% replacement to 4.1% at 10% replacement, the concrete still maintained good durability and structural stability under acid exposure. This behavior may be attributed to the pozzolanic action of She-Oak ash, which contributes to the formation of a denser concrete matrix and reduces the penetration of aggressive chemicals. Fig.7. shows the Acid Attack test setup. Fig.8. shows the Acid attack test results.

Figure.7 Acid Test Setup

TABLE 7 Acid attack test values

S. No	SHE-OAK LEAF ASH REPLACEMENT (%)	ACID ATTACK (% LOSS)
1	0	5.2
2	5	4.4
3	10	4.7

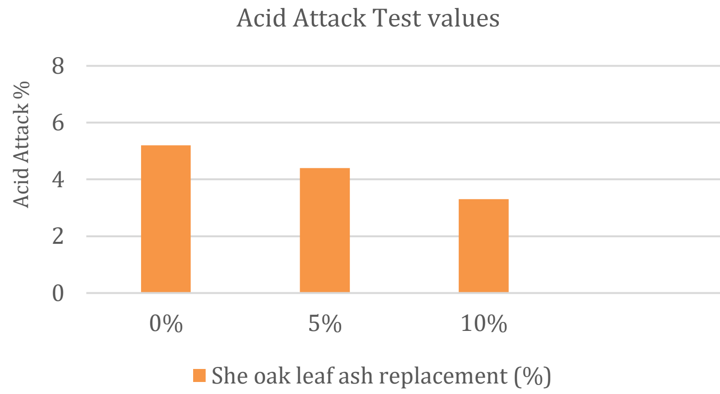


Fig.8. Acid Attack Test

5.6 SULPHATE ATTACK TEST

The sulphate attack test was carried out to evaluate the durability of concrete containing She-Oak (Casuarina equisetifolia) leaf ash under sulphate exposure. After 28 days of curing, the concrete specimens were dried and their initial weights were recorded. The sulphate attack test results revealed that the incorporation of She-Oak leaf ash improved the resistance of concrete against sulphate exposure compared to conventional concrete. The conventional concrete exhibited a percentage loss of 5.5%, whereas the mixes containing 5% and 10% She-Oak ash showed lower losses of 4.6% and 4.9% respectively. The 5% replacement mix demonstrated the best sulphate resistance with minimum deterioration, while the 10% replacement also maintained satisfactory durability under sulphate exposure. The improved performance may be attributed to the pozzolanic action and filler effect of the fine She-Oak ash particles, which contributed to the formation of a denser and less permeable concrete matrix, thereby reducing the penetration of sulphate ions. Table.8. shows the sulphate attack test results. Fig.9. shows the sulphate attack test setup. Fig.10. shows the sulphate attack test results.

Figure.9. Sulphate Attack Test Setup

TABLE 8 Sulphate test values

S. No	SHE-OAK LEAF ASH REPLACEMENT (%)	SULPHATE ATTACK (% LOSS)
1	0	5.5
2	5	4.6
3	10	4.9

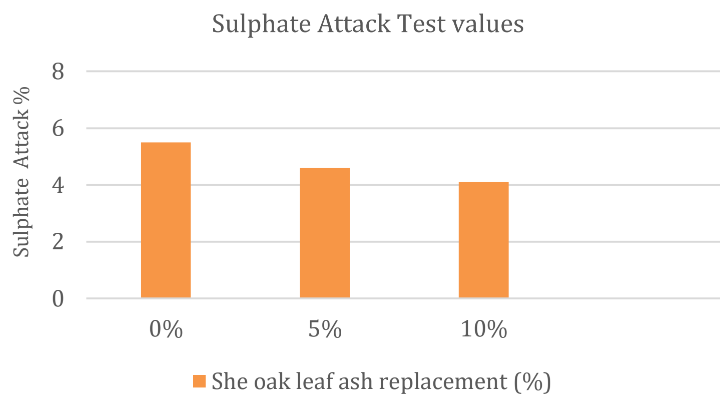


Fig.10. Sulphate Attack Test

5.7 CRACK PATTERN ANALYSIS

The crack pattern analysis was carried out to study the failure behaviours of concrete containing She-Oak (*Casuarina equisetifolia*) leaf ash under loading conditions. The control specimen exhibited wider and more distinct vertical cracks after failure. In contrast, the concrete containing 5% She-Oak ash showed reduced crack width and a more uniform crack distribution, indicating improved bonding and better stress distribution within the concrete matrix. The specimen with 10% ash replacement displayed slightly increased crack formation compared to the 5% mix, which may be due to the reduction in cementitious content at higher replacement levels. However, the cracks remained relatively controlled, demonstrating satisfactory structural performance and durability characteristics. Fig.11. shows the crack patterns analysis.

a) 0% of She-oak leaf ash **b)5% of She-oak leaf ash** **c)10% of She-oak leaf ash**

Fig.11. CRACK PATTERN ANALYIS OF CONCRETE SPECIMENS

RESULTS AND DISCUSSIONS

The experimental investigation carried out on M20 grade concrete containing She-Oak (Casuarina equisetifolia) leaf ash as partial replacement for cement demonstrated noticeable improvements in both mechanical and durability properties of concrete. The study mainly focused on replacement levels of 5% and 10%, and the obtained results were analysed through slump cone test, compressive strength test, split tensile strength test, water absorption test, acid attack test, and sulphate attack test. The results indicated that the incorporation of She-Oak ash improved the strength and durability characteristics of concrete while maintaining satisfactory workability suitable for practical construction applications.

The slump cone test results showed that the workability of concrete decreased with the increase in She-Oak ash content. The conventional concrete exhibited a slump value of 78 mm, while the mixes containing 5% and 10% She-Oak ash showed slump values of 71 mm and 64 mm respectively. The reduction in workability may be attributed to the finer particle size and higher water absorption capacity of the She-Oak ash, which reduced the free water available in the concrete mix. However, all the mixes maintained medium workability suitable for reinforced cement concrete applications.

The compressive strength test results after 28 days of curing indicated that the incorporation of She-Oak ash improved the compressive strength of concrete. The conventional concrete achieved a compressive strength of 20.3 MPa, whereas the 5% and 10% replacement mixes attained strengths of 22.7 MPa and 23.9 MPa respectively. The 10% replacement mix exhibited the highest compressive strength due to the pozzolanic reaction and filler effect of the She-Oak ash, which enhanced the density and bonding characteristics of the concrete matrix.

The split tensile strength test results demonstrated that the addition of She-Oak ash improved the tensile performance of concrete. The conventional concrete exhibited a split tensile strength of 2.34 MPa, while the 5% and 10% replacement mixes achieved strengths of 2.52 MPa and 2.66 MPa respectively. The increase in tensile strength may be attributed to improved particle packing, reduced micro voids, and better bonding between cement paste and aggregates caused by the incorporation of fine She-Oak ash particles.

The water absorption test results showed that the incorporation of She-Oak ash reduced the water absorption capacity of concrete compared to conventional concrete. The conventional concrete exhibited a water absorption value of 5.2%, whereas the 5% and 10% replacement mixes showed lower absorption values of 3.1% and 3.3% respectively. The reduced water absorption indicates lower porosity and improved durability characteristics due to the denser concrete structure formed by the filler effect and pozzolanic action of the She-Oak ash.

The acid attack test results indicated that concrete containing She-Oak ash exhibited satisfactory resistance against acidic exposure. The percentage loss observed for the 5% and 10% replacement mixes were 4.1% and 4.4% respectively, which were lower than the deterioration generally observed in conventional concrete under similar conditions. The improved acid resistance may be due to the formation of additional calcium silicate hydrate (C-S-H) gel, which reduced the permeability of the concrete and limited the penetration of aggressive acidic compounds.

The sulphate attack test results revealed that the incorporation of She-Oak ash improved the sulphate resistance of concrete. The conventional concrete exhibited a percentage loss of 5.5%, whereas the 5% and 10% replacement mixes showed lower losses of 4.6% and 4.9% respectively. The improved sulphate resistance may be attributed to the denser and less permeable concrete matrix formed by the pozzolanic reaction and filler effect of the fine She-Oak ash particles, which restricted the penetration of sulphate ions into the concrete structure.

CONCLUSION

The present study investigated the performance of M20 grade concrete with partial replacement of cement using She-Oak (Casuarina equisetifolia) leaf ash at 5% and 10% replacement levels. Based on the experimental results, it was observed that the incorporation of She-Oak ash improved the compressive strength, tensile strength, and durability characteristics of concrete within the optimum replacement range. The concrete mixes containing She-Oak ash exhibited better resistance against water absorption, acid attack, and sulphate attack due to the pozzolanic behaviour and filler effect of the ash particles. Although a slight reduction in workability was noticed with increasing ash content, the mixes remained suitable for practical construction applications. Crack pattern analysis also indicated improved bonding and more uniform stress distribution at lower replacement levels. Among the tested mixes, the 5% and 10% replacements showed the most satisfactory overall performance. Therefore, She-Oak leaf ash can be considered a sustainable supplementary cementitious material that not only enhances concrete performance but also promotes eco-friendly construction by reducing cement consumption and utilizing biomass waste effectively.

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