IJDIAS International Journal of Discoveries and Innovations in Applied Sciences

| e-ISSN: 2792-3983 | www.openaccessjournals.eu | Volume: 3 Issue: 6

Evaluation of Pozzolana's Impact on Fibre Reinforced Concrete

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Abstract:

High-performance concrete is a specialized type of concrete that surpasses typical performance standards in terms of strength, flowability, and durability. While high-strength concrete is considered high-performance, the reverse is not always true. Achieving durability in concrete is challenging, and specifying high strength does not guarantee durability. To produce high-performance concrete, additional materials such as Ground Granulated Blast furnace Slag (GGBS), silica fume, Rice husk ash, Fly ash, and High Reactive Metakaolin can be used as partial replacements for cement. We conducted XRD tests on these materials to analyze their constituent variations. Maintaining an optimal water-cement ratio is crucial, and superplasticizers, water-reducing admixtures, play a vital role in achieving this. In our project, we tested materials like rice husk ash, ground granulated blast furnace slag, and silica fume to meet our desired requirements. We also performed X-ray diffraction tests on various pozzolanic materials to analyze their ingredient content. Synthetic fiber (Recron fiber) was incorporated at different percentages in the concrete mixture, and casting was carried out. Additionally, different percentages of silica fume were used as a cement replacement while keeping the fiber content constant. Two types of cement, Portland slag cement and ordinary Portland cement, were utilized. We prepared mortar, cubes, cylinders, and prisms for testing, including compressive, splitting, and flexural tests. Finally, porosity and permeability tests were conducted. Achieving the desired properties of high-performance concrete requires numerous trial mixes to select the optimal combination of materials.

Keywords: Concrete, Pozzolanic materials, Admixture, Fibre reinforcement.

1. INTRODUCTION

Concrete is a widely used construction material created by mixing cementitious materials, water, aggregate, and sometimes admixtures in specific proportions. When freshly mixed, it is known as plastic concrete, which can be shaped into various forms and eventually hardens into a solid mass called concrete. The hardening process occurs through a chemical reaction between water and cement, resulting in increased strength over time. During the first half of the previous century, concrete structures were constructed using ordinary Portland cement (OPC) and plain round bars of mild steel. The availability of concrete constituents and the belief that any combination of these materials would result in concrete led to a disregard for the importance of durability. Emphasis was placed on strength, while little thought was given to the long-term durability of structures. As a consequence, the durability of concrete and concrete structures has suffered, with a clear decline in quality.This decline can be attributed to several factors that gained momentum around 1970. Firstly, the use of high-strength rebars with surface deformations became common. Secondly, significant changes were made to the properties and constituents of cement. Lastly, engineers began incorporating supplementary cementitious materials and admixtures into concrete without adequate consideration. As a result, the journey towards self-destruction of concrete structures has accelerated, particularly in those constructed after 1970. It is crucial to address these issues and prioritize durability to ensure the longevity and reliability of concrete structures.

2. HIGH PERFORMANCE CONCRETE

The construction industry has recently adopted the term "High-Performance Concrete." According to the American Concrete Institute (ACI), high-performance concrete is defined as concrete that meets specific combinations of performance and uniformity requirements, which are not easily achieved using conventional constituents and standard practices of mixing, placing, and curing. The ACI commentary further explains that high-performance concrete is developed with particular characteristics in mind to suit a specific application and environment. Some examples of critical characteristics for an application include

- Ease of placement,
- Compaction without segregation,
- Early age strength,
- Long-term mechanical properties,
- Permeability,
- Density,
- Heat of hydration,
- Toughness,
- Volume stability,
- Ability to withstand severe environments for an extended period.

3. SALIENT FEATURES OF HIGH PERFORMANCE CONCRETE

- Improved dispersion of cement particles
- Enhanced compressive strength
- Reduced water-to-binder ratio
- Variety of grain sizes in the mixture
- Compact and dense cement paste
- Uniform and non-bleeding mixture
- Reduced presence of capillary pores
- Discontinuous pore structure
- Stronger bond between cement paste and aggregate at the interface
- Low content of free lime
- Controlled shrinkage within the material
- Effective confinement of aggregates
- Minimal micro-cracking until reaching approximately 65-70% of the specified compressive strength
- Smooth fracture surface in case of failure

4. LITERATURE REVIEW

Several research studies have focused on the development of high-performance concrete by incorporating different pozzolanic materials as cement replacements, along with the use of superplasticizers. Additionally, advancements have been made in the field of fiber reinforced concrete, combined with the utilization of pozzolanic materials. The following provides an overview of various studies conducted in these areas.

Aitcin[1] (1995) Significant advancements have been made in the application of high-performance concrete, particularly in terms of compressive strength. In the past few years, there has been a remarkable increase in the strength of concrete used in construction projects. For instance, in 1988, a concrete with a compressive strength of 120 MPa was successfully implemented on-site, whereas a strength of 40 MPa was traditionally considered indicative of high strength. The notable improvement in compressive strength can be attributed to recent technological developments, most notably the discovery of the remarkable dispersing properties of superplasticizers. These additives enable the production of flowing concretes using approximately the same amount of mixing water required for the hydration of all cement particles, or even less. This breakthrough has revolutionized the manufacturing of high-performance concrete, allowing for the creation of highly workable and strong mixtures.

Ajdukiewicz and Radomski[2] (2002) The research conducted in Poland on high-performance concrete (HPC) has focused on identifying and analyzing the main trends in this field. Several relevant investigations have been cited as examples of this research. The studies have addressed the fundamental engineering and economic challenges associated with the structural applications of HPC in Poland. Additionally, the needs and justifications for the increased utilization of this material have been briefly outlined.

Aitcin[3] (2003) The researcher investigated the durability properties of high-performance concrete, specifically focusing on the issues related to durability in ordinary concrete. The durability problems observed in ordinary concrete can be attributed to the harshness of the environment and the use of excessive water-to-binder ratios. In contrast, high-performance concrete, which typically maintains a water-to-binder ratio ranging from 0.30 to 0.40, tends to exhibit improved durability. This enhanced durability can be attributed to the lower porosity of high-performance concrete, as well as the development of a somewhat disconnected capillary and pore network resulting from the self-desiccation process.

Al-Khalaf and A. Yousif [4] (1984) The researchers conducted a study on the utilization of rice husk ash (RHA) in concrete. They examined the specific temperature range required to burn rice husk and obtain the desired pozzolanic product. Additionally, they investigated the effects of using rice husk ash as a partial replacement for cement on the compressive strength and volume changes of various concrete mixtures. The study revealed that a replacement of up to 40% of cement with rice husk ash resulted in no significant change in compressive strength when compared to the control mix without rice husk ash. To evaluate this, mortar cubes with dimensions of 50 mm were subjected to testing. In summary, the researchers explored the potential of rice husk ash as a partial cement replacement and demonstrated that it can be incorporated into concrete mixtures without compromising the compressive strength, as evidenced by their findings from the mortar cube tests.

Ismail and waliuddin[5] (1996) The researchers conducted a study on the impact of rice husk ash (RHA) on high-strength concrete (HSC). Specifically, they investigated the effect of incorporating RHA, which passed through 200 and 325 micron sieves, as a partial replacement for cement at levels ranging from 10% to 30%. The RHA used in the study was derived from the combustion of rice husk, an agricultural waste material that is readily abundant in developing countries.

De Sensale[6] (2006) The researchers conducted a study on the strength development of concrete using rice husk ash (RHA). The paper focuses on the compressive strength development of concrete over a period of 91 days. The study utilized two types of RHA: residual RHA obtained from a rice paddy milling industry in Uruguay and RHA produced through controlled incineration in the USA. The aim was to compare the effects of these two types of RHA. Different replacement percentages of cement by RHA were examined, specifically 10% and 20%. Additionally, three different water-to-cementitious material ratios (0.50, 0.40, and 0.32) were considered in the study. The researchers compared the results of the concrete samples containing RHA with those of concrete without RHA in terms of splitting tensile strength and air permeability.

Oner A and Akyuz S [7] (2007) The researchers conducted a study to determine the optimal level of ground granulated blast furnace slag (GGBS) for achieving the desired compressive strength in concrete. The study involved the partial replacement of cement with GGBS in all the concrete mixtures. A total of 32 mixtures were prepared and classified into four groups based on their binder content. To calculate the Bolomey and Feret coefficients (KB, KF), eight control mixtures were prepared with varying cement content of 175, 210, 245, and 280 kg/m3. GGBS was then added to the remaining mixtures according to the partial replacement method. In summary, the study aimed to determine the appropriate amount of GGBS required to achieve the desired compressive strength in concrete, and it involved the preparation of various mixtures categorized by their binder content. Control mixtures were used to calculate the Bolomey and Feret coefficients, and GGBS was added to the other mixtures to evaluate its effect on compressive strength.

Qian Jueshi and Shi Caijun [8] (2000) The researchers conducted a study on the utilization of industrial slags as high-performance cementing materials. They discovered that many industrial slags are either underutilized, not fully benefiting from their properties, or simply disposed of instead of being used effectively. These industrial slags possess cementitious or pozzolanic properties that make them suitable for use as partial or complete replacements for Portland cement. The researchers proposed using industrial slags as substitutes for Portland cement due to the high cost associated with Portland cement production, which involves significant energy consumption. Instead of being used as mere bulk aggregates or ballasts, industrial slags can be utilized to their full potential, thereby reducing reliance on costly Portland cement.

Ganesh Babu K and Sree Rama Kumar V[9] (2000) The researchers conducted a study on the effectiveness of ground granulated blast furnace slag (GGBS) in concrete. They highlighted the wide acceptance of utilizing supplementary cementitious materials in concrete composites due to the potential improvements they offer and the overall cost-effectiveness. The study introduced the concept of the "overall strength efficiency factor (k)" for evaluating the performance of pozzolanic materials. This factor encompasses two components: the "general efficiency factor (ke)" and the "percentage efficiency factor (kp)". Through evaluations, it was observed that the overall strength efficiency factor (k) ranged from 1.29 to 0.70 at 28 days, corresponding to percentage replacement levels of GGBS ranging from 10% to 80%. The research also revealed that the overall strength efficiency factor (k) could be calculated as the sum of a constant general efficiency factor (ke) of 0.9 at 28 days, along with a percentage efficiency factor (kp) that varied from +0.39 to -0.20, depending on the level of cement replacement studied (10% to 80%).

Collepardi[10] (1998) The researcher conducted an observation on the use of admixtures to enhance the placing characteristics of concrete. They noted that the placing characteristics of concrete can be improved by incorporating plasticizing and superplasticizing admixtures, without altering the water-cement ratio compared to plain concrete mixtures. Superplasticizers, the main ingredients used in these admixtures, are typically derived from sulfonated melamine formaldehyde

(SMF) condensate or naphthalene formaldehyde (SNF) condensate. However, the researcher proposed a new group of products based on acrylic polymers (AP). These AP-based polymers were found to be more effective than those based on SMF or SNF, as they allowed for a lower base water-cement ratio while maintaining a desired slump, and also resulted in reduced slump loss over time.

Papayianni, Tsohos, Mavria[11] (2005) The researchers conducted a study on the influence of superplasticizer type and mix design parameters on their performance in concrete mixtures. They emphasized the crucial role of superplasticizers in the development of high-strength and high-performance concrete. Superplasticizers are specific admixtures that are added to concrete in small amounts. Their incorporation leads to a notable improvement in the workability of the concrete mixture and allows for a reduction in the water-to-cement ratio or even the amount of cement required.

Zollo[12] (1997) The researchers provided an overview of the development of fiber reinforced concrete (FRC) over a span of 30 years. Their review focused on commonly used terminology and models that explain the mechanical behavior of FRC, aiming to provide a comprehensive understanding of the material's performance without delving into complex mathematical details. Their review was focused on presenting a proper and thorough analysis of FRC, rather than simply providing a historical account.

A. M. Alhozaimy, P. Soroushian & F. Mirza [13] (1996) The researchers conducted a study on the mechanical properties of concrete reinforced with polypropylene fibers and investigated the effects of pozzolanic materials. They carried out a series of experiments to gather comprehensive data on how collated fibrillated polypropylene fibers, at low volume fractions (below 0.3%), influence the compressive, flexural, and impact properties of concrete with various binder compositions. Through statistical analysis, they were able to draw reliable conclusions about the mechanical properties of polypropylene fiber reinforced concrete, as well as understand how the fibers interact with pozzolanic admixtures to determine these properties.

Potrzebowski[14] (1983) The researcher conducted a study on the application of the splitting test to steel fiber reinforced concrete. Cube specimens were prepared by cutting them from flexural test prisms, which were obtained from concrete slabs. The findings of the study indicate that the splitting tensile strength of the concrete is significantly affected by the number of fibers that intersect the failure plane and their orientation. It was observed that specimens subjected to loads perpendicular to the plane of vibration consistently provided reliable results, while specimens loaded parallel to the plane of vibration yielded lower results.

Bhanja and Sengupta[15] (2003) The researcher focused on developing a modified relationship to assess the strength of silica fume concrete. They conducted a comprehensive experiment to isolate the impact of silica fume on concrete strength. By analyzing the 28-day strength results of 32 concrete mixes with varying water-binder ratios and silica fume replacement percentages, simplified models were proposed to assist in proportioning concrete mixes that incorporate silica fume. These models provide practical guidance for designing concrete mixes with silica fume.

Bhanja and Sengupta[16] (2005) The researcher investigated the impact of silica fume on the tensile strength of concrete. They conducted extensive experiments, varying the water-binder ratios from 0.26 to 0.42 and the silica fume-binder ratios from 0.0 to 0.3. The compressive, flexural, and split tensile strengths were measured at 28 days for all the concrete mixes. The results showed that both the compressive and tensile strengths increased with the addition of silica fume. Interestingly, the optimal replacement percentage of silica fume was found to depend on the water-cementitious material (w/cm) ratio of the mix, rather than being a constant value.

Zain, Safiuddin and Mahmud[17] (2000) The researcher focused on developing high-performance concrete using silica fume with relatively high water-binder ratios. They specifically investigated water-binder ratios of 0.45 and 0.50. The test specimens were subjected to both air and water curing and exposed to temperatures ranging from 20°C to 50°C. In the laboratory, the compressive strength, modulus of elasticity, and initial surface absorption (ISA) of the hardened concrete were measured. The results showed that concrete cured under water conditions yielded the most favorable outcomes.

Bozkurt and Yagicioglu[18] (2010) The researcher conducted a study to examine the impact of incorporating pozzolanic materials and different curing methods on the mechanical properties and capillary water absorption of lightweight concrete. The study involved preparing specimens using volcanic pumice as an aggregate along with Portland cement, with the addition of 20% fly ash and 10% silica fume as replacements for cement. The specimens were subjected to curing durations of 3, 7, and 28 days. Compressive strength, tensile strength, and ultrasonic pulse velocity tests were performed to evaluate the concrete's properties.

Safiuddin and Hearn[19] (2005) The researcher conducted a study comparing three ASTM saturation techniques, namely cold-water saturation (CWS), boiling-water saturation (BWS), and vacuum saturation (VAS), for measuring the permeable porosity of concrete. Two ordinary concretes with water-cement ratios of 0.50 and 0.60 were prepared and tested at ages of 7 and 28 days. The permeable porosity was determined using the different saturation techniques, and the efficiency of each method was compared. Compressive strength tests were also conducted to support the permeable porosity results, and the workability of the concrete was assessed through the slump test. The findings of the study indicate that the vacuum saturation technique is the most effective method for measuring the permeable porosity of concrete, surpassing the cold-water and boiling-water saturation techniques.

5. DISCUSSION

- X-ray diffraction (XRD) analysis was carried out on RHA-I, RHA-2, GGBSS, and silica fume to determine their distinct chemical compositions as pozzolanic materials. The tests were conducted at an angle of 45 degrees with a 2θ value of 90 degrees, and various graphs were obtained. These graphs were then analyzed using the "X-pert High Score" software.
- Based on the XRD analysis, it was observed that GGBS exhibited a purely amorphous form, without any crystalline compounds. Additionally, the formation of $Mg2Al2O4$ (indexed as no. 74-1133) and $Mg2SiO4$ (indexed as no. 74-1680) compounds was identified. For RHA-I and RHA-II, obtained XRD graphs showed that RHA-I (black type) had some degree of crystallinity compared to RHA-II (white type). However, both forms of rice husk ash displayed the presence of low-temperature crystalline silica (indexed as no. 76-0939) according to the software analysis. The XRD graph of silica fume indicated that it was predominantly in an amorphous state, with the presence of $SiO2$ (indexed as no. 03-0865) and CaO (indexed as no. 80-2146) compounds.
- The results show that the consistency percentage gradually increases with an increasing percentage of GGBS as a replacement for cement, although the change is not significant. However, it was observed that the consistency percentage increases rapidly with a higher percentage of rice husk ash.
- The consistency of cement is influenced by its fineness. Silica fume, which has a finer particle size and larger surface area than cement, significantly increases the consistency when the percentage of silica fume is higher compared to plain cement. The study observed that the

normal consistency increases by approximately 45% when the percentage of silica fume increases from 0% to 30%.

- When using Recron fiber in Portland slag cement, it was observed that the compressive strength did not increase with fiber percentages ranging from 0.0% to 0.1%. However, as the fiber percentage was increased from 0.1% to 0.2%, the compressive strength showed improvement. Beyond 0.2% fiber content, the strength decreased. Among the different fiber compositions, the concrete with 0.2% fiber exhibited higher compressive strength at 28 days compared to other fiber compositions, but still lower than unreinforced concrete. In addition to fiber, silica fume was used as a partial replacement for cement. Various percentages of silica fume replacement (10%, 20%, and 30%) were combined with 0.2% Recron fiber. The concrete with 20% replacement of slag cement with silica fume showed the highest strength among the different replacement percentages. However, in the case of ordinary Portland cement, the strength was higher with 30% replacement of silica fume.
- The addition of silica fume in Recron fiber reinforced concrete has a significant impact on the capillary absorption coefficient. With a 10% silica fume content, the capillary absorption decreases by approximately two times compared to the concrete with 0.2% fiber only. When the silica fume content is increased to 20%, the capillary absorption decreases by about 70% compared to the same fiber content. However, with 30% silica fume content, there is a slight increase in the capillary absorption coefficient again.

6. CONCLUSIONS

- The use of ground granulated blast furnace slag (GGBS) as a cement replacement increases the consistency of the mortar. However, despite its fineness, GGBS passing the 75-micron sieve does not contribute to good strength in mortar. When using GGBS in Portland slag cement at replacement levels higher than 10%, there is a rapid reduction in strength.
- The incorporation of rice husk ash (RHA) as a cement replacement increases the consistency of the mortar. Properly burned RHA at controlled temperatures improves the strength of the mortar, but its use does not yield satisfactory strength results.
- The use of superplasticizers allows for the achievement of a low water-to-cement ratio, resulting in the desired strength in the concrete mixture.
- In the case of Portland slag cement with the addition of Recron fiber, the maximum 28-day compressive strength is obtained at a fiber content of 0.2%. The splitting tensile and flexural strengths also increase by approximately 5% with 0.2% fiber content compared to normal concrete. However, increasing the fiber percentage beyond 0.2% leads to a significant loss in strength.
- Increasing the replacement percentage of cement with silica fume results in an increase in consistency.
- When using Portland slag cement with a constant 0.2% Recron fiber content and varying silica fume percentages, the compressive, splitting tensile, and flexural strengths are significantly affected. Using 20% silica fume with 0.2% fiber content results in a 28-day compressive strength increase of 7% compared to concrete with 0.2% fiber only. The splitting tensile and flexural strengths increase even further, by approximately 12% and 10%, respectively, compared to normal concrete.
- Therefore, it is determined that the optimum combination for achieving the desired results is 0.2% Recron fiber and 20% silica fume.

- In the case of ordinary Portland cement (OPC), the compressive strength increases as the percentage of silica fume increases from 0% to 30% when combined with 0.2% Recron fiber. The resulting strength is approximately 20% higher than that of normal concrete with OPC.
- The splitting tensile strength initially increases by about 15% with 10% silica fume content and constant 0.2% Recron fiber, but then decreases with higher silica fume percentages. The flexural strength does not provide a clear indication and consistently decreases, with a reduction of approximately 40% as the silica fume percentage reaches 30%.
- Ordinary Portland cement yields better compressive strength results compared to Portland slag cement when silica fume and 0.2% Recron fiber are incorporated into the mix.
- The capillary absorption coefficient (k) decreases significantly as the percentage of silica fume increases at a constant fiber content of 0.2%. With 20% silica fume content, the k value progressively decreases, resulting in a 70% reduction compared to concrete without silica fume.
- The porosity value also decreases as the silica fume percentage increases from 0% to 30% in Recron fiber reinforced concrete.

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