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Evaluating the Impact of Pozzoloniz Additives on the Mechanical Properties of Fiber-Reinforced Concrete

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Abstract
High-performance concrete (HPC) is defined as concrete that meets special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices. Ever since the term HPC was introduced into the industry, it has been widely used in large-scale concrete construction that demands high strength, high flowability, and high durability. High-strength concrete is always a type of HPC, but HPC is not always high-strength concrete. Specifying high-strength concrete does not ensure durability. Achieving a product that simultaneously fulfills all desired properties is challenging.
Pozzolanic materials such as Ground Granulated Blast Furnace Slag (GGBS), silica fume, rice husk ash, fly ash, and high reactive metakaolin can be used in concrete as partial replacements for cement. These pozzolans are essential for producing HPC. In this study, X-ray diffraction (XRD) tests were conducted on these materials to analyze their constituents. Maintaining a minimal water-cement ratio is crucial, necessitating the use of superplasticizers, which play a significant role in HPC production.
The study involved testing materials like rice husk ash, GGBS, and silica fume to achieve the desired properties. XRD tests were conducted on these pozzolanic materials to analyze their content. Synthetic fiber (Recron fiber) was added in varying percentages (0.0%, 0.1%, 0.2%, 0.3% by total weight of concrete), and concrete was cast. Additionally, different percentages of silica fume were used to replace cement while keeping the fiber content constant, and concrete was cast. Two types of cement were used: Portland slag cement and ordinary Portland cement. Mortar, cubes, cylinders, and prisms were prepared, followed by compressive, splitting tensile, and flexural tests. Porosity and permeability tests were also conducted. To achieve the performance characteristics not attainable with conventional concrete, numerous trial mixes were required to select the optimal material combinations.

Keywords: High-Performance Concrete, Pozzolanic Additives, Fiber-Reinforced Concrete, Ground Granulated Blast Furnace Slag, Silica Fume, Rice Husk Ash, X-Ray Diffraction, Superplasticizer, Synthetic Fiber, Mechanical Properties, Durability.

1. Introduction

Concrete is the most widely used man-made construction material, obtained by mixing cement, water, aggregates, and sometimes admixtures. Freshly mixed concrete can be molded into any shape and hardens due to the chemical reaction between water and cement. Historically, concrete structures built with ordinary Portland cement (OPC) and mild steel have shown utility, elegance, and durability. However, since the 1970s, the durability of concrete has declined due to changes in materials and the use of high strength rebars, supplementary cementitious materials, and admixtures, often without adequate consideration. This has led to an alarming rate of infrastructure deterioration globally.

OPC is essential in concrete production, but its manufacture emits significant carbon dioxide, contributing to global warming. Therefore, finding alternative or supplementary materials is crucial for sustainable development. Pozzolanic materials like fly ash, GGBS, rice husk ash, high reactive metakaolin, and silica fume can partially replace cement. Studies have shown promising results regarding the impact of these materials on concrete properties. Concrete strength and durability depend on ingredient properties, mix proportions, compaction methods, and curing controls.

High strength concrete (HSC) emerged in the late 1960s with the development of water-reducing admixtures, leading to precast products and structural elements with strengths from M60 to M120. Compressive strengths up to 138N have been used in cast-in-place buildings. In India, HSC is utilized in prestressed concrete bridges and projects like the Kaiga power project, which used HPC of 60MPa with silica fume. The construction industry is now moving towards pre-cast elements and post-tensioning, necessitating high strength concrete for durability and efficiency. The focus is on achieving cost savings and meeting the high strength requirements of modern construction.

1.2 High Performance Concrete

High-Performance Concrete (HPC) is defined by the American Concrete Institute (ACI) as concrete that meets specific performance and uniformity requirements not achievable with conventional materials and methods. HPC is designed to exhibit certain characteristics for particular applications, such as ease of placement, compaction without segregation, early age strength, long-term mechanical properties, permeability, density, heat of hydration, toughness, volume stability, and durability in severe environments.

2. Literature Review

2.1 Introduction

As our aim is to develop concrete which does not only concern on the strength of concrete, it also having many other aspects to be satisfied like less porous, capillary absorption, durability. So for this we need to go for the addition of pozzolanic materials alongwith super plasticizer with having low water cement ratio. The use of silica fume is many, which is having good pozolanic activity and is a good material for the production high performance concrete. Also now a day’s one of the great applications in various structural fields is fiber reinforced concrete, which is getting popularity because of its positive effect on various properties of concrete.

2.2 Earlier Researches

Some of the early research works had done using different pozzolanic materials with the replacement of cement using super plasticizer for the development high performanceconcrete. Also the development in the field of fiber reinforced concrete along with pozzolanas. So below an over view of different studies has been represented.

Aitcin[1] (1995) cited on development in the application of high performance concrete. Over the last few years, the compressive strength of some of the concrete used has increased dramatically. In 1988, a 120 MPa concrete was delivered on site, while, until relatively recently, 40 MPa was considered indicative of high strength. The spectacular increase in compressive strength is directly related to a number of recent technologicaldevelopments, in particular the discovery of the extraordinary dispersing action of super plasticizers with which flowing concretes can be made with about the same mixing water that is actually required to hydrate all the cement particles or even less. The reduction in water/cement ratio results in a hydrated cement paste with a microstructure so dense and strong that coarse aggregate can become the concrete’s weakest constituent. Silica fume, a highly reactive pozzolana, considerably enhances the paste/aggregate interface and minimizesdebonding. Lastly, the use of supplementary cementitious materials, such as fly ash and especially slag, helps solve slump loss problems which become critical at low w/c ratios.

Ajdukiewicz and Radomski [2] (2002) delve into Trends in the Polish research on high performance concrete. They analysed the main trends in the research on high- performance concrete (HPC) in Poland. There they sighted on some examples of the relevant investigations. The fundamental engineering and economical problems concerning the structural applications of HPC in Poland are presented as well as the needs justifying the increased use of this material are briefly described.

Aitcin[3] (2003) studied on the durability characteristics of high performance concrete. He examined durability problems of ordinary concrete can be associated with the severity of the environment and the use of inappropriate high water/binder ratios. High- performance concrete that have a water/binder ratio between 0.30 and 0.40 are usually more durable than ordinary concrete not only because they are less porous, but also because their capillary and pore networks are somewhat disconnected due to the development of self- desiccation. In high-performance concrete (HPC), the penetration of aggressive agents is quite difficult and only superficial. However, self-desiccation can be very harmful if it is not controlled during the early phase of the development of hydration reaction, therefore, HPC must be cured quite differently from ordinary concrete. Field experience in the North Sea and in Canada has shown that HPCs, when they are properly designed and cured, perform satisfactorily in very harsh environments. However, the fire resistance of HPC is not as good as that of ordinary concrete but not as bad as is sometimes written in a few pessimistic reports. Concrete, whatever its type, remains a safe material, from a fire resistance point of view, when compared to other building materials.

2.3 Scope and Objective of Present Work

The objective of this work is to develop concrete with high strength, low porosity, and minimal capillarity to enhance durability. This requires the use of various pozzolanic materials such as rice husk ash, ground granulated blast furnace slag (GGBS), and silica fume, along with fibers. The experimental program will include:

- Determining the mix proportions incorporating rice husk ash, GGBS, silica fume, and fiber to achieve the desired properties.
- Establishing the optimal water/binder ratio to ensure proper workability and strength in the design mix.
- Investigating the fundamental properties of concrete, including compressive strength, splitting tensile strength, and flexural strength, and comparing the results across different mix proportions.
- Evaluating the porosity and capillarity of the various concrete mixtures.

This research aims to provide concrete with enhanced durability through optimized mix designs and the incorporation of advanced materials.

3. Material and Properties

3.1 Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBS) is a by-product of pig iron production, obtained by rapidly cooling molten slag with water, a process known as quenching. This rapid cooling forms granulated slag, which, when ground, becomes GGBS. Properly processed GGBS develops hydraulic properties, making it an effective pozzolanic material, whereas slowly air-cooled slag remains inert and unusable as a pozzolan.

In India, GGBS is often used in Portland slag cement, though its use as a partial replacement for cement in concrete is less common. GGBS mainly consists of silicates and alumino-silicates of calcium, with a chemical composition similar to Portland cement but in different proportions.

The hydraulic activity of GGBS is influenced by four main factors: glass content, chemical composition, mineralogical composition, and fineness. The glass content impacts hydraulic properties, while the chemical composition affects alkalinity and glass structure. The compressive strength of concrete varies with the fineness of GGBS.

Table 3.1. Chemical Composition (%) of GGBS

SiO_2	39.18
Al_2O_3	10.18
Fe_2O_3	2.02
CaO	32.82
MgO	8.52
Na_2O	1.14
K_2O	0.30

3.2 Rice Husk Ash

Rice husk ash (RHA) is produced by burning rice husk in a controlled manner, resulting in high SiO2 content and making it a valuable concrete admixture. Properly burnt RHA exhibits high pozzolanic characteristics, contributing to high strength and impermeability in concrete. RHA primarily consists of amorphous silica (85-90%), with about 5% carbon and 2% K2O, and has a specific surface area of 40,000-100,000 m^2/kg.

India produces about 122 million tons of paddies annually, yielding approximately 40 kg of RHA per ton. RHA has the potential to be a valuable pozzolanic material, offering similar properties to microsilica. In the USA, highly pozzolanic RHA is marketed under the trade name Agrosilica. Used in small quantities (around 10% by weight of cement), RHA significantly enhances concrete's workability and impermeability.

Table 3.2. Chemical Composition (%) of RHA

SiO_2	85.88
K_2O	4.10
SO_3	1.24
CaO	1.12
Na_2O	1.15
MgO	0.46
Al_2O_3	0.47
Fe_2O_3	0.18
P_2O_5	0.34

3.3 Silica Fume

Silica fume, also known as microsilica or condensed silica fume, is a by-product of producing silicon or ferrosilicon alloy in an electric arc furnace. It is formed when high-purity quartz is reduced with coal at around 2000°C, creating SiO vapors that oxidize and condense at lower temperatures. The resulting silica fume is collected through filters, processed to remove impurities, and has an ultra-fine particle size, primarily consisting of more than 90% non-crystalline silicon dioxide (SiO2).

Silica fume particles are extremely fine, with sizes less than 1 micron and an average diameter of about 0.1 micron, making them roughly 100 times smaller than typical cement particles. Its specific surface area is about 20,000 m²/kg, compared to 230 to 300 m²/kg for standard cement particles. This high fineness and pozzolanic activity make silica fume a crucial component in modern high-performance concrete, especially when used with superplasticizers. The fineness and uniformity of silica fume enhance the modulus of elasticity and durability of high-performance concrete.

Table 3.3. Chemical Composition of Silica Fumes in %

SiO_2	93
Al_2O_3	0.4
CaO	1.2
Fe_2O_3	0.2
MgO	1.2
Na_2O	0.1
K_2O	1.1
SO_3	0.3

4. Experimental Programme

4.1 Outline of Present Work

This study investigates the use of Rice Husk Ash (RHA), Ground Granulated Blast Furnace Slag (GGBS), and Recron fiber in concrete to assess their effects on strength and durability.

- **Rice Husk Ash (RHA):** Used as a partial replacement for cement in mortar cubes to evaluate its strength and performance. RHA's suitability is based on its physical and chemical properties.

- **Ground Granulated Blast Furnace Slag (GGBS):** Examined in different percentages, with specific surface ranging from 275-550 m²/kg. GGBS's benefits include lower energy costs, higher abrasion resistance, and reduced heat evolution. Mortar samples are tested with GGBS passing through a 75-micron sieve.

- **Recron Fiber:** Added at 0%, 0.1%, 0.2%, and 0.3% by weight of concrete. The study evaluates its impact on compressive, splitting tensile, and flexural strength at 7 and 28 days, while maintaining a water-cement ratio of 0.35-0.41.

- **Silica Fume:** Incorporated at 10%, 20%, and 30% with a fixed fiber percentage of 0.2%. Compressive, splitting tensile, and flexural strengths of cubes, cylinders, and prisms are assessed.

- **Cement Types:** Portland Slag Cement and Ordinary Portland Cement (53 grades) are used in the study.

- **Tests:** XRD analysis is performed to determine the chemical composition of RHA, GGBS, and silica fume. Additionally, porosity and capillary absorption tests are conducted to evaluate the impact of silica fume on concrete.

The study aims to evaluate the effectiveness of various pozzolanic materials, fibers, and superplasticizers in enhancing concrete properties.

Cement

For the experiment following two types cements were used,

- Portland Slag Cement
- Ordinary Portland cement (53 grade)

The chemical composition and different properties are shown below.
Fineness -340 m^2/kg
Specific gravity- 2.96
Initial setting time - 120 min
Final setting time – 240 min

Table 4.1. Properties of Portland Slag Cement

Specific Gravity	2.96
Initial Setting Time (Min)	125
Final Setting Time (Min)	235

Table 4.2. Properties of Ordinary Portland Cement

Specific Gravity	3.1
Initial Setting Time (Min)	90
Final Setting Time (Min)	190

Fine Aggregate

In this study it was used the sand of Zone-II, known from the sieve analysis using different sieve sizes (10mm, 4.75mm, 2.36mm, 1.18mm, 600µ, 300µ, 150µ) adopting IS 383:1963.

Table 4.3. Properties of Fine Aggregate

Properties	**Results Obtained**
Specific Gravity	2.65
Water Absorption	0.6%
Fineness Modulus	2.47

Coarse Aggregate

The coarse aggregate used here with having maximum size is 20mm. We used the IS 383:1970 to find out the proportion of mix of coarse aggregate, with 60% 10mm size and 40% 20mm.

Table 4.4. Properties of Coarse Aggregate

Specific Gravity	2.67
Water Absorption	0.4%
Fineness Modulus	4.01

Fiber

In this project work it was used Recron fiber. It is a type of synthetic fiber. Indifferent weight fraction (0.0%, 0.1%, 0.2%, 0.3%) to concrete it was used.

Ground Granulated Blast Furnace Slag (GGBS)

As pozzolanic activity greatly depends on fineness, so GGBS passing through 75 micron whose fineness of order of 275-550 m^2/kg was used. Specific gravity test was conducted using Le-Chatelier apparatus and found to be 2.77. X-Ray diffraction test was conducted shown below in figure no. 4.1.

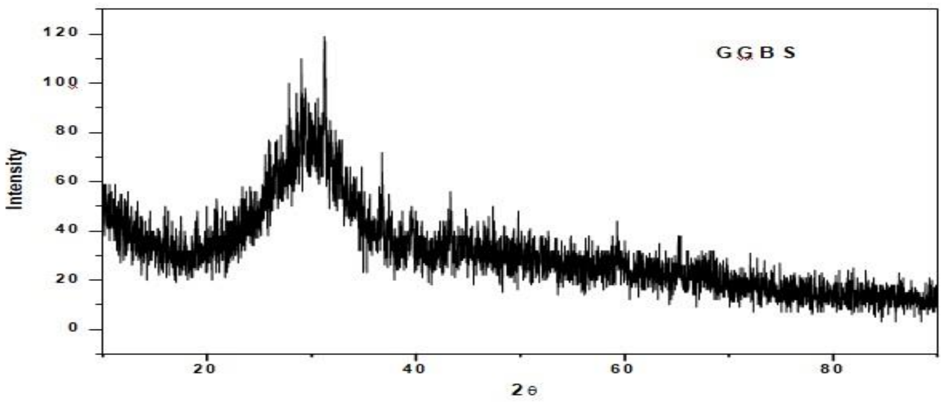

Fig. 4.1 X-Ray Diffraction Test of GGBS

4.3.1 Test Results

Table 4.5. Effect of GGBS in Normal Consistency of Cement

% of Cement ReplacedBy GGBS (%)	Consistency (%)
0	31.0
10	32.0
20	33.0
30	34.5
40	36.5

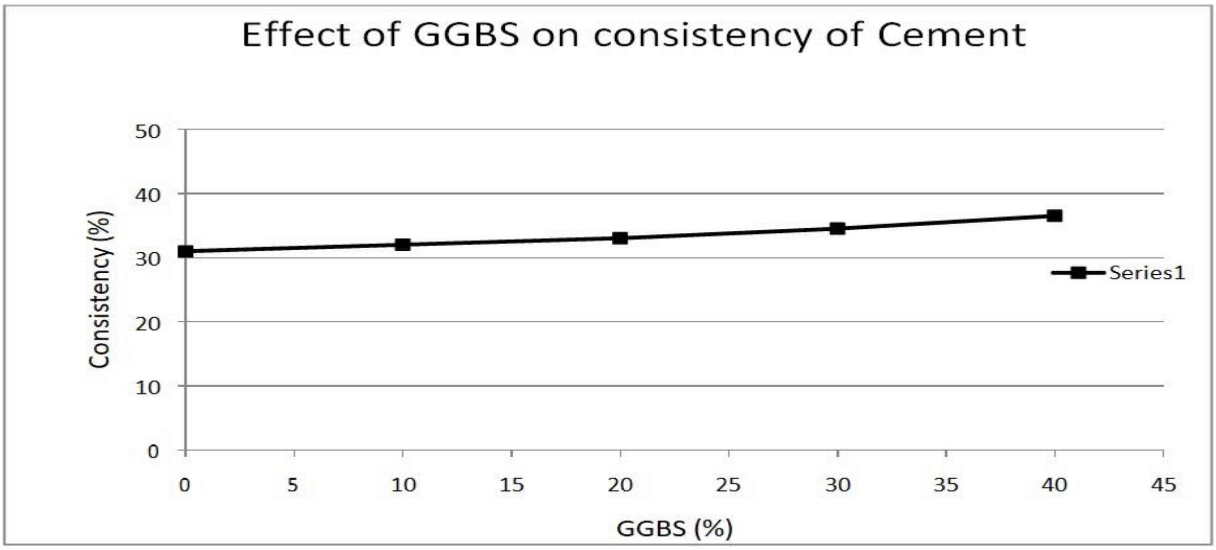

Fig. 4.5 Variation of Consistency of Cement Containing Different % ofGGBS

Table 4.6. Effect of GGBS on Compressive Strength of Cement

% of GGBS With Cement Replacement	**3 Days Strength (Mpa)**	**7 Days Strength (Mpa)**
0	11.176	24.31
10	9.66	15.63
20	7.117	10.85
30	6.10	9.15
40	4.74	7.46

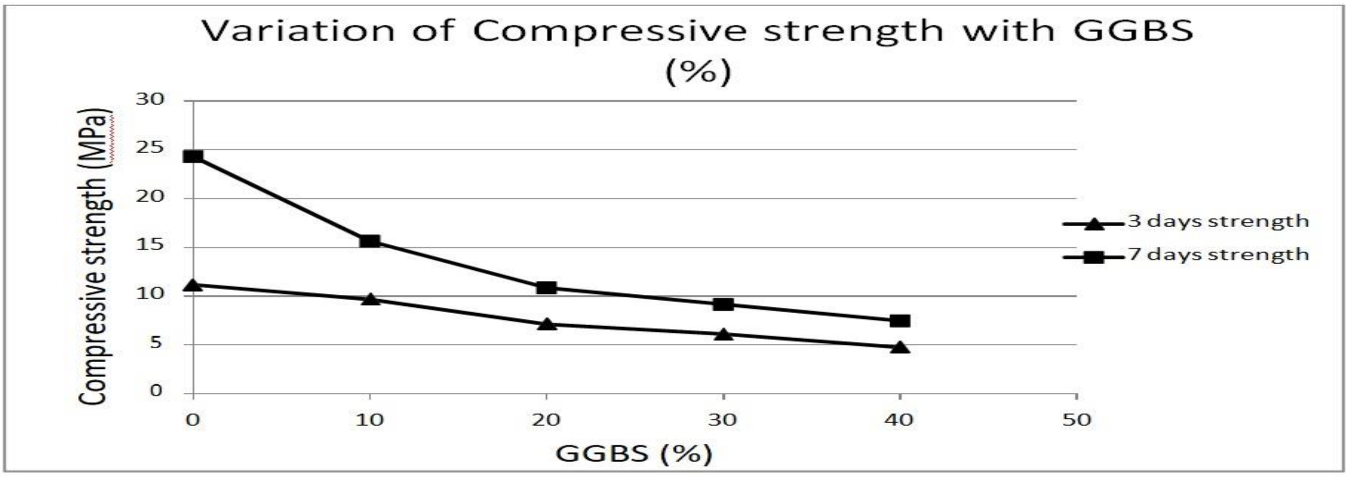

Fig. 4.6. Variation of Compressive Strength of Mortar with Different GGBS %

Table 4.7. Effect of RHA on Normal Consistency of Cement

% of Cement Replaced by RHA	**Consistency (%)**
0	31.0
10	45.0
20	48.0
30	52.0

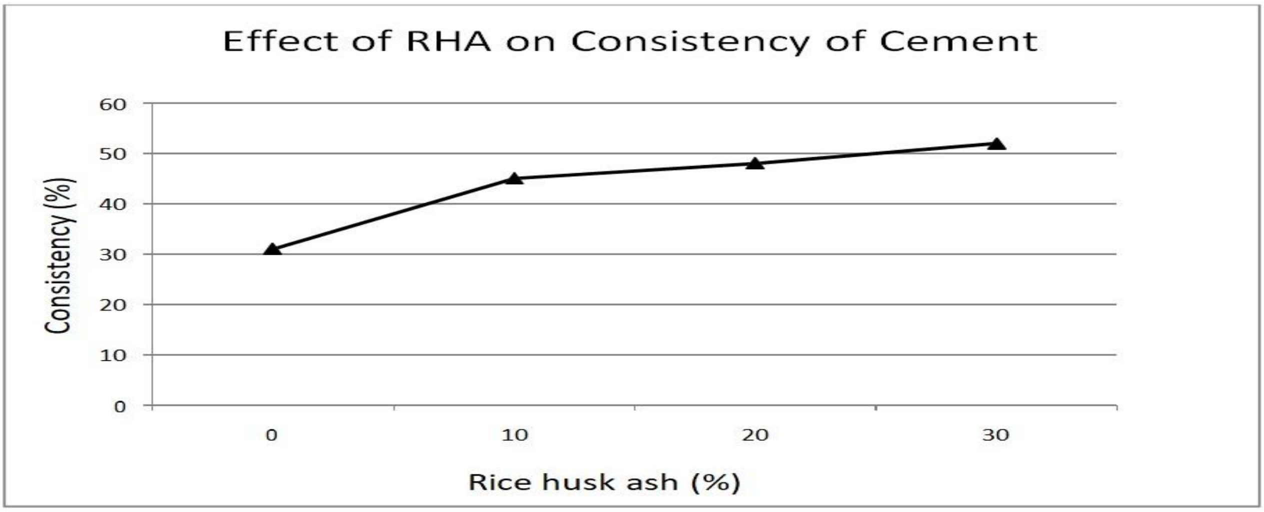

Fig. 4.7 Variation in Consistency of Cement with Different % of RHA

Table 4.8. Effect of RHA on Compressive Strength of Cement

% of Cement Replaced by RHA	**3 Days Strength (Mpa)**	**7 Days Strength (Mpa)**
0	11.176	24.31
20% (RHA I)	2.23	4.74
20% (RHA II)	3.65	7.45

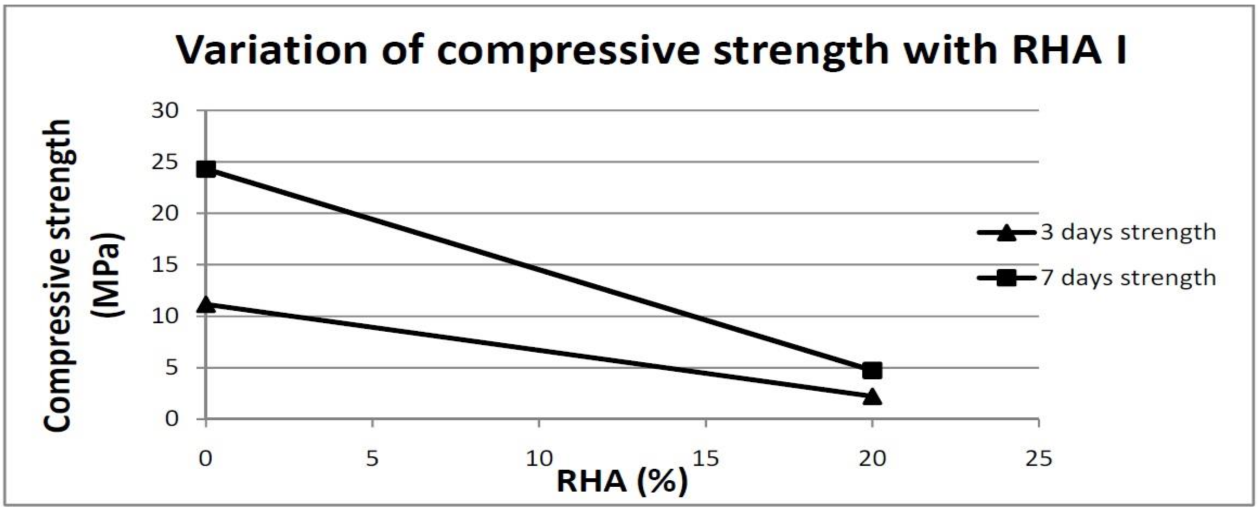

Fig. 4.8 Variation in Compressive Strength of Mortar with Use of RHA I

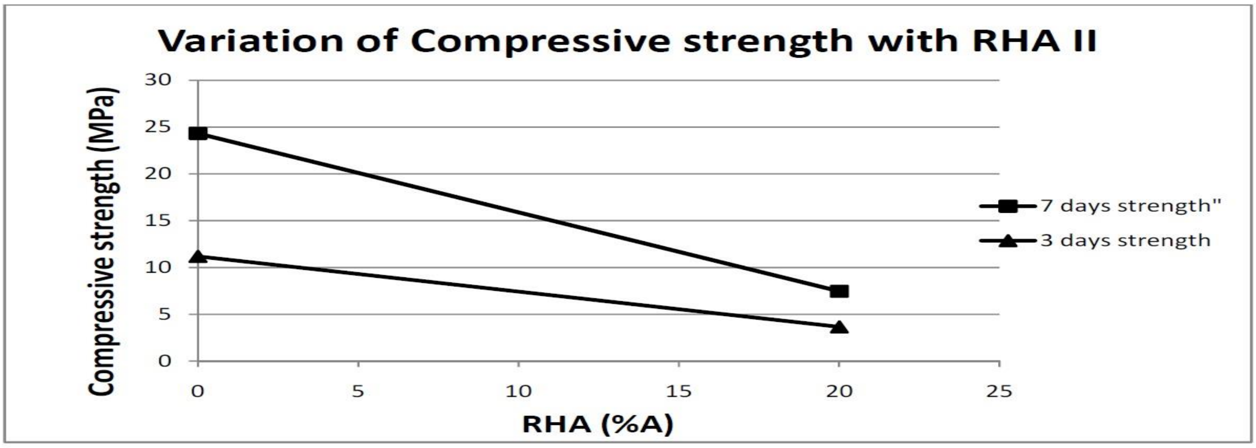

Fig. 4.9 Variation in Compressive Strength of Mortar with Use of RHA II

4.3.2. Discussion

It is observed here that the consistency percentage is increasing as the percentage of GGBS increases as a cement replacement, but the change is not so abrupt. But found that as we go on increasing the percentage of Rice husk ash the consistency percentage increases rapidly.

The variation of compressive strength of mortar mix with different proportion of GGBS partial replacement of cement is shown in fig. It was observed that 3 days and 7 days compressive strength reduces about 13% and 35% that is from 11.176 MPa to 9.66 MPa and 24.31 to 15.63 respectively, as GGBS percentage increases from 0 to 10%. If percentage of GGBS was further increased the compressive strength reduces greatly. Finally when the GGBS percentage increased to 40% the strength reduces by about 60% and 70% in 3 days and 7 days respectively of its initial values. So it was concluded that the use of GGBS especially in Portland slag cement leading to adverse effect on strength of mortar. Also use of Rice husk ash as a partial replacement of cement is not giving satisfactory strength. Although RHA II (white type) is giving better strength as compared to that of RHA I, still it was not of to the mark. Though RHA I having higher carbon percentage, it is not suitable for using as a pozzolanic material leads to give very poor strength and RHA II which was burnt more than as compared to RHA I, so here the carbon percentage was less and looking white in colour.

5.1 Conclusion

This study evaluated the effects of various pozzolanic materials—ground granulated blast furnace slag (GGBS), rice husk ash (RHA), and silica fume—on fiber reinforced concrete, focusing on their performance and suitability. The findings are summarized as follows:

- **GGBS:** As a cement replacement, GGBS increases consistency but does not enhance strength significantly, particularly when used in amounts exceeding 10% with Portland slag cement. GGBS passing through a 75-micron sieve did not achieve satisfactory mortar strength.

- **RHA:** The use of properly burned RHA improves consistency and mortar strength but does not provide satisfactory results compared to other materials.
- **Super Plasticizers:** These are effective in achieving a low water-to-cement ratio, essential for obtaining the desired strength in concrete.
- **Recron Fiber:** For Portland slag cement, the optimal compressive strength at 28 days is achieved with 0.2% Recron fiber. Both splitting tensile and flexural strengths also improve by about 5% with 0.2% fiber content, though increasing fiber beyond this percentage leads to a significant strength loss.
- **Silica Fume:** Increasing silica fume content enhances consistency. With Portland slag cement, combining 0.2% Recron fiber with 20% silica fume yields the best results, showing a 7% increase in compressive strength, a 12% increase in splitting tensile strength, and a 10% increase in flexural strength compared to normal concrete.
- **Ordinary Portland Cement (OPC):** OPC with silica fume shows improved compressive strength up to 20% more than normal concrete. However, the splitting tensile strength increases by 15% with 10% silica fume but decreases with higher percentages, while flexural strength declines significantly, up to 40% reduction at 30% silica fume.
- **Porosity and Capillary Absorption:** Both decrease with increasing silica fume content. At 20% silica fume, the capillary absorption coefficient drops by 70% compared to concrete without silica fume, and porosity reduces as silica fume content rises.

5.2 Scope of Further Work

Future research on pozzolanic materials and fibers in concrete is promising and can explore the following areas:
- **GGBS Fineness:** Investigate the required fineness and percentage of GGBS for optimal strength development.
- **RHA Utilization:** Explore the use of well-burned and finely ground RHA as a cement replacement to enhance strength.

- **Silica Fume Optimization:** Determine the optimal percentage of silica fume for superior strength and performance.

- **Advanced Fibers:** Research the effects of Recron fiber combined with finely ground silica fume to reduce costs while improving durability and strength for high-performance concrete.

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