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Experimental Study on Mechanical and Durability Properties of Concrete Using Mineral Admixtures

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Abstract

This study explores the partial replacement of OPC with Fly Ash (FA), Rice Husk Ash (RHA), Glass Powder (GP), Palm Oil Fuel Ash (POFA) at varying percentages of 10%, 20%, 30% with the addition of 1% chemical admixture with water-cement ratio of 0.45. The influence of these replacements on the fresh properties, mechanical and durability properties is evaluated at 7, 28, and 56 days of curing. The results indicate that fly ash shows good results for the replacement of cement at a replacement of 30% at long term curing. The concrete with 30% replacement of FA achieves good mechanical and durability properties compared with conventional concrete. POFA shows potential as a partial substituent material, with a 20% optimum level of replacement. The substitution of GP and RHA is found to be more effective at only 10%. The higher percentage replacements of RHS and GP might lead to reduction in the mechanical and durability properties of the concrete due to pozzolanic nature. The results suggest that these sustainable alternatives can be effectively incorporated into the concrete.

Keywords: Palm oil fuel ash, Fly ash, Glass powder, Durability and Mechanical properties, Rice husk ash

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INTRODUCTION

The use of concrete in the construction field has been one of the main ingredients and its inheritance has been growing from decades of construction. The concrete mix was made by mixing fine and coarse aggregate, cement, and water, with the required proportion for the desired grade of concrete for the structure [1]. Cement plays an essential factor in concrete which acts as a hydraulic binder for binding all other materials in concrete when water is mixed. In addition to emitting a huge quantity of CO2, cement also leads to the atmosphere's concentration of greenhouse gases. Cement production and consumption is higher in the construction sector due to which discharge of greenhouse gases is also more compared to other sources of environmental destruction [2]. To avoid potential risks to human health, additional cementitious materials were partially substituted with cement. The usage of additional cementitious materials as a replacement does not change the existing characteristics of concrete but also provides additional properties to the concrete. Various industrial by-products and solid waste materials which consist of cementitious properties were considered for replacement where sustainability comes into existence[3]. The utilization of these supplement materials will reduce expenses compared to cement and they are more helpful in achieving the performance of the non-combustible mineral part of coal makes up fly ash. Before being utilized in the power plant, coal is ground till it is as fine as powder. When carbon is blown into a power plant's boiler, it burns and leaves behind molten particles that are high in calcium and silica-alumina [4]. Numerous studies focused on small replacements of cement substitution, and that too for lower-grade concrete. Experiments conducted at various periods signify that the inclusion of Fly Ash (FA) in concrete mix will decrease its strength. Mixtures with higher strengths may sometimes be more cost-effective than ones with a lower strength, based on the properties of FA and the curing period [5]. In both the fresh and hardened phases, adding fly ash to concrete as a substitution of cement would be useful. FA has many advantages in its hardened condition, such as strength and durability. On the other hand, fly ash tends to delay the concrete's setting time. The cement process generates excess calcium hydroxide, which is reduced by the pozzolanic reaction, creating a stronger CSH [6].

This research examined the creative use of mineral admixture-admixture-magnesium potassium phosphate cement as a surface treatment slurry to enhance the performance of recycled aggregate concrete. the kinds of mineral admixture (FA, GGBS) and their doses (0 %, 5%, 10%, and 15%) were taken into consideration. Moreover, the most efficient recycled course aggregate surface treatment method was determined by comparing pre-coating with pre-curing and pre-coating without pre-curing techniques [1]

RHA is an agricultural waste produced in tons every year [7]. RHA is formed from burning rice husk in rice mills. In many areas of the world, rice husk is a substantial agricultural byproduct that is prompted from rice industries. The increasing concern for the atmosphere and the need to preserve energy and resources, RHA. was formed of non-crystalline silica with high specific area and strong pozzolanic reactivity [14]. Several benefits arise from using RHA as pozzolanic components in cement and concrete, including increased strength and durability, lower material costs since less cement is used, and environmental advantages through waste material disposal [8]. Cement is partially substituted by RHA as a mineral admixture. Additionally, reducing alkali and silica reactivity, RHA decreases efflorescence, facilitates finishing, and increases the concrete strength [17]. Both crystalline and amorphous RHA are utilized to make an RHA mix, or RHA may be substituted in concrete [9].

Considering that people contribute maximum amount of glass waste, the use of glass is vital to human growth. As glass is often utilized in produced items like bottles, sheet glass, and glasses in everyday life. As glass is not a recyclable material, dumping it in a landfill is not a sustainable solution. In addition, this leftover glass might be used in construction for alternative substitution of cement [10]. Glass is employed as a building material, masonry aggregates, and road construction aggregates. Glass must be crushed into the appropriate size before being added to the concrete. Glass trash is an extremely tough substance. Glass pieces are crushed to create glass powder [15]. Millions of tons of abandoned glass are created every year. The conventional method is to dispose of this loss in landfills. Glass does not provide a healthy environment since it’s a non-biodegradable substance [11].

POFA is a recyclable ingredient from the palm oil industry. The fruit and copra of palm oil tree are utilized to extract palm oil. During the extraction process, waste materials such as empty fruit bunches, palm oil fibers, and shells are burned as biomass fuel to boil water, generating steam powering the extraction process in palm oil mills as well as energy. The end product is called POFA, which contains around 5% of total weight of waste material [12]. Calcium hydroxide ($CaOH_2$) from the hydration process, which degrades to concrete, may react with the silica oxide content in POFA. The pozzolanic reactions increase the amount of C-S-H, a gel component, and decrease the amount of calcium hydroxide [16]. Recent data reveals that many industrial waste products or by-products are disposed of in open fields, which deteriorates the surrounding groundwater streams and soil [13].

The use of superabsorbent polymer (SAP) as internal curing agents in a variety of conglomerates and

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the improvement of certain characteristics, such lowering drying and self-shrinkage. However, since SAP is a synthetic polymer, variations in its kind, dose, particle size, water absorption capacity, or extra water diversion would affect the test findings [18]

MATERIALS AND MATERIAL PROPERTIES

Materials

In this work, the following materials were used: OPC, coarse and fine aggregate, FA, GP, POFA, RHA, tap water, and superplasticizer. The detailed description of all these materials is discussed below.

Binding Materials

Cement

In this research, OPC (ordinary Portland cement) 53-grade cement conforming to IS: 12269:2013 that is locally available is used. Cement is a binder material when reacted with water it turns into a hydraulic binder which keeps all other materials in concrete together.

Fly Ash (FA)

FA is an industrial by-product that is obtained when coal is heated in thermal power plants at high temperatures, there remains ashes that are rich in alumina, silica, and ferric oxide. The usage of Fly ash (FA) in concrete helps improve workability and reduces heat of hydration and it can withstand severe chemical attacks. The FA used in the experiment is class F-type fly ash.

Rice Husk Ash (RHA)

RHA is formed from burning rice husk in rice mills. It is much finer than cement and highly reactive to some chemical reactions which provides additional strength to concrete when reacted with lime that is generated during cement hydration. It is a good pozzolanic substance that is rich in silica and alumina which helps in improving the performance of concrete. RHA is taken from a local shop.

Glass Powder (GP)

Glass powder is amorphous and produced by breaking glass waste into fine powder. Glass powder has good pozzolanic properties which helps in producing good standard concrete. Glass powder contains mostly silica and alumina which makes it a good cementitious material. The glass powder adopted in this work was taken from the nearby glass industry.

Palm oil Fuel Ash (POFA)

POFA is a hazardous waste that contains a pozzolanic property that makes a replacement material in concrete. POFA contains mostly silica and alumina which is contained in cement that helps in providing good strength and binding nature in concrete.

Fine Aggregate

The aggregate that passed through a 4.75mm sieve was utilized for experimental research. The fine aggregate adopted in this research work is river sand which lies in zone-II, obtained from local sources.

Coarse Aggregate

The aggregate passed through the 12.5mm sieve and retained on the 10mm sieve are utilized at about 40% and aggregate passed through the 22.5mm sieve and retained on the 20mm sieve are utilized at about 60%. For experimental work, the maximum aggregate is taken as 20mm, and the minimum aggregate is taken as 10mm. Both sizes of aggregates were adopted in the experiment for good compaction and for attaining good workability.

Water

It is the main source of concrete which participates in chemical reactions when encounters cement and helps in the hardening of concrete. For this experimental work, potable water is used for concrete mixing.

Chemical Admixture

The chemical admixture has different properties that help concrete to prevent air entraining, shrinkage, and water reduction and acts as an accelerator, and retarder in improving concrete performance. The admixture taken in this research work is an accelerator that is produced by Hi-Bond construction chemicals.

The specific gravity for the above-replaced materials is shown below in Table 1.

Table 1. Specific Gravity of Materials.

S.N.	Materials	Specific Gravity
1	Cement	3.16
2	Chemical admixture	1.1
3	FA	2.2
4	RHA	2
5	GP	3
6	POFA	2.2

EXPERIMENTAL INVESTIGATION AND TEST METHODS

Mix Details

As per IS code 10262:2019 specifications, the mix design is conducted for the M30 grade of concrete. In this experimental investigation, the OPC is replaced with FA, RHA, GP and POFA with the replacement percentages of 10, 20, and 30 by weight of total cementitious material. Mix details are represented in below Table 2.

Table 2. Mix Ratios

S.N.	Materials	% of Replacement	Mix Ratios
1	FA (F1, F2, F3)	10	1:0.11:1.52:3
		20	1:0.25:1.6:3
		30	1:0.43:1.62:3.05
2	RHA (R1, R2, R3)	10	1:0.11:1.61:3.04
		20	1:0.25:1.59:2.99
		30	1:0.43:1.57:2.97
3	GP (G1, G2, G3)	10	1:0.11:1.58:2.98
		20	1:0.25:1.57:2.97
		30	1:0.43:1.57:2.97
4	POFA (P1, P2, P3)	10	1:0.11:1.64:3.1
		20	1:0.25:1.63:3
		30	1:0.43:1.56:2.95

Preparation of Specimens

The iron moulds were used for this work to prepare the cube (150 × 150 ×150 mm), cylinder (150 mm × 300 mm), and prism (100 × 100 × 500 mm) specimens. The moulds were initially tightened to avoid leaks after filling the concrete. A thin layer of grease was applied to the moulds before the concrete was placed. After 24 hours of casting the specimens were demoulded and transferred to the curing tank.

Test Methods

Workability

The Consistency of concrete is known as how simple it is to mix the concrete, and ease of placing the concrete. There are numerous testing methods for determining the workability of concrete, one among them is the slump cone test. Initially, the slump cone is applied with a thin layer of grease to avoid the sticking of concrete to the mould then the concrete is placed in 3 layers, 25 blows from a

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tamping rod are used to compress each layer.

Compressive Strength (CS)

The Compressive Strength (CS) is conducted for the cube specimens of size 150X150X150mm. The compressive test is conducted for 7, 28, and 56 days of curing as per IS specification 516:1959. Three specimens were tested and the average of those three specimens was represented for the respective mix.

Split tensile Strength (STS)

The Split tensile strength (STS) test was conducted on a compressive testing machine. The cylinder specimen was placed horizontally, and the load was applied gradually to the specimen. The test was performed on 7, 28, and 56 curing days.

Flexural Strength (FS)

Flexural strength (FS) test was conducted on prism specimens. Initially, the specimen was marked as per the IS specification 516:1959. The tests were performed at 7, 28, and 56 days of curing.

RESULTS AND DISCUSSIONS

Workability

The workability of concrete mix is determined by slump cone test. The results for CC and replacement materials were shown in Figure 1. For the conventional concrete (CC) the slump value is 115mm. As the quantity of FA increases the consistency of concrete is also increasing, with the substitution of rice husk ash reducing the workability as the percentage is increasing, similarly for the substitution of GP and POFA the workability is decreasing with the increase in percentages. From all the mixes fly ash replaced with 30% has having high workability of 125mm and for mix P3 the workability is very low among all these mixes.

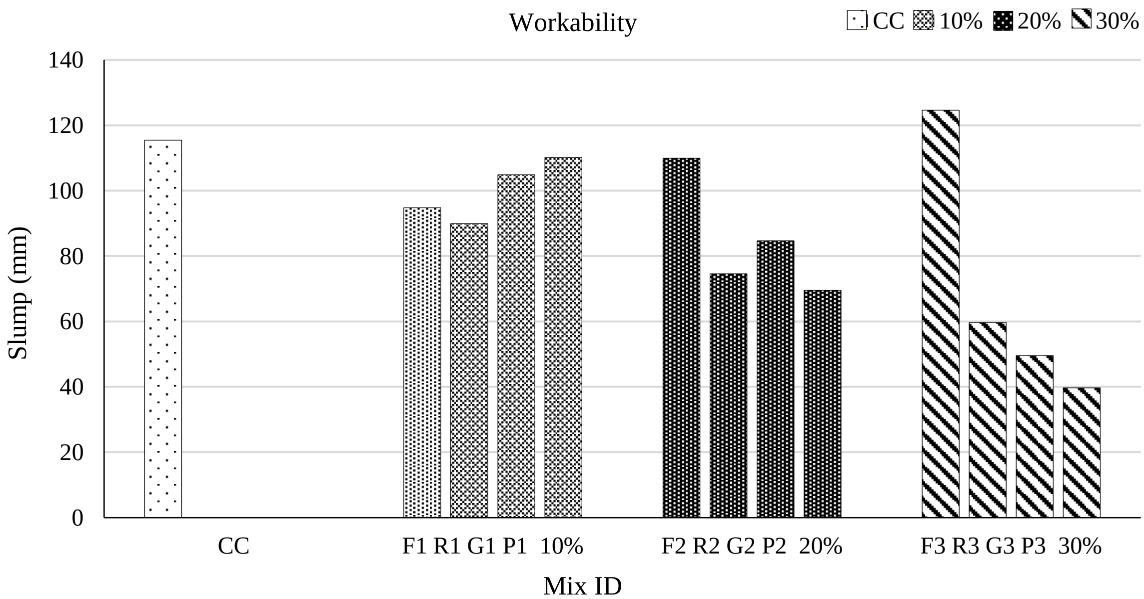

Figure 1. Workability of all concrete mixes.

Compressive Strength (CS)

The compressive strength test results of concrete are shown below in Figures 2–5 for CC and substitute concretes. For CC the compressive strength was 35.2 MPa for 7 days and the mix F3 got maximum strength of 49.8 MPa at 56 days. The replacement of fly ash at 30% shows greater compressive strength among all the mixes. The results show that the replacement of FA provides good strength at a later age of curing. Initially, the cube specimens replaced with FA show lesser strength as the replacement of FA will reduce the heat of hydration and it takes much time for setting. The substitution of cement with RHA and GP provides CS less than that of CC. The maximum CS in the substitution of RHA was obtained for CC which was 47.35 MPa at 56 days and similar for the substitution of glass powder. With the increase in RHA and GP percentages, the CS is reducing gradually. The substitution of POFA with cement shows lesser compressive strength (CS) with increase in percentages of POFA, the CS is higher for the conventional concrete in this mix which was 47.35MPa at 56 days.

Split Tensile Strength (STS)

Tensile strength is a mechanical property that is used to examine the split tensile strength (STS) of hardened specimen concretes. The results for the STS of concrete are shown below in Figures 6–9 for CC and replacement concretes. For CC the tensile strength was 2.45MPa at 7 days and the mix F3 got maximum tensile strength of 3.25MPa at 56 days. The substitution of FA at 30% shows greater tensile strength among all the mixes. The substitution of cement with RHA and GP provides lesser tensile strength than CC. The maximum STS in the replacement of RHA was achieved for CC which was 3.25MPa at 56 days and similar for the substitution of glass powder. With the increase in RHA and GP percentages, the tensile strength is reducing gradually. The substitution of POFA with cement shows lesser STS with the percentage increase in POFA, the tensile strength is higher for the CC in this mix which was 3.25MPa at 56 days.

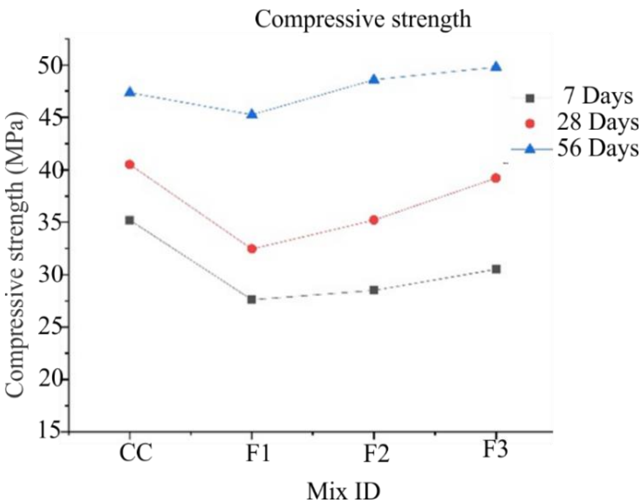

Figure 2. Comparison in Compressive strength for Conventional and Fly Ash Concrete.

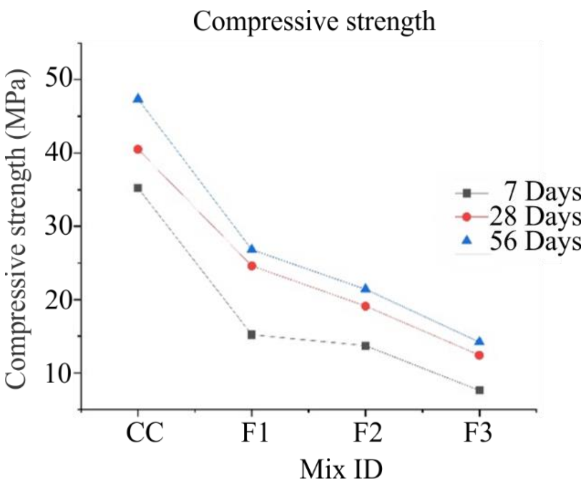

Figure 3. Comparison in Compressive strength for Conventional and Rice Husk Ash Concrete.

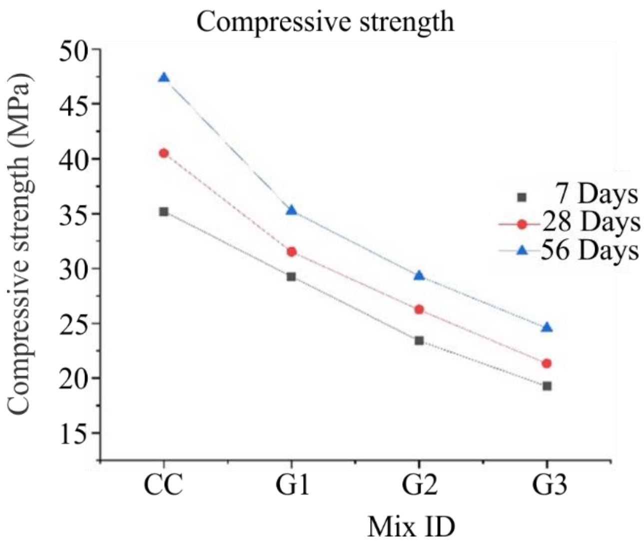

Figure 4. Comparison in Compressive strength for Conventional and Glass Powder Concretes.

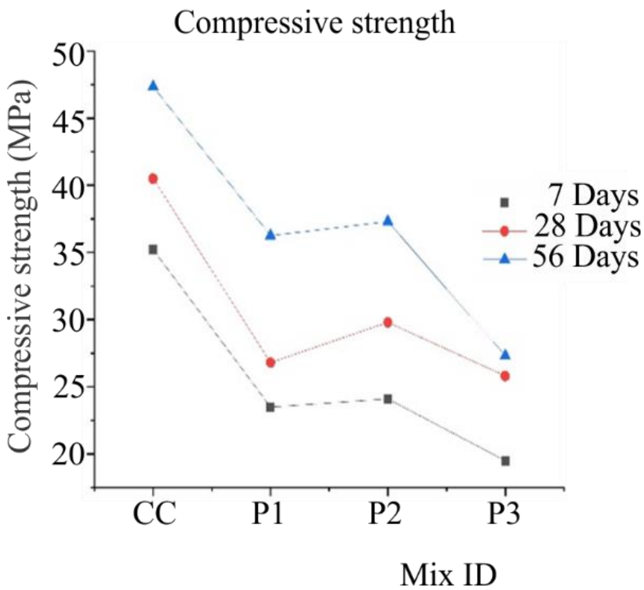

Figure 5. Comparison in Compressive strength for Conventional and POFA Concrete.

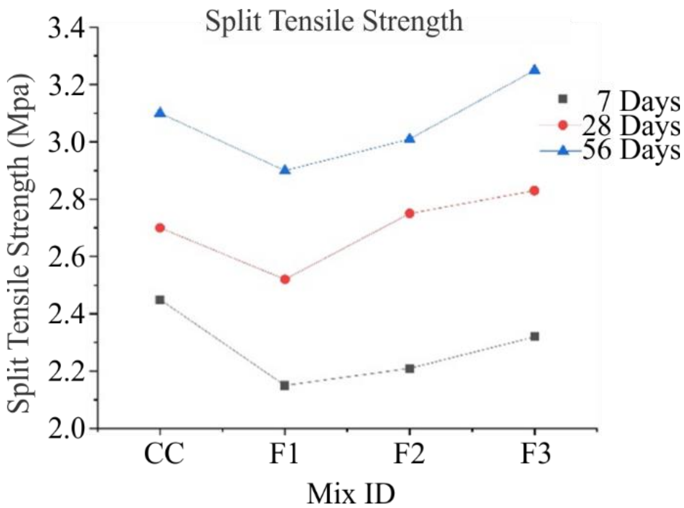

Figure 6. Comparison in 3. for Conventional and Fly Ash Concrete.

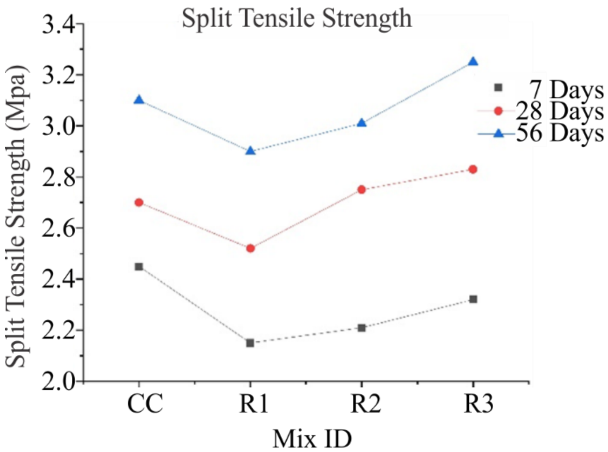

Figure 7. Comparison in Split Tensile Strength for Conventional and Rice Husk Ash Concrete.

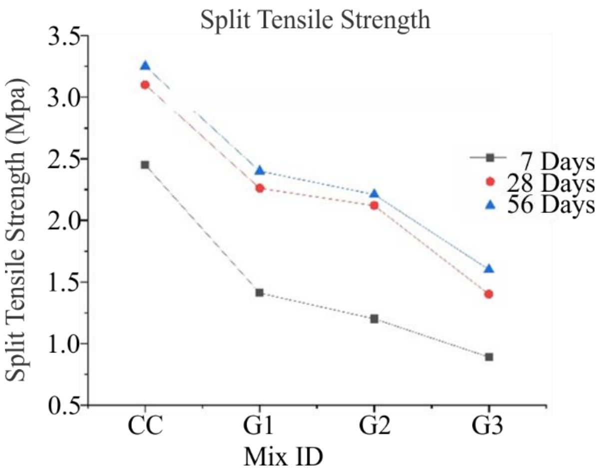

Figure 8. Comparison in Split Tensile Strength for Conventional and Glass Powder Concrete.

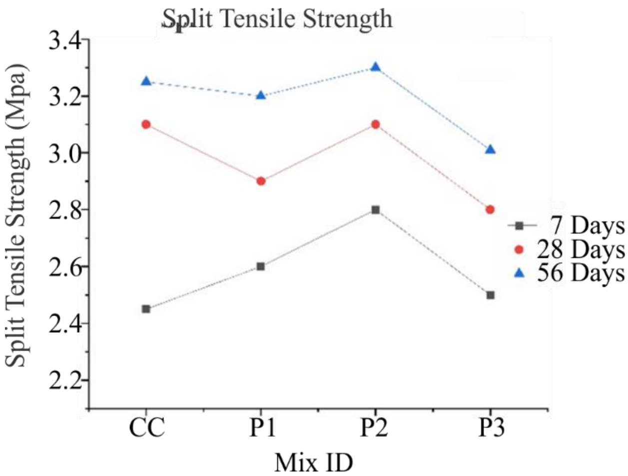

Figure 9. Comparison in Split Tensile Strength for Conventional and POFA Concrete.

Flexural Strength (FS)

FS test is conducted to consider the capacity of concrete to withstand bending or flexural stresses. This test will be essential to evaluate the concrete performance under the utilization of different loadings that cause bending. This FS can be characterized for beams both with reinforcement and without reinforcement. The results for the FS of concrete are shown below in Figures 10–13 for Nominal concrete and replacement concretes. The replacement of FA at 30% shows greater bending strength

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among all the mixes. The results shows that the substitution of FA provides good strength at the later age of curing period. The substitution of cement with GP and RHA provides lesser FS than CC. The maximum flexural strength (FS) in the substitution of RHA was achieved for CC which was 6.1MPa at 56 days and similar for the substitution of glass powder. With the increase of GP and RHA percentages, the FS is reducing gradually.

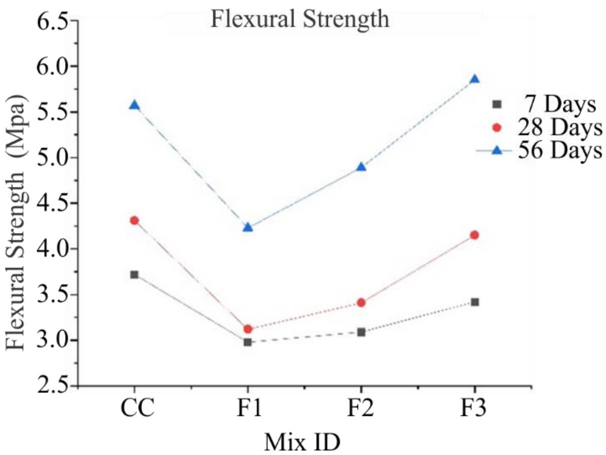


Figure 10. Flexural Strength for CC and FA.

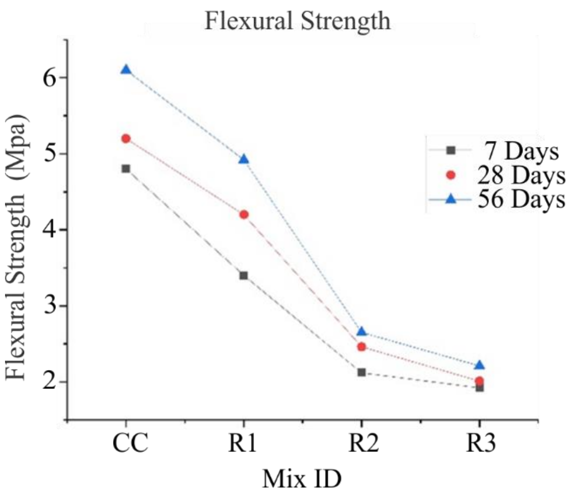


Figure 11. Flexural Strength for CC and RHA.

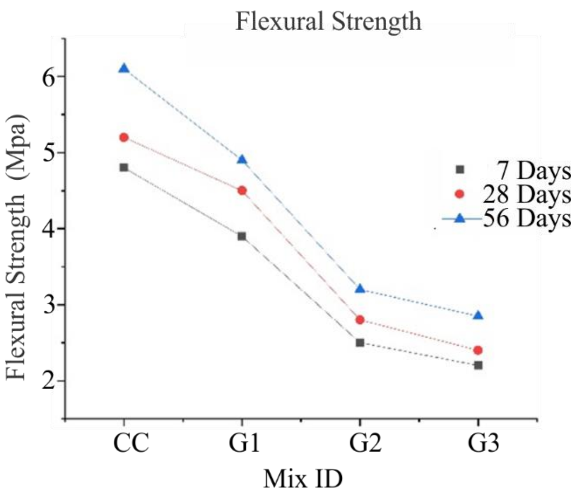


Figure 12. Flexural Strength for CC and GP**.**

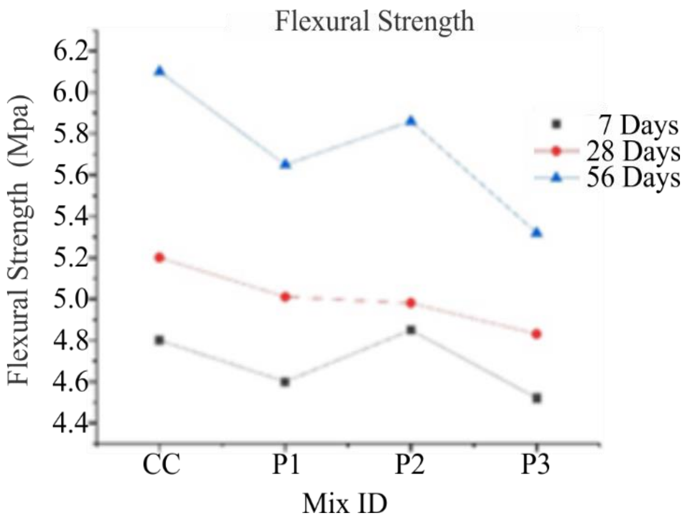
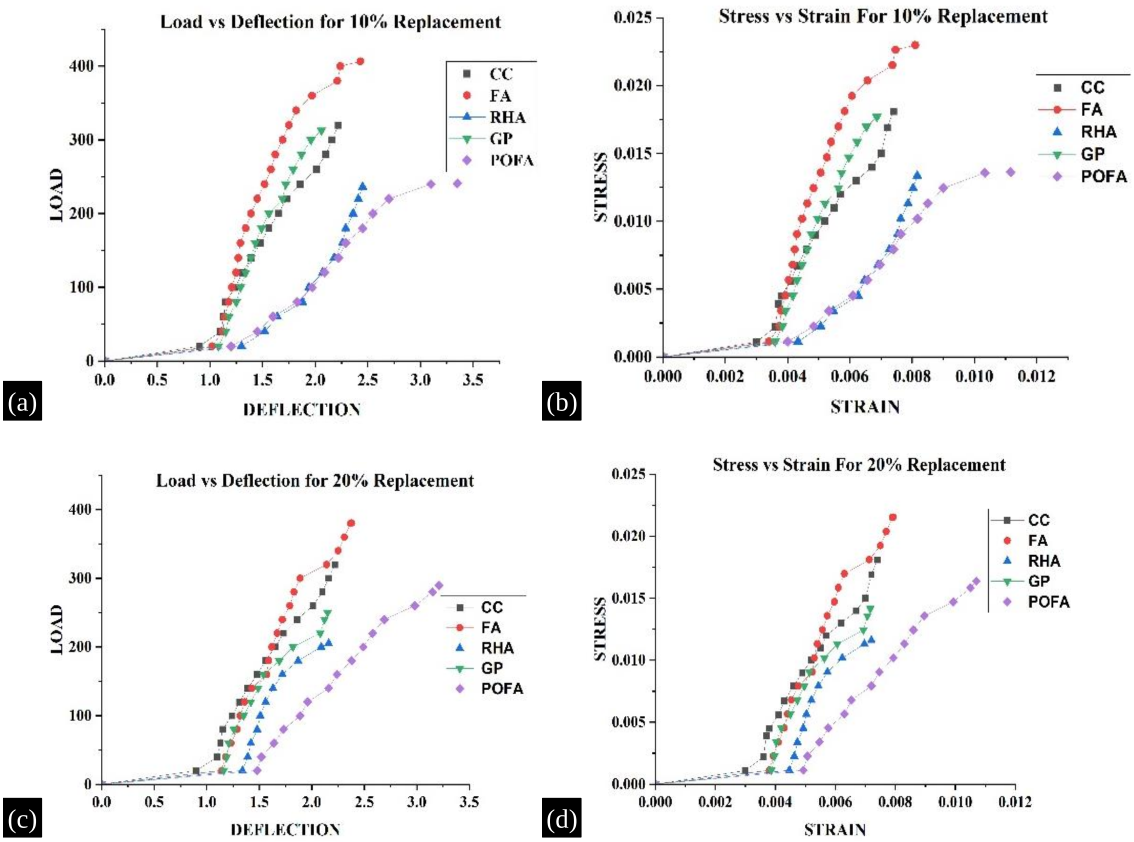


Figure 13. Flexural Strength for CC and POFA.

Young's Modulus Test

Young's Modulus, which is also known as the modulus of elasticity which gives the stiffness of a material can be find by the tensile test. A series of uniaxial loading is applied on the cylinder specimens after curing period of 28 days, the resulting deformation is measured. Thus, the resulting deformation helps in providing the stress-strain curve for concrete. The ratio of stress to strain in concrete with varying strengths is seen in Figure 14. Maintaining a steady stress-to-strength ratio results in better strain and elasticity modulus for durable concrete. The tensile test may be used to assess a material's modulus of elasticity, which determines its stiffness. After curing period of 28 days, a series of uniaxial loads is applied to the cylinder specimens, and the resulting deformation is measured. Therefore, the resulting deformation contributes to creating the concrete stress-strain curve.



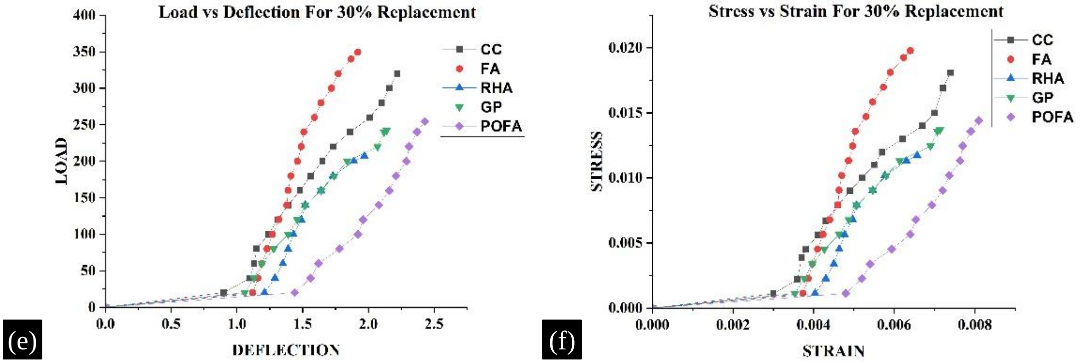


Figure 14. Stress vs Strain AND Load vs Deflection for Conventional concrete and Replacement Materials for all Percentages**.**

DURABILITY PROPERTIES

Water Absorption

Concrete’s ability to absorb water and hold it in its pores and capillaries is referred to as water absorption. Since concrete is porous, its capacity to absorb water is affected by the mix’s porosity, permeability, density, curing conditions, and age. Overabsorption may result in decreasing durability, increasing susceptibility to freeze-thaw damage, and perhaps even reinforcement corrosion. To maintain the structural integrity and long-term performance of concrete, water absorption must be closely monitored and controlled. For this experimental investigation, the test for water absorption is performed for the specimens of conventional concrete and the specimens that attained the highest compressive strength in all the replacements. The test results of water absorption for CC and replacement materials are shown in Table 3.

Table 3. Water Absorption.

Mix ID	Initial weight (W1)	Final weight (w2)	Water absorption (%)
CC	8.24	8.52	3.39
Fly Ash	8.924	9.212	3.22
Rice husk ash	8.014	8.324	3.8
Glass Powder	8.024	8.263	2.9
Palm Oil Fuel Ash	8.094	8.314	2.7

Water Permeability

The water’s ability to pass through the pores and capillaries of concrete is described to as its water permeability. Porosity, pore structure, connectivity, water-to-cement ratio, and curing conditions are the factors that effect it. Problems involving corrosion of reinforcement, damage from freeze-thaw cycles, and durability might also be brought on by high permeability. The concrete structures durability depend significantly on controlling permeability. Concrete's water permeability may be decreased by using methods including adding pozzolanic components, surface treatments, and low water-cement ratio mixes. For this experimental investigation, the water permeability test is carried out for the specimens of CC and the specimens that attained the highest compressive strength in all the replacements. The test results of water permeability for CC and replacement materials are shown in the below Table 4.

Table 4. Water Permeability.

Mix ID	Water Permeability (m/s) 28 days
CC	1.88×10^{-12}
Fly Ash	1.34×10^{-12}
Rice Husk Ash	1.44×10^{-12}
Glass Powder	1.29×10^{-12}
Palm Oil Fuel Ash	1.32×10^{-12}

CONCLUSIONS

The experimental work is conducted on M30 grade of concrete with the replacement of different types of supplementary cementitious materials about 10,20 & 30% for ages 7, 28, & 56 days of curing.

1. The use of industrial by-products and waste as a substitution for cement in concrete helps in reducing the accumulation of waste and helps in attaining good strength equal and higher to plain cement concrete.
2. Compressive strength (CS) of concrete decreases with the replacement of glass powder in concrete. 10% is the optimum value for the substitution of glass powder in concrete.
3. Compressive strength (CS) of concrete increases as the percentage of POFA increase in concrete. 20% of POFA in concrete is the optimum value for the substitution in concrete. As POFA consists of a lot of LOI content it is preffered to use up to 20% in concrete mix.
4. The use of RHA as a substitution of cement in concrete reduces the strength when it exceeds 10 %. It is recommended to use RHA about 10% replacement for good strength. RHA fails to obtain the required compressive strength (CS) of concrete for 28 days of curing period due to the unburnt nature of RHA.
5. The FA used for substitution of cement in class F FA due to which compressive strength of concrete increases with the decrease in substitution percentages. It is identified that a 10% substitution of cement with FA obtained more strength when compared to other percentages.

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