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# Improvement the Concrete Fire Resistance by Using By-Product Materials: A Review

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### ABSTRACT

The utilization of lime within the cement manufacturing procedure yields a considerable quantity of carbon dioxide emissions, thereby contributing to the phenomenon of the greenhouse effect and the subsequent escalation of global warming. To mitigate the emissions, it is imperative to employ diverse materials during the manufacturing process. Granulated blast furnace slag, a finely ground aggregate derived from the byproduct of blast furnace operations, has found significant application in the realm of concrete production. This material, obtained from the blast furnaces, has proven to be highly advantageous in enhancing the properties of concrete. This study aims to investigate the utilization of Ground Granulated Blast Furnace Slag (GGBS) as a supplementary material in concrete, serving as a partial replacement for cement. The utilization of ground grainy blast furnace slag and RHA has been found to enhance the properties of concrete and can be incorporated in concrete production without causing any adverse impact on the surrounding environment. This makes it a sustainable and eco-friendly solution. The strength degradation of high strength concrete, both during and post-fire exposure, may exhibit dissimilar behavior when compared to that of conventional strength concrete. The primary objective of this review is to examine the alterations in concrete properties after fire exposure, while also investigating the potential of GGBS and RHA in enhancing the fire resistance of concrete.


## 1. INTRODUCTION

In most typical scenarios, concretes made with Ordinary Portland Cement (OPC) typically offer sufficient fire resistance. Nevertheless, it is worth noting that the strength of Ordinary Portland Cement (OPC) concrete tends to diminish when exposed to high temps as a result of both chemical and physical alterations [1]. Moreover, it should be noted that traditional concrete is susceptible to spalling when exposed to fire. This spalling phenomenon results in the gradual and sequential

removal of concrete cover, which can ultimately expose the primary reinforcements embedded within the concrete to the fire hazard [2]. Consequently, attempts were undertaken to ascertain an alternative adhesive that exhibits commendable fire resistance, encompassing both the ability to withstand strength deterioration under high temps and resistance to spalling. The concept of fire resistance can be described as the structural member's capacity to endure fire exposure without compromising its load-bearing

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capabilities or its ability to serve as a fire containment barrier [3]. The fire resistance of concrete can be characterized as the enduring compressive strength of the concrete after being subjected to elevated temps for a designated period. Based on the analysis, it is possible to identify two distinct zones. In civil engineering, it is common to refer to the area with a one-hour fire resistance as the "normal zone" and the area with a two-hour fire resistance as the "safe zone." In the realm of civil engineering, it is imperative to meticulously craft structures in a manner that ensures the utmost safety in the event of a fire. This entails guaranteeing the preservation of the structure's integrity while simultaneously allowing ample time for occupants to evacuate or receive assistance. The comprehension of the structural response of actual fire incidents within buildings and its alignment with empirical and established fire assessments has witnessed notable advancements in recent times. This document encompasses the prevalent secondary outputs that are employed as alternatives for the primary constituents of concrete. A comprehensive evaluation is presented regarding the potential utilization of recyclable industrial and agricultural waste materials in concrete. Additionally, the merits and demerits of each potential candidate are discussed. Upon careful examination of the by-products, this scholarly document effectively demonstrates the suitability of alternative materials for the three primary constituents of conventional concrete. Furthermore, it provides valuable insights into the optimal proportions for substituting each ingredient. In the realm of civil engineering, it is common practice to incorporate various pozzolanic ashes such as fly ash (FA) [4], RHA [5], and silica fume (SF) [6] as substitutes for cement. Additionally, recycled coarse aggregates serve as a viable alternative to the conventional virgin coarse aggregates. Ground granular blast-furnace slag (GGBFS) [7], waste glass (WG) [8], plastic (P), and various agricultural and aquacultural by-products can be utilized as substitutes for cement and/or aggregates in civil engineering applications. In the study

conducted by [9], an investigation was carried out to analyze the impact of varying temps on specific mechanical properties of concrete. Three temp levels, namely 400, 500, and 700 degrees centigrade, were deliberately selected for analysis. These temp levels were subjected to four distinct exposure durations, namely 30 minutes, 1 hour, 1 hour 30 minutes, and 2 hours, without any external loading during the heating process. The specimens underwent a uniform heating and cooling process and were subsequently subjected to temp exposure at three different time intervals: 30 days, 60 days, and 90 days. It has been determined that the concrete exhibits fire resistance levels ranging from 70% to 85% when subjected to a temp of 400 degrees centigrade. Similarly, at 500 degrees centigrade, the fire resistance ranges from 59% to 78%, and at 700 degrees centigrade, it ranges from 43% to 62%. This finding was additionally corroborated by [10] conducted a study on the impact of elevated temps on various mechanical properties of high strength concrete. The specimens underwent exposure to varying temps for durations of one hour, two hours, and four hours, without the application of any external loads during the exposure period. Following the heating process, the specimens were subsequently subjected to a cooling phase and subsequently underwent testing either after a period of one day or one month. Additionally, it was determined that the concrete exhibited fire resistance within the range of 90% to 106% at a temp of 100 degrees centigrade, 72% to 103% at 300 degrees centigrade, 55% to 87% at 500 degrees centigrade, and 22% to 66% within the temp range of 600 to 800 degrees centigrade. The research findings indicate that the duration of exposure exceeding one hour has a notable impact on the residual compressive strength of concrete. Nevertheless, it is worth noting that this impact becomes less pronounced as the temp level rises. Khoury [11] conducted a comprehensive investigation on the impact of fire on both concrete and concrete structures. It has been observed that at temps below 200 degrees centigrade, there is a loss of evaporable water. As the temp rises between 200

and 400 degrees centigrade, the siliceous aggregates begin to weaken. Further heating between 400 and 600 degrees centigrade leads to the decomposition of  $\text{Ca(OH)}_2$ . At temps ranging from 600 to 800 degrees centigrade, the C- S-H undergoes decomposition, resulting in a loss of load bearing capacity. At temps exceeding 1000 degrees centigrade, the concrete undergoes a phase transition, transitioning from its solid state to a liquid state. In accordance with the specified standards [12], it is imperative to consider the intended purpose of a structure when selecting the appropriate materials for both regular and high strength concrete. These materials must meet specific fire resistance criteria. According to the findings of [13], the assessment of retained compressive strength can be primarily deduced by considering the combined effects of color and temp variations observed during a fire event.

## 2. EFFECT OF FIRE EXPOSURE ON CONCRETE

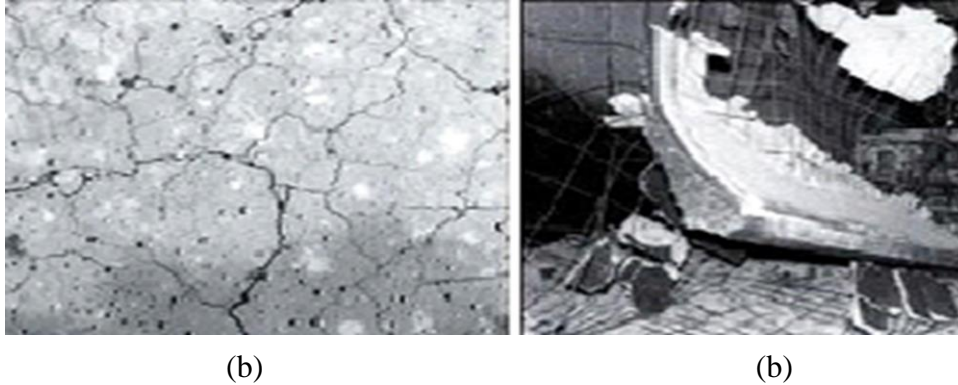


Fig.1. a) Surface cracking after subjected to high temps; b) Structural failure [14].

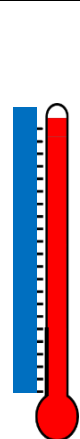
## 3. PHYSIOCHEMICAL TRANSFORMATIONS OF CONCRETE UNDER FIRE EXPOSURE

In accordance with the findings of [11], a comprehensive analysis was conducted to evaluate the structural response of reinforced concrete under fire conditions. The outcomes of this study, as depicted in Fig. 2, provide valuable insights into the extent of impact experienced by reinforced

Concrete, a composite material, primarily comprises mineral aggregates that are firmly held together by a matrix of hydrated cement paste. The matrix exhibits a notable degree of porosity and harbors a considerable quantity of unbound water, unless subjected to artificial drying methods. In the presence of elevated temps, concrete experiences alterations in its chemical composition, physical arrangement, and moisture levels. The alterations predominantly manifest within the solidified cementitious matrix under unsealed circumstances. The alterations in the physical and mechanical characteristics of concrete, which are linked to an elevation in temp, manifest such modifications. The manifestation of concrete degradation under elevated temps can be observed in two distinct manners [14]:

1. Localized material damage (cracks), as seen in Fig. 1a.
2. The components fail due to global damage, as seen in Fig. 1b.

concrete elements throughout fire events. In the context of concrete members, it is observed that with each degree of heating experienced over a 1hr exposure period, there is a corresponding increase in the degree of deterioration. This deterioration is primarily attributed to the combined impact of emitted gases from burning materials, as well as the impact of flames and elevated air temps.

Temp (°C)		The events
1000		
900-700		Air temps in fires rarely exceed this level, but flame temp can rise to 1200 degree centigrade.
600		Above this temp, concrete is not functioning at its full structural capacity.
550-600		Cement-based materials experience considerable creep and lose their load bearing capacity.
400-300		Strength loss starts, but only the first few centimeters of concrete exposed to a fire will get any hotter than this, and internally the temp is well below this.
250-420		Some spalling may take place, with pieces of concrete breaking away from the surface.

**Fig.2.** Concrete in the fire, the physiochemical process for the 1 hr period reproduced from [11].

In the study conducted by [15], it was observed that an elevation in temp leads to various physiochemical transformations. At approximately 100 degrees centigrade, the observed reduction in mass signifies the occurrence of water vaporization from the micro pores. The process of dehydration of ettringite ( $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 31\text{H}_2\text{O}$ ) is observed within the temp range of 50 to 110 degrees centigrade. Within the specified temp range of 100-300 degrees centigrade, the process of evaporation occurs, leading to the removal of both free and bound water present in the C-S-H gel. At temps exceeding 300 degrees centigrade, a decrease in structural integrity within the range of 15-40% is observed. At a temp of 550 degrees centigrade, it is observed that the strength of the material decreases within the range of 55-70%. Additionally, the process of dihydroxylation of  $\text{Ca}(\text{OH})_2$  occurs. The process of dehydration in calcium silicate hydrated and the subsequent thermal expansion contribute to the elevation of internal stresses and the formation of micro cracks, both of which are initiated by the cementing material. The process of fire suppression typically involves the utilization of water, which effectively combats and mitigates the flames. Additionally, it is worth noting that the transformation of calcium oxide ( $\text{CaO}$ ) into calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) can induce structural deterioration, leading to the development of cracks and the subsequent crumbling of concrete materials. The

dehydration process of calcium silicate hydrates was observed to occur at a temp of 700 degrees centigrade.

The structural modifications induced by elevated temps become increasingly pronounced as the thermal threshold exceeds 500 degrees centigrade. At this temp level, it is important to note that the alterations observed in concrete are predominantly deemed irreversible in nature. The C-S-H gel, a crucial component responsible for providing strength to cement paste, undergoes additional decomposition beyond the temp threshold of 600 degrees centigrade. At a temp of 800 degrees centigrade, concrete typically undergoes a process of disintegration, wherein its structural integrity is compromised, thereby exposing its remaining compressive strength, as observed by [15].

#### 4. RICE HUSK ASH (RHA)

Rice husks, being the resilient outer shells of rice grains, undergo separation from the grains as part of the milling procedure. Rice husk, a readily accessible byproduct found in rice-producing nations, boasts a substantial organic carbon content ranging from 30% to 50%. During the customary milling procedure, the extraction of husks from the unprocessed grain occurs, thereby exposing intact brown rice [16]. Subsequent milling operations are then conducted to eliminate the outer bran layer, resulting in the production of white rice. The current estimated global rice production stands at

a substantial 700 million tons [17]. The weight of rice husk is approximately 20% of the total weight of rice. Its composition can be described as follows: cellulose comprises around 50% of its composition, lignin makes up 25%-30%, silica accounts for 15%-20%, and moisture content ranges from 10% to 15%. The bulk density of rice husk is characterized by its relatively low value, typically falling within the range of 90 to 150 kilograms per cubic meter (kg/m<sup>3</sup>) [18].

RHA is the resultant residue derived from the rice milling industry. Throughout the developmental stages of the rice plant, it actively engages in the process of silica uptake from the surrounding soil, effectively incorporating this essential element into its anatomical framework [19]. The ash is acquired through the combustion of rice husk at temps ranging from 500 to 800 degrees centigrade, resulting in the formation of a non-crystalline amorphous RHA [20].

The disposal of rice husk presents a significant environmental concern due to the inherent resistance of its siliceous content to natural decomposition [21], [22]. Nevertheless, the combustion process of rice husk results in the production of ash containing approximately 20-30% amorphous silica, a substance known to enhance the characteristics of both fresh and hardened concrete [5], [23], [24]. The combustion technique and manufacturing procedure are significant factors that impact the characteristics of cement blended with RHA. In rural areas, it is common practice to engage in open heap burning of rice husk at temps ranging from 300 to 400 degrees centigrade. This method is widely adopted in various developing nations as a cost-effective means of waste disposal for rice husk [25], [26]. The airborne nature of RHA particles, owing to their relatively low density, results in the deposition of particulate matter in the surrounding environment. Additionally, it is important to note that unregulated combustion at temps below 500 degrees centigrade can lead to inadequate ignition, resulting in the presence of uncombusted carbon and diminished pozzolanic

effectiveness of the resulting ash. In their study, Al-Khalaf and Yousif [27] conducted an investigation on the development of compressive strength in cement mortar. They explored the potential of replacing 27% of the weight of cement with RHA, which was produced at various temps ranging from 450 to 850 degrees centigrade. The predetermined duration of combustion was uniformly set at 2 hours across all the assessed production temps. It is intriguing to observe that while the pozzolanicity of ash exhibited an increase with the rise in production temp, there was no discernible variation in the strength of the mortar blended with RHA, regardless of the change in production temp. The potential cause for the observed phenomenon could be attributed to the presence of elemental carbon within the low temp ash. This carbon content is believed to contribute to the enhancement of the mechanical strength of cement composites, as it imparts a toughening effect [28]. However, it should be noted that the pozzolanic reactivity of the ash may be relatively low [29].

Upon the combustion of rice husk, a notable quantity of ash is generated, comprising approximately 90% silica content, as reported by Swamy [30]. The exceptional pozzolanic properties of this material can be attributed to its notable characteristics, including a significant surface area and a substantial silica content. In the study conducted by Bahrami et al. [31], a comprehensive investigation was carried out to extract crystalline and amorphous silica powder from rice husk. The extraction process involved the utilization of water as a liquid medium. It has been determined that monoliths composed of crystalline RHA exhibit superior mechanical strength, whereas monoliths composed of amorphous RHA possess a higher surface area. The utilization of RHA has facilitated the enhancement of concrete's hardened properties and durability, as demonstrated by Safiuddin et al. [32]. The incorporation of RHA in concrete has shown promising results in reducing porosity and enhancing the compressive, tensile, and

flexural strengths of the material. The enhancement of corrosion resistance and freeze-thaw durability in concrete was observed as well [33]. According to the findings of Givi et al. [16], it was observed that the incorporation of RHA in concrete and mortars resulted in favorable workability characteristics. The utilization of RHA was employed in the production of high-strength concrete, as demonstrated by Ismaila and Waliuddin [34]. In a separate investigation conducted by Zhang and Malhotra [35], the utilization of RHA as a cementing material was explored in the production of high-performance concrete. According to Nehdi et al. [36], it has been observed that RHA possesses the potential to be utilized in the production of self-consolidating concrete with normal strength.

## **5. FIRE PERFORMANCE OF GGBFS CONCRETE**

Blast furnace slag (BFS), as per the definition provided by ASTM C 125-16 (2016), refers to the non-metallic byproduct that primarily comprises calcium silicates and alumina silicates. It is formed in a molten state alongside iron within a blast furnace. Over the course of 80 years, BFS has gained significant traction within the construction industry. Upon the introduction of a carefully proportioned amalgamation of iron-ore, coke, and limestone into the confines of a blast furnace, an intricate thermal process ensues, resulting in the generation of molten iron and molten slag, both attaining a formidable temp of approximately 1500 degrees centigrade. Typically, the production of one metric ton of hot metal results in the generation of approximately 200-400 kilograms of liquid slag. In the context of a blast furnace, it is observed that molten iron and liquid slag tend to accumulate at the lowermost section of the structure. This results in the formation of a stratified arrangement, with the molten slag, being less dense, occupying the upper layer while the molten iron resides beneath it. The molten slag is carefully directed out of the

furnace in a manner that resembles the flow of molten lava. It effortlessly floats atop the molten iron and can subsequently be separated using a skimmer. The uniformity of the chemical composition of BFS is notable. The composition primarily comprises silica, alumina, and lime, in conjunction with magnesia, sulfur, and select oxides like iron oxide and manganese oxide. There exist three noteworthy classifications of BFS, namely granulated, air-cooled, and expanded slags, which can be generated based on the specific techniques employed for cooling and solidifying the molten slag. The acquisition of granulated blast furnace slag (GBFS) is achieved through the expeditious quenching of the molten slag via the utilization of high-pressure water jets. The material in question can be described as a composition of glassy granular particles, typically exhibiting a particle size smaller than 5 mm, like that of sand. The utilization of Ground GBFS is commonly observed after undergoing additional treatment involving the processes of drying and subsequent grinding, resulting in the production of an exceedingly refined powder. Ground GBFS possesses the potential to serve as a viable alternative to conventional cement, exhibiting a range of replacement ratios spanning from 30% to 85%. When the molten slag is carefully channeled into designated pits or ground bays, it undergoes solidification in accordance with the surrounding atmospheric conditions. As a result, it transforms into aircooled blast furnace slag (ABFS), characterized by a robust and crystalline rock-like composition. ABFS, an abbreviation for Aggregate Base Fine Stabilizer, is a robust and compact material commonly employed in civil engineering projects. It finds extensive use in various applications, including but not limited to railroad ballast, roadbed stabilization, concrete aggregate, and any scenario demanding a sturdy and weighty foundation. Expanded slag is meticulously generated through the utilization of a sophisticated mechanical apparatus, accompanied by judicious quantities of cooling water, thereby facilitating the creation of a

remarkably lightweight and desiccated substance. In the realm of civil engineering, gypsum finds its application predominantly in the construction of lightweight building blocks, as well as in the fabrication of bricks. Additionally, it serves as an insulating material and plays a crucial role as an aggregate in the production of lightweight concrete.

Ground granulated blast furnace slag (GGBFS) is a highly valuable industrial by-product derived from the iron and steel industry. Due to its numerous environmental, economic, and technological advantages, Ground Granulated Blast Furnace Slag (GGBFS) has been increasingly utilized as a substitute for cement in concrete within the past few years. In the study conducted by [37], an investigation was carried out to assess the impact of incorporating bottom ash (BA), GBFS, and a combination of these materials as fine aggregate in concrete on the overall durability of the concrete. In general, the utilization of GBFS and BA as fine aggregate in concrete has been observed to have a positive impact on its durability properties. [38] conducted a series of experimental investigations to evaluate the performance of cement paste and concrete mixes that incorporated 7% and 10% of silica fume (SF) as a replacement for cement. These investigations were conducted under three different exposure conditions. Based on the findings, it can be observed that the SF mix demonstrates superior strength development, whereas the blended ternary GGBS-SF mix showcases comparatively lower strength development [39]. The investigation conducted by [37] focused on examining the impact of elevated temps on the characteristics of concrete incorporating non-ground granulated blast-furnace slag (GBFS) and coal bottom ash (BA) as fine aggregate. The experimental findings indicate that the reduction in weight caused by elevated temps remains unaffected by the substitution ratio of ground GBFS.

The impact of temp on the reduction in mass of GGBFS concrete was observed to be below 8%

when subjected to temps below 700 degrees centigrade. This finding aligns with the behavior exhibited by ordinary Portland cement (OPC) concrete under similar conditions. The impact of temps exceeding 400 degrees centigrade on the compressive strength of concrete was found to be more prominent in the case of concrete incorporating Ground Granulated Blast Furnace Slag (GGBFS) [40]. The investigation conducted by [41] focused on the impact of incorporating silica fume in improving the rate of strength development and durability properties of binary concretes that contain a low reactivity slag. The findings indicate that the utilization of silica fume and slag in combination leads to a decrease in water requirement when compared to mixtures solely comprising silica fume. [42] conducted experimental investigations pertaining to the potential utilization of by-products derived from the steel production industry as aggregates in concrete, with the aim of enhancing its post-fire characteristics. The findings indicate that the utilization of slag within the lower temp range (up to 400 degrees centigrade) has the potential to enhance the performance characteristics of the concrete types under investigation.

Several studies have been conducted to examine the impact of increased temps on the characteristics of GGBS concrete samples that have been cooled in ambient air [37], [43]–[46]. The findings indicated that the incorporation of a higher proportion of Ground Granulated Blast Furnace Slag (GGBS) did not yield a substantial impact on the weight reduction of concrete when subjected to temps as high as 800 degrees centigrade. This observation is supported by the studies conducted by [37], [43], [44]. According to Uysal et al. [44], it has been observed that the performance of concrete incorporating blastfurnace slag deteriorates when exposed to temps exceeding 400 degree centigrade, in comparison to ordinary Portland cement (OPC) concrete. In the study conducted by Xiao et al. [46], an investigation was carried out to examine the residual compressive behavior of GGBS concrete under elevated temps spanning from 20

degree centigrade to 800 degree centigrade. The findings revealed that the residual compressive strength exhibited by the GGBS concrete closely resembled that of OPC concrete. However, it was observed that the elastic modulus of the GGBS concrete was comparatively lower. In the study conducted by Yüksel et al. [37], various properties of concrete were evaluated under the influence of exposure to a temp of 800 degree centigrade. These properties included the loss in weight, compressive strength, and dynamic modulus of elasticity. The findings of their study demonstrated that the residual compressive strength of ordinary Portland cement (OPC) concrete exhibited superior performance compared to the concrete incorporating non-GGBS. Siddique and Kaur [45] conducted mechanical property tests on concrete incorporating GGBS after subjecting it to temps of 100, 200, and 350 degrees centigrade. Based on the findings, it was observed that the mechanical properties of the concrete did not exhibit any substantial degradation when subjected to a temp of 100 degree centigrade. Additionally, the extent of mass loss experienced at a temp of 200 degree centigrade was deemed to be relatively insignificant. Upon being subjected to a temp of 350 degree centigrade, it was observed that the compressive strength, splitting tensile strength, and modulus of elasticity exhibited a reduction of less than 40% in comparison to their initial values.

## 6. CONCLUSION

Concrete, when subjected to elevated temperatures, undergoes significant physicochemical transformations. The modifications occasionally result in detrimental impacts on the concrete's performance and introduce supplementary intricacies.

The compressive strength values of the binary blended cement concrete exhibit a consistent decrease as the percentage replacement of Ordinary Portland Cement (OPC) with pozzolans increases. The compressive strength of the concrete, which consisted of 5% weight of Rice

Husk Ash (RHA) and 95% weight of Ordinary Portland Cement (OPC), reached its highest value of 40.0 N/mm<sup>2</sup> after 200 days of curing. This blend demonstrated superior performance compared to other replacement percentages of RHA.

In the binary blended cement concrete of grade 20, it is possible to substitute OPC with RHA pozzolans in quantities of up to 15% by weight. This replacement can be done without compromising the compressive strength of the concrete, even when it is cured for a period of up to 200 days. The incorporation of 5% weight of Rice Husk Ash (RHA) in binary blended cement concrete exhibits commendable fire resistance characteristics, particularly when subjected to temperatures of up to 500 degrees centigrade after a curing period of 200 days. In the experimental study, it was observed that the concrete mixture containing 5% weighted RHA exhibited a notable superiority in terms of compressive strength compared to the ordinary Portland cement (OPC) concrete under the exposure of temperatures reaching up to 700 degrees centigrade for a duration of two hours.

The impact of a substantial increase in the volume of Ground Granulated Blast Furnace Slag (GGBS) substitution did not yield a noteworthy outcome in relation to the reduction in mass experienced by concrete when subjected to elevated temperatures. The compressive strengths exhibited by concretes containing 60 and 70% GGBS were noticeably inferior compared to the compressive strengths observed in concretes incorporating lower proportions of GGBS. Upon being subjected to temperatures exceeding 300 degrees centigrade, it was observed that the compressive strength of the concretes incorporating Ground Granulated Blast Furnace Slag (GGBS) experienced a notable reduction. Following exposure to a temperature of 500 degree centigrade, it was observed that concrete containing a significant proportion of Ground Granulated Blast Furnace Slag (GGBS) exhibited a retention rate of approximately 60% in terms of its initial compressive strength.

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