An Experimental study on Replacement of cement by Rice husk ash and Silica fume with addition of Polymer

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***Abstract*— The manufacturing of Ordinary Portland cement (OPC) is done with very high consumption of carbon dioxide emission. To enhance durability in construction, this study investigates the replacement of cement with rice husk ash and silica fume with addition of polymer. Rice husk ash is generated by burning of husks of paddy which is an agricultural waste, very rich in amorphous silica. Silica fume is a highly reactive pozzolanic material. These materials were replaced with cement in different replacement levels (0-30%) combined in equal parts mix. Polymer was added in a fixed percentage of 10% of weight of cementitious materials, to improve microstructure and reduce permeability. Experimental study includes tests on physical strength on specimens like compressive, split tensile, flexural strength tests. And durability test done was alternate wetting and drying. Results indicated that the combined use of RHA and SF improved strength and durability, while polymer improved bonding. The optimum replacement level was identified at 10% for compressive strength and 20% for split tensile strength, beyond which strength reduction was observed. While for flexural strength test the optimum replacement level was observed at 30% replacement in which strength was gradually increasing at different replacement levels. In alternate wetting and drying, water absorption and cumulative dry mass loss after drying was checked after wetting and during cycle for 24 hours and best resistance was observed in cylinders,it showed low dry mass loss and less waster absorption with no visible deterioration. This study concludes that RHA-SF-polymer blender concrete is a sustainable.**

***Index Terms*— Rice husk ash, Silica fume, Supplementary cementitious material, Concrete strength, Pozzolanic activity, Compressive strength, Durability.**

I. INTRODUCTION

Concrete remains the most prevalent building material globally, with production expected to surpass 550 crore tons by 2050, but this demand exacerbates environmental concerns, as cement production alone accounts for around 8% of global CO_2 emissions due to limestone calcination and depletion of natural resources. This concern has driven researchers to investigate sustainable replacements for cement, particularly focusing on pozzolanic materials derived from industrial and agricultural waste, such as silica fume (SF) and rice husk ash (RHA).The use of RHA stands out due to its pozzolanic activity, derived from its rich amorphous silica content, as noted by Ganesan et al. (2008), who observed that incorporating RHA at 10–20% replacement led to significant improvements in concrete's compressive and tensile strength, and enhanced durability against chloride and acid attack. Similarly, SF, according to Bhanja and Sengupta (2005), increases mechanical strength and reduces permeability, with 10% replacement yielding the optimum strength gain attributable to microstructural densification. Neville and Brooks (2010) further confirmed that SF at 5–10% replacement levels deliver maximum improvements in compressive strength and sulfate resistance by refining the paste structure. Polymer incorporation furthers these benefits; Ohama (1998) presented a comprehensive review demonstrating that polymer-modified mortars, especially those containing latex and acrylic-based admixtures, achieve better adhesion, lower shrinkage, and improved durability properties that are further amplified when combined with pozzolanic materials like SF and RHA. Together, SF and RHA contribute to microstructural densification, as revealed by SEM studies, by increasing C-S-H formation and reducing calcium hydroxide, thus leading to overall enhancements in mechanical and durability properties. Despite widespread investigations into SF, comparatively fewer studies have rigorously explored the durability characteristics of RHA, especially regarding resistance to aggressive environments. Hence, this research aims to systematically evaluate the strength, durability, and sustainability of concrete using varying proportions of RHA and SF, both individually and combined, with polymers

II. MATERIALS AND METHODOLOGY

2.1 Materials

2.1.1 Cement

The cement which is employed in research purpose is a type Ordinary Portland cement (OPC). The cement we used is locally available and generally used in all type of construction works. The details of the Composition and basic properties of this type of cement are mentioned in IS 12269:2004.

Table 2.1 Basic properties of OPC 53 grade cement

Properties	Test outcome	Limitations as per IS 12269-2004	Testing apparatus
Consistency in (%)	34	30-35	Vicat apparatus
Specific gravity	3.15	<or= 3.15	SG bottle
Initial setting time	38 min	>30 min	Vicat apparatus
Final setting time	220 min	<600	Vicat apparatus
Finness in (%)	5.00	<10	Sieve analysis

Table 2.2 Basic properties of OPC 53 grade cement

Constituents	Percentage
Silica (Sio_2)	19.35
Calcium oxide (Cao)	68.64
Magnesium Oxide (Mgo)	1.39
Iron Oxide (Na_2O)	1.21
Sodium Oxide (Na_2O)	0.47
Alumina (Al_2O_3)	4.57
Sulphur Trioxide (SO_3)	3.14

Fig. 2.1 OPC 53 grade cement

2.1.2 Fine Aggregate

Regionally sourced river sand is utilized as fine aggregate. It was clean, free from clay and organic matter, and confirming to IS standards. The sand was sieved to remove oversized particles before use.

Table 2.3 Physical Properties of fine aggregate

Description	Fine aggregate
Specific gravity	2.65
Water absorption	1.52%
Fineness modulus	3.0(Zone II)
Surface moisture	NIL
Bulk density	1450 kg/m^3

Fig.2.2 Fine aggregate

2.1.3 Coarse Aggregate

Crushed angular aggregates of size 20mm down size were used. The aggregates were free from dust and other impurities and satisfied the requirements of IS standers.

Table 2.4 Physical properties of coarse aggregate

Sl. No	Particulars	Value
1	Shape	Angular
2	Density (Kg/cum)	1832
3	Fineness modulus	7.2
4	Specific gravity	2.75

Fig.2.3 Coarse aggregate

2.1.4 Water
Clean portable water, free from acids, oils, and salts was used for both blending and maturation of concrete.

2.1.5 Superplasticizer
A market ready high range water admixture Polycarbocylate Ether Superplasticizer was used enhance the pumpability and finishability of fresh concrete and achieve the required slump without excess water.

Fig.2.4 Polycarbocylate Ether Superplasticizer

2.1.6 Rice Husk Ash
RHA is obtained from controlled burning of rice husk and was used as partial replacement material. It is significantly high in amorphous silica and contributes to strength and durability through pozzolanic reaction. RHA is procured from Herenba Instruments and engineers, Ambattur Chennai.

Fig. 2.5 Rice husk ash

2.17. Silica Fume
Silica fume, a byproduct of silicon industry, was served as pozzalanic additive. Its ultrafine particles help in pore refinement, improve strength, and increases durability. Silica fume is procured from Herenba Instruments and engineers, Ambattur Chennai.

Table 2.5 Characteristics and reactivity properties of Silica fume

Property	Description
Chemical composition	SiO_2 85-98% (amorphous) Other oxides: Fe_2O_3, Al_2O_3,CaO.
Physical form	Extremely fine grey powder, Spherical particles.
Particle size	0.1 to 1 micron, average 0.15 micron
Specific surface area	15,000-30,000 m^2/kg (Very high surface area)
Bulk density	200-300 kg/m^3 undensified, 500-700 kg/m^3 densified.
Pozzalonic reactivity	Very high reacts fastely with calcium hydroxide in cement paste from C-S-H GEL

Fig. 2.6 Silica fume grey powder

2.1.8 Styrene Butadiene Rubber Latex (Sbr)
Styrene butadiene rubber (SBR) polymer was used as an enhancer. It was added to improve bonding, workability, and durability of concrete.

2.2 Methodology

Table 2.6 Mix proportion in percentage levels for replacement

Mix	Proportion (Cement+ RHA+ SF + Polymer)
A	100%+0%+0%+0%
B	90%+5%+5%+10%
C	80%+10%+10%+10%
D	70%+15%+15%+10%

The experimental programme of the present study was explored in a systematical manner to achieve the research objectives. The methodology contains the matrix forming as pet IS code, procurement of materials, property tests of materials, casting of specimens and testing at 28 days.

The batching is done by taking weight of the materials. Firstly, the dry mixing of aggregates was done; the fine aggregates and course aggregates were firstly introduced into mixer and left to mix for 2 minute, to gain a uniform mix. Followed by this, the addition of binder materials was done for the conventional mix that is 0% replacement, where only cement was added and mixed thoroughly to ensure even distribution of components. The half of the water was added and mixed until a uniform paste was formed. The 2% super plasticizer, dissolved in the remaining half of the water, was added to the mix to enhance flow ability and achieve the desired consistency.

Subsequently, Concrete mixes were prepared by partially substituting cement with RHA and SF in equal proportions at the replacement levels of 10% that is by retaining 90% of cement by replacing 5% of rice husk ash with 5 % of silica fume with cement with, 20% that is by retaining 80% of cement and replacing 10% of rice husk ash with 10% of silica fume with cement, 30% that is by retaining 70% of cement and replacing 15% of rice husk ash with silica fume and 15% of silica fume. Next addition of water and polymer by adding half of the total water, together with 10% of polymer (by weight of cementitious material), was gradually added and mixed a consistent mix was achieved. Than 2% of super plasticizer is dissolved in remaining half of the water is which is introduced to the mix to enhance workability and fluidity. The mixing was continued until a homogeneous and workable concrete mix was obtained.

Casting of test specimens was done by placing the fresh concrete into the moulds for 150×150×150 mm Cubes, 300 mm height 150 mm diameter Cylinders. 500×100×100 mm Beams. Adequate compaction was ensured for each layer by tamping to remove entrapped air and ensure adequate compaction and the top surfaces were finished smoothly.

2.3 TESTS DONE ON CONCRETE

2.3.1 TESTS ON FRESH CONCRETE

2.3.1.1 SLUMP CONE TEST

Freshly mixed M30 grade concrete is filled into the slump cone in three equal layers and each layer is compacted by tamping it for 25 times with a standard tamping rod, after the third layer is compacted, excess concrete is taken out to make the top surface level with the cone. The cone is lifted vertically in a smooth and steady motion, without any sideways movement within 5 seconds. The vertical difference between the cones top and the highest point of the slumped concrete is measured in millimeters. The slump reading obtained and taken is 100mm.

2.3.2 Tests on Harden Concrete

2.3.2.1 Compressive Strength Test

1. 150×150×150 mm cubes are casted and compacted properly, surface leveled and moulds kept undisturbed for 24 hours. Cubes are held for curing in clean water for 7 to 28 days.
2. Cubes are taken out, dried the surface and kept in Compression testing machine (CTM). The cube is aligned properly so that load is applied uniformly on opposite faces. Load is applied gradually and continuously at specific rate until the cubes fail. The maximum load at failure is taken. Compressive strength = $\frac{\text{Load at failure}}{\text{Cross sectional area}}$.

Fig 2.7 Compressive strength test on concrete cubes

2.3.2.2 Split Tensile Strength Test

1. The specimen is placed horizontally in compressive testing machine so that the load will act along diameter.
2. Load is applied gradually and uniformly until cylinder fractures.
3. The higher load at which failure occurs is noted.
4. The split tensile strength is calculated using the formula
5. Split tensile strength = $\frac{2p}{\pi.L.D}$.

Where:
P= Load at failure (N)
L= Length of cylinder (mm)
D= Diameter of cylinder (mm).

Fig 2.8 Split tensile strength test on concrete cylinders

2.3.2.3 Flexural Strength Test

1. Concrete beams of 500×100×100 mm are casted and cured in water for 7 to 28 days as per the mix design.
2. The beams are taken out and cleaned and surface dried.
3. The beam is placed two supporting rollers in the flexural testing machine.
4. Load is applied gradually at uniformly until the beam breaks in the middle.
5. The flexural strength is calculated using the formula for two point loading, $F_b = \frac{P \times L}{b \times d^2}$.

Where:
P= Load at failure (N)
L= Span length between supports (mm)
b= Width of specimen (mm)
d= Depth of specimen.

Fig 2.9 Flexural strength test on concrete beams

2.3.3 Durability Test on Concrete Specimens

2.3.3.1 Alternate Wetting and Drying

1. The alternate wetting and drying test helps in indication of the materials resistance to surface cracking, shrinkage, and loss of mass, reduction of strength. The use of supplementary cementitious ingredients such as RHA and SF and polymers are forecast to upgrade the durability by reducing porosity and refining the pore structure.
2. The concrete specimen's cubes were casted as per mix design and demoulded after 24 hours. They were cured in water for 28 days to achieve the required maturity before durability testing, specimens are extracted from water and surface dried.

Alternate wetting and drying cycle:

1. Wetting phase: The specimens were plunged in clean water for nearly 8 hours.
2. Drying phase: The specimens were then removed and kept in open air for 20 hours during and after cycles; the specimens were monitored for surface cracks, loss of mass, change in appearance.

Fig. 2.10 Concrete specimens subjected to Alternate wetting and drying

III. MIX DESIGN

Stipulations for properties
Concrete grade = M-30
Size of aggregates in mm = 20 mm
Workability = 100 mm
Degree of work = Good
Exposure condition = Severe

Material properties data

Specific gravity of cement	3.15
Specific gravity of CA	2.75
Specific gravity of FA	2.65
Specific gravity of water	1
Specific gravity of superplasticizer	1.1

Design procedure

Step 1: Target strength of concrete
Ft= f_{ck} + 1.6×S
= 30 + 1.65×5 (SD for M30 grade concrete S)

= 30 + 8.25
= 38.25 Mpa
Step 2: water cement ratio
Free water cement ratio as per fig 1- 0.50
Maximum water cement ratio as per graphical representation – 0.5
Free water cement ratio – 0.6
Water cement ratio – 0.40
Step 3: Water content Selection
Water content per cubic meter of concrete in for 50 mm slump – 186 kg
For 100 mm slump increase by 6% - 186+ (0.6×186)
= 197.16 kg
Step 4: Cement content determination
Water cement ratio – 0.4
Water for estimated slump – 197.16 kg
Water content since superplasticizer is used reduced by 23% -
197.16-(0.23×197.16) = 151.81 kg
Cement content = (water content / water cement ratio)
= 151.81/0.40
= 379.52 kg/m^3.
Step 5: Determination of volume of entrapped air
Volume of entrapped air for 20 mm aggregates 0.10%
Step 6: Volume of CA and FA
For maximum size of aggregates of 20 mm for zone of FA
Volume of CA per volume of total aggregates is

Zone 3	Zone 2	Zone 1
0.64	0.62	0.6

The corrected proportion of volume of coarse aggregate for water cement ratio of 0.4 is 0.62+ 0.02= 0.64
Volume of FA content = 1-0.64
= 0.36

Mix calculations:
Total volume in m^3= 1
Volume of entrapped air in wet concrete in m^3 = 0.01 m^3
Volume of cement in m^3 = (379.53/3.15) × (1/1000)
= 0.12 m^3
Volume of water in m^3 = (151.812/1×1/1000)
= 0.15 m^3
Volume of chemical admixture 1.2% of cementitious material
= (0.012×379.53)
= 4.55 m^3
Volume of chemical admixture = (4.55/1.15) × (1/1000)
= 0.0039 m^3
Volume of all in aggregates
=1-(0.01+0.12+0.15+4.55+0.0039)
=0.71 m^3
Volume of CA = 0.71×0.64
= 0.45 m^3
Volume of FA = 0.71× 0.36
= 0.25 m^3.
Mass of CA in kg = (0.45×2.75×1000)
= 1256.18 kg
Mass of FA in kg = (0.25×2.65×1000)
= 680.908 kg
Mix proportion for trail mix in kg/m^3
Cement = 379.53
Water = 151.81
Fine aggregate = 680.90
Coarse aggregate = 1256.18
Free water cement ratio = 0.4
Mix design ratio = 1:1.79:3.3

Table 5.1 Mix Design Ratio

Water	Cement	Fa	Ca
151.8	379.53	680.90	1256.18
0.4	1	1.79	3.3

IV. RESULTS AND DISCUSSION

4.1 Introduction

The performance of concrete can be evaluated by examination of physicals and sustainability properties under different test conditions. In present study, the outcomes of various strength tests namely compressive strength, split tensile strength, and flexural strength along with durability assessment through alternate wetting and drying cycles are presented and discussed.

Mix	Proportion (Cement+ RHA+ SF + Polymer)
A	100%+0%+0%+0%
B	90%+5%+5%+10%
C	80%+10%+10%+10%
D	70%+15%+15%+10%

4.2 Compressive Strength Test Results

Table 4.1 Compressive strength results at different cement replacement levels at 7 day

Specimen description	Average load at failure (kN)	Average compressive strength Mpa
Mix A	580	25.81
Mix B	603	26.81
Mix C	520	23.11
Mix D	520	23.10

Table 4.2 Compressive strength results at different cement replacement levels at 28 days

Specimen description	Average load at failure (kN)	Average compressive strength Mpa
Mix A	830	36.88
Mix B	850	38.35
Mix C	770	34.22
Mix D	770	34.22

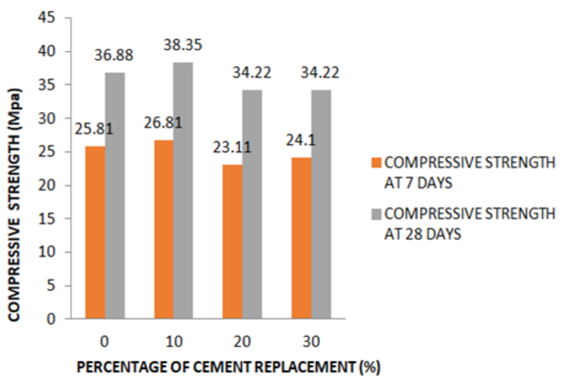

Fig. 4.1 Compressive strength of Cubes for different cement replacement levels

4.3 Slit Tensile Strength Test Results

Table 4.3 split tensile strength results at different cement replacement levels at 7 days

Specimen description	Average load at failure (kN)	Average split tensile strength Mpa
Mix A	143	2.02
Mix B	143	2.02
Mix C	157	2.21
Mix D	143	2.02

Table 4.4 split tensile strength results at different cement replacement levels at 28 days

Specimen description	Average load at failure(kN)	Average split tensile strength Mpa
Mix A	200	2.82
Mix B	200	2.82
Mix C	230	3.25
Mix D	213	3.01

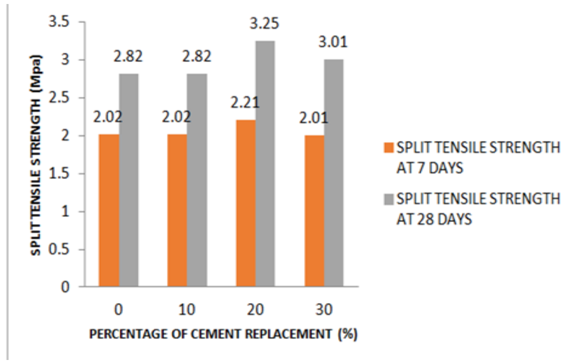

Fig. 4.2 Split tensile strength of cylinders for different cement replacement levels

4.4 Flexural Strength Test Results

Table 4.5 Flexural tensile strength results at different cement replacement levels at 7 days

Specimen description	Average load at failure(kN)	Average flexural strength Mpa
Mix A	8	3.2
Mix B	12	4.66
Mix C	12	4.66
Mix D	14	5.46

Table 4.6 Flexural tensile strength results at different cement replacement levels at 28 days

Specimen description	Average load at failure(kN)	Average flexural strength Mpa
Mix A	11	4.26
Mix B	16	6.53
Mix C	17	6.8
Mix D	20	7.86

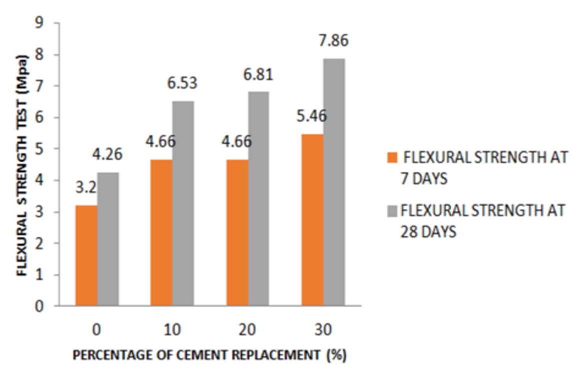

Fig. 4.3 Flexural strength of beams for different cement replacement levels

4.5 Alternate Wetting and Drying Test Results

Outcomes of Alternate wetting and drying cycles For Cubes

Phase	Wetting	Drying
Weight	8.300	8.140
Colour	Almost grey/black	Light greyish white
Water absorption (%)	0.97	-
Mass loss (%)	-	1.35
Surface pores	Less visible, Shiny	Open, more numerous after drying
Texture	Smooth, Dense, Glossy	Rough, Flacky in regions

Outcomes of Alternate wetting and drying cycles For Cylinders

Phase	Wetting	Drying
Weight	13.00	12.66
Colour	Darker grey	Light grey
Water absorption (%)	3.22	-
Mass loss (%)	-	0.435
Surface pores	Pores with water droplets	Open, More numerous after drying
Texture	Smooth, Shiny, wet	Rough,Powdery

Outcomes of Alternate wetting and drying cycles For beams

Phase	Wetting	Drying
Weight	12.310	11.80
Colour	Darker grey	Light grey
Water absorption (%)	2.58	-
Mass loss (%)	-	1.66
Surface pores	More visible as pores	Slightly devoleped
Texture	Smooth, Glossy	May show slight rough texture

VI. CONCLUSION

After seeing the results and analyzing the graph the following points are viewed

1. The Optimum replacement levels vary by properties of materials.
2. In compressive strength test 10% replacement concrete cubes with Mix B yields best compressive strength at both 7 and 28 days making it optimal choice in performance, replacement levels above 10% led to reduced compressive strength especially at early stages. In split tensile strength 20% Replacement with mix C provided the highest strength at 28 days, making it optimal for applications where resistance to stretching is critical, all mixes improved between 7 and 28 days, showing typical concrete hydration and strength development. For Flexural strength 30% replacement with mix D produced the highest flexural strength at both 7 and 28 days followed by 20% replacement, strength increased considerably with age.
3. The addition of RHA and SF improved the microstructure through the pozzolanic reaction, while polymers enhanced workability and bonding.
4. Excessive replacement with mix D reduced compressive and tensile strengths, thought it improved flexural strength, indicating that strong enhancement is not uniform across all loading condition.
5. The study shows that a balanced replacement level 10-20% is most beneficial for achieving an overall improvement in mechanical properties.
6. With respect to durability test, conducting alternate wetting and drying of the concrete cubes showed water absorption of 0.97% after wetting for 9-10 hours and showed 1.33% of cumulative dry mass loss after evaporation for nearly 20 hours. The specimen looked smooth and tightly packed when wet, but turned rough and flaky in patches after drying, shows good resistance to alternate wetting and drying with low water absorption, but average mass loss indicates gradual deterioration.
7. The cylinders showed water absorption of 2.32% after wetting and showed 0.43% of cumulative dry mass loss after drying. This shows very low mass loss it retained mass better after drying. Efflorescence was observed, but structural deterioration was less severe. This shows specimen is more durable against wetting and drying cycles compared to others.
8. The beams showed water absorption of 2.58% after its wetting, more among three specimens; 1.66% of cumulative dry mass loss after drying, highest among the three specimens. Pores and cracks were visible after drying; surface becomes rough and white, showing signs about micro cracking. Beams show the worst sustainability,

with more absorption and mass loss, making it the less resistant to alternate wetting and drying cycles.

9. The best resistance is shown by Cylinders, as they showed low dry mass loss; hence they are more durable. Cubes showed medium resistance, with low absorption but medium mass loss. Beams show less resistance to alternate wetting and drying with more absorption and mass, loss with damages

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