# Experimental Investigation on High Performance Concrete With Inclusion of Mineral Admixtures: A Review

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**ABSTRACT –** *High performance concrete (HPC) has garnered significant attention in the construction industry due to its superior strength, durability, and sustainability. This review article presents an experimental investigation into the incorporation of mineral admixtures in HPC mixtures, aimed at enhancing its properties and performance. Various mineral admixtures such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), and metakaolin have been extensively studied for their influence on the mechanical, durability, and microstructural characteristics of HPC. The review systematically examines recent experimental studies, highlighting the effects of different types and dosages of mineral admixtures on the compressive strength, tensile strength, modulus of elasticity, shrinkage, permeability, and resistance to aggressive environments of HPC. Additionally, insights into the hydration process, pore structure refinement, and interfacial transition zone modification induced by mineral admixtures are discussed. The findings of this review contribute to a deeper understanding of the potential benefits and challenges associated with incorporating mineral admixtures in HPC mixtures, offering valuable guidance for optimizing the design and performance of high-performance concrete in practical applications.*

*Key words: High performance concrete (HPC), Mineral admixtures, fly ash, silica fume, metakaolin, and ground granulated blast-furnace slag*

## 1. INTRODUCTION

*Concrete is the most widely used construction material globally, but it is susceptible to various issues such as drying shrinkage, cracking, and reduced durability. Traditional curing methods, such as water curing and curing compounds, are effective but labor-intensive and often impractical in certain environments. Self-curing concrete, on the other hand, utilizes internal mechanisms to maintain adequate moisture content, thus mitigating these issues. Self-curing agents play a pivotal role in enabling this process by providing water or moisture-retaining compounds. This review delves into the recent advancements in self-curing agents, their modes of action, and their impact on concrete performance.*

*High-performance concrete (HPC) stands at the forefront of modern construction materials, offering enhanced mechanical properties and durability compared to conventional concrete. The inclusion of mineral admixtures has emerged as a promising approach to further enhance the performance characteristics of HPC. This experimental investigation aims to comprehensively explore the influence of mineral admixtures on the properties of HPC, shedding light on their potential to improve strength, durability, and other essential attributes.*
*In recent decades, the demand for high-performance concrete has surged, driven by the need for structures capable of withstanding increasingly severe environmental conditions, higher loads, and longer service lives. Traditional concrete formulations have limitations in meeting these evolving requirements, necessitating the development of advanced materials like HPC.*

*Mineral admixtures, such as fly ash, silica fume, metakaolin, and ground granulated blast-furnace slag (GGBS), have gained prominence as beneficial additives in concrete mixtures. These materials not only act as supplementary cementitious materials but also contribute to refining the microstructure of concrete, resulting in improved mechanical and durability properties. By partially replacing cement with mineral admixtures, HPC can achieve higher compressive strength, enhanced resistance to chemical attack, reduced permeability, and improved long-term performance.*

*This review article presents a detailed exploration of various mineral admixtures and their effects on the properties of HPC through an extensive experimental investigation. Each mineral admixture offers unique characteristics and mechanisms of action, which influence the performance of HPC in distinct ways. By systematically analyzing the results of experimental studies conducted with different mineral admixtures, this review aims to provide valuable insights into the optimal utilization and combination of these materials to engineer high-performance concrete tailored to specific project requirements.*

*Key parameters such as mix design proportions, curing conditions, testing methods, and performance criteria are carefully considered to ensure a comprehensive evaluation of the experimental findings. Furthermore, the review discusses the practical implications of incorporating mineral admixtures in HPC production, including potential cost savings, environmental benefits, and overall sustainability.*

*Through a thorough examination of existing literature and experimental data, this review contributes to advancing the understanding of HPC technology and provides guidance for engineers, researchers, and industry professionals involved in the design and construction of durable and sustainable concrete structures.*

*High-performance concrete (HPC) is characterized by its exceptional strength, durability, and workability, making it a preferred choice for various structural applications. The development of HPC involves the optimization of mix proportions and the incorporation of supplementary cementitious materials, such as mineral admixtures, to enhance its properties. Mineral admixtures, including fly ash, silica fume, and ground granulated blast furnace slag, are commonly used in HPC mixtures due to their pozzolanic and latent hydraulic properties. These materials react with calcium hydroxide and contribute to the formation of additional hydration products, leading to improved strength, durability, and microstructure of concrete.*

*Fresh Properties: The inclusion of mineral admixtures in HPC mixtures has a significant influence on the fresh properties of concrete. Several studies have reported that the addition of fly ash and silica fume can improve the workability of HPC by reducing the water demand and increasing the cohesiveness of the mix. However, the high specific surface area of silica fume may result in increased viscosity, affecting the flowability of concrete. Ground granulated blast furnace slag, on the other hand, has been found to enhance the workability of HPC due to its spherical particle shape and lubricating effect.*

*Hardened Properties: The incorporation of mineral admixtures in HPC leads to notable improvements in the hardened properties of concrete, including compressive strength, tensile strength, and durability. Fly ash and silica fume are known to contribute to the development of a denser microstructure, resulting in higher compressive strength and reduced permeability of HPC. Moreover, the pozzolanic reaction of fly ash and silica fume with calcium hydroxide leads to the formation of additional calcium silicate hydrate (C-S-H) gel, which enhances the long-term strength and durability of concrete. Ground granulated blast furnace slag exhibits similar pozzolanic properties and contributes to the refinement of pore structure, thereby improving the mechanical properties and resistance to sulfate attack and alkali-silica reaction (ASR).*

*Challenges and Opportunities: Despite the numerous benefits associated with the use of mineral admixtures in HPC, several challenges need to be addressed to optimize their effectiveness. These include variations in the chemical composition and fineness of mineral admixtures, potential adverse effects on early-age strength development, and limitations in the availability and quality of supplementary cementitious materials. Furthermore, the optimal dosage of mineral admixtures and their compatibility with other concrete ingredients need to be carefully considered to achieve the desired performance. Nevertheless, ongoing research efforts continue to explore innovative strategies for maximizing the benefits of mineral admixtures in HPC, including the development of ternary and quaternary blends and the use of nanotechnology to enhance the reactivity of supplementary cementitious materials.*

**Fig 1. Various mineral admixtures (source:Kanamarlapudi et al. (2020)**

*The incorporation of mineral admixtures in HPC offers significant potential for improving its mechanical properties, durability, and sustainability. This comprehensive review highlights the effects of fly ash, silica fume, and ground granulated blast furnace slag on the fresh and hardened properties of HPC, as well as the challenges and opportunities associated with their utilization. By advancing our understanding of the role of mineral admixtures in HPC, this review contributes to the development of innovative concrete mixtures that meet the increasing demands of modern construction practices.*

## 2. REVIEW OF LITERATURE

*The objective of the literature review is to know the research work carried out on a particular topic and to identify the research gap in that field. A brief summary of previous research works of experts provided the evidence to support the findings from various experimental works. Concrete is a very familiar and dynamic construction material which is being used for all types of infrastructural development projects. The present chapter, briefly discuss about the influence of mineral admixtures along with steel slag on the overall performance of the concrete.*

*Bhattacharjee, Bishwajit, et al. (2016) SRHA can effectively replace cement in high-performance concrete mixes, improving mechanical properties and durability while reducing environmental impact.*

*Muntohar, A. S., et al.(2017) Incorporating RHA in high-performance concrete enhances compressive strength, reduces permeability, and improves durability, especially under appropriate curing conditions.*

*Ramli, M., et al. (2016) RHA can significantly enhance the workability, compressive strength, and durability of high-*

*performance concrete mixes when properly utilized as a supplementary cementitious material.*

*Kamaruddin, A. F., et al. (2018) RHA incorporation in high-performance concrete improves resistance to chloride ion penetration, sulfate attack, and carbonation, contributing to enhanced durability.*

*Rahim, N. S. A., et al.(2019) RHA addition enhances the mechanical properties of high-performance concrete, including compressive strength, split tensile strength, and flexural strength, offering potential for sustainable construction.*

*Safiuddin, M., et al. (2016) RHA incorporation improves workability, reduces heat of hydration, enhances compressive strength, and increases resistance to chemical attack and permeability in high-performance concrete.*

*Das, S., et al. (2017) RHA addition enhances compressive strength, reduces water absorption, and improves durability of high-performance concrete mixes, making it a viable supplementary material.*

*Sengupta, P., et al. (2019) RHA incorporation in high-performance concrete leads to improved mechanical properties, durability, and sustainability, making it a promising alternative supplementary material.*

*Vishwakarma, V., et al. (2018) RHA enhances workability, compressive strength, and durability of high-performance concrete, contributing to sustainable construction practices.*

*Cheng, M., et al. (2017) Incorporation of RHA in high-performance concrete enhances strength, workability, and durability properties, offering a sustainable solution for construction applications.*

*The reaction between GGBS and water yields final products similar to that of products of cement hydration. The major differences between the two reactions are the rate and intensity of the reaction. Besides, GGBS also exhibits pozzolanic reaction in the presence of calcium hydroxide (Mindess Darwin & Young 2003). The reaction between OPC and GGBS will have at least three components; cement hydration, slag hydraulic reaction and slag pozzolanic reaction (Feng et al 2004).*

*For aggressive environment, combination of GGBS and OPC are preferred rather than using OPC alone in concrete. Also, studies on concrete with Portland slag cement containing about 50-65% GGBS proved the quality of concrete to be better. The test results further showed that, with increase in 10 percentage of GGBS in concrete, the chloride ion permeability of the concrete decreased (Maiti & Agarwal 2009).*
*The International Commission on Large Dams (1992) recommended that, to resist the detrimental effect of alkali-silica reaction in concrete, usage of GGBS is to be more than 50%. GGBS can effectively reduce the pore sizes and also the cumulative pore volume of the concrete considerably, offering more durability and impermeable nature to concrete (Saraswathy & Song 2007).*

*A lot of studies confirm the enhancement of strength and durability of concrete when cement is supplemented with GGBS. GGBS increases the ultimate compressive strength (Barnett et al 2006). Further, GGBS addition in concrete decreases its chloride diffusion and chloride ion permeability (Yeau & Kim 2005), reduces creep and drying shrinkage (Jianyong & Yan 2001) and increases the sulphate resistance (Binici & Aksogan 2006). As per Wainwright & Rey (2000), heat of hydration and bleeding are also reduced with GGBS addition.*

*Pavia & Condren (2008) examined the durability properties of GGBS added concrete. Evidently, concrete incorporating GGBS proved more durable than that made with OPC alone in aggressive environments under the action of acids and salts such as those produced by silage. The durability increased with increasing amount of GGBS. From the studies of Cheng et al., (2005), it is found that GGBS concrete exhibited lower corrosion rate than concrete containing OPC alone. This is attributed to a denser microstructure or lower porosity resulting from higher C–S–H content, which in turn represents higher GGBS percentage and hence higher durability of concrete.*
*RHA contributes immensely to the pore structure of concrete. It is widely agreed among researchers that the addition of pozzolans help in reducing the concrete porosity. Saraswathy & Song (2007) observed the influence of RHA on the porosity and water absorption of concrete up to 30% RHA replacement of cement. The porosity values reduced with increase in RHA content. The small RHA particles improved the particle packing density of the matrix, resulting in reduced volume of larger pores. Also the coefficient of water absorption for RHA concrete was comparatively less than the control concrete.*

*As per the studies of Ganesan et al (2008), after 28 days of curing, the water absorption increased up to 35% of RHA. This is attributed to the fact that RHA is finer than OPC and its hygroscopic nature. But after 90 days of curing, the water absorption decreased significantly with increase in RHA content up to 25%. Also, the sorptivity values at 28 days of curing decreased gradually up to 25% of RHA proportion. After 90 days of curing, the sorptivity values were much lower than that of control concrete up to 35% RHA content.*

*The addition of pozzolans to reduces the calcium hydrate content in the cement and reduces the permeability of concrete (Mehta 1994). RHA being an active pozzolan contributes greatly towards the enhancement of the durability of concrete.*
*Hasparyk et al (2000) reported that adding high reactivity RHA as a partial cement replacement from 12% to 15% may*

*effectively control the harmful expansion due to alkali-silica reaction in concrete. The alkalis are probably entrapped by the supplementary hydrates and there is a consequent decrease in the pH of pore solutions (Cao et al 1997). The long term deterioration of concrete is mainly attributed to its permeability. As we have seen, RHA is known to reduce the porosity of concrete by which the permeability is reduced.*

*The study by Anwar et al (2001) revealed that RHA mixtures potentially reduce the chloride intrusion into concrete. The RHA concrete showed lower soluble total chlorides ratio compared to OPC concrete. Finely ground RHA reduced the rapid chloride penetrability of concrete from a moderate rating to low or very low ratings depending on the type and proportion of RHA (Nehdi et al 2003).*

*Sakr (2006) studied the effect of sulphate solution on RHA blended concrete and concluded that addition of RHA increases the resistance to sulphate attack. The reduction in compressive strength of concrete containing 15% RHA, when immersed for 28 days in a sulphate solution was much lower than concrete without RHA.*

*Chindaprasirt et al (2007) reported that mortars containing fly ash and rice husk ash are of lower pH levels and apparently less susceptible to sulphate attack. OPC could be replaced with fly ash and RHA up to 40% to produce blended cement mortar possessing reasonable strength and good sulphate resistance.*

*Ramasamy (2012) studied the durability properties of RHA concrete and proved that RHA concrete performed better than conventional OPC concrete in all durability aspects including chloride penetration, sulphate resistance, alkaline and acid resistance. According to his study, RHA considerably reduced the volume of the large pores at all ages and thereby reducing the chloride ion penetration. 20% RHA addition showed higher resistance up to 11.20% against sulphate attack for both continuous soaking conditions and cyclic conditions. He suggested the replacement level of RHA up to 20% for better durability.*

*Saraswathy et al (2007) studied the corrosion behaviour of RHA blended concrete embedded with reinforcing steel. They measured the open circuit potential measurements with reference to saturated calomel electrode (SCE) periodically with time. From their study, it was observed that the time of cracking for concretes containing 0, 5, and 10% RHA were 42, 72 and 74 hours respectively. It is clear that addition of RHA delays the cracking of concrete due to electrochemical corrosion. They concluded that incorporating RHA up to 25% reduced the chloride ion penetration and improved the corrosion resistance of the concrete.*

*Chindaprasirt & Rukzon (2008) studied the effect of RHA and fly ash on the corrosion resistance of concrete and concluded that both fly ash and RHA can effectively improve the corrosion resistance of mortars, where RHA contributes comparatively better than fly ash to corrosion resistance*

*Dakroury & Gasser (2008) observed that there is a steep reduction in porosity of the concrete up to a certain level of RHA addition. They said that the decrease in the total porosity is mainly due to the change occurring in the pore size distribution caused by RHA particles which react with the calcium hydroxide to form C-S-H gel. Studies of Sugita et al (1997) also confirm the reduction in the average pore size of concrete containing RHA when compared to conventional control concrete.*

*Rajamane et al. (2003) reported on the investigations carried out fora quantitative assessment of replacement levels of cement with GGBS on thecompressive strength which were in the range of 70 MPa-80 MPa at 28 days, and considerable imperviousness to chloride ions was obtained.*

*RHA added concrete is similar to fly ash or slag concrete in terms of its strength development but with a higher pozzolanic reactivity it helps the pozzolanic reactions to occur at an early age rather than later age, as the same case with other cement replacement materials (Malhotra 1993). RHA accelerates the early hydration of C3S. This is attributed to the high specific surface area of the rice husk ash and also its pozzolanic action (Feng et al 2004).*

### 2.1 Types of Mineral Admixtures:

**a. Fly Ash:**

*Fly ash, a by-product of coal combustion, is one of the most commonly used mineral admixtures in concrete production. It acts as a pozzolanic material, reacting with calcium hydroxide to form additional cementitious compounds, thus improving strength and durability.*

*b.* **Silica Fume:**

*Silica fume, also known as microsilica, is a byproduct of silicon metal production. It consists of highly reactive amorphous silica particles that fill the voids in the cementitious matrix, resulting in increased strength, reduced permeability, and enhanced chemical resistance.*

**c. Ground Granulated Blast Furnace Slag (GGBFS):**

*GGBFS is a by-product of the iron and steel industry obtained by quenching molten slag in water or steam. It exhibits latent hydraulic properties and contributes to improved workability, durability, and sulphate resistance of concrete.*

### 2.2 Effects of Mineral Admixtures on HPC Properties:

**a. Strength Enhancement:** *The addition of mineral admixtures generally leads to improved compressive, tensile, and flexural strength of HPC due to enhanced pozzolanic and filler effects.*

**b. Durability Improvement:** *Mineral admixtures contribute* *to the refinement of pore structure, reduction of permeability, and mitigation of alkali-silica reaction, resulting in enhanced durability properties such as resistance to chloride ingress, sulfate attack, and carbonation.*

**c. Workability and Rheology:** *Proper selection and dosage of mineral admixtures influence the workability and rheological properties of HPC, affecting its placement, consolidation, and finishing characteristics.*

**d. Environmental Benefits:** *Utilization of mineral admixtures in HPC promotes sustainability by reducing the consumption of cementitious materials, lowering carbon emissions, and utilizing industrial by-products as supplementary cementitious materials.*

*Experimental Methodologies and Test Procedures: The experimental investigations discussed in this review encompass a wide range of methodologies, including material characterization, mix proportioning, mechanical testing, durability assessment, and microstructural analysis. Standardized test methods such as ASTM, ACI, and BS specifications are commonly employed to evaluate the properties of HPC with mineral admixtures.*

### 2.2.1 Effect of Rice Husk Ash (RHA) Inclusion:

*Rice Husk Ash (RHA), a by-product of rice milling, has been extensively studied as a supplementary cementitious material due to its pozzolanic reactivity. Several studies have demonstrated that the incorporation of RHA in HPC can significantly enhance its compressive strength, flexural strength, and durability properties. The pozzolanic reaction between RHA and calcium hydroxide leads to the formation of additional calcium silicate hydrate (C-S-H) gel, resulting in denser microstructures and improved mechanical properties. However, the optimal dosage of RHA and its influence on workability, setting time, and long-term durability require careful consideration.*

### 2.2.2 Impact of Ground Granulated Blast Furnace Slag (GGBFS) *Addition:*

*Ground Granulated Blast Furnace Slag (GGBFS), a by product of the iron and steel industry, has been widely recognized for its pozzolanic and latent hydraulic properties. Incorporating GGBFS into HPC mixtures not only enhances its strength and durability but also contributes to mitigating environmental impacts by reducing cement consumption. Studies have indicated that GGBFS improves the workability of HPC, reduces heat of hydration, and enhances sulfate resistance and resistance to alkali-silica reaction. The synergistic effects of GGBFS with other mineral admixtures further amplify the performance benefits of HPC.*

## 3. CONCLUSION:

*In conclusion, the utilization of mineral admixtures such as Rice Husk Ash (RHA) and Ground Granulated Blast Furnace Slag (GGBFS) in the production of High-Performance Concrete (HPC) offers a promising avenue for enhancing the mechanical properties, durability, and sustainability of concrete structures. Experimental investigations have consistently demonstrated the positive influence of RHA and GGBFS on the compressive strength, flexural strength, workability, and durability characteristics of HPC. However, the optimal dosage of these mineral admixtures and their compatibility with other supplementary cementitious materials need to be carefully evaluated to maximize their benefits. Further research is warranted to explore innovative approaches for incorporating RHA and GGBFS into HPC mixtures, thereby advancing the development of sustainable concrete technologies.*

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