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Durability and Flexural Strength of High Strength Concrete Beams Exposed to Elevated Temperature: Review Study

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Abstract: In building, high-strength concrete (HSC) is frequently utilized. Although high-strength concrete has a high compressive strength, it has issues with flexural strength and cracking. Fire affects reinforced concrete (RC) members because it increases the bulk temperature of the concrete. This rise in temperature significantly reduces the mechanical qualities of concrete and steel. Transient creep, thermal creep, and other strains are also brought on by fire temperatures. Reviewing previous research on the impact of high temperatures on the flexural strength and durability of high-strength concrete beams is one of the study's goals. According to study findings, concrete spalling, mass reduction, and durability are critical markers for assessing HPC's mechanical performance at high temperatures. HPC's mechanical performance declined as the exposure temperature rose. Furthermore, weight loss rose nonlinearly with the maximum temperature, and concrete's strength decreased with abrupt cooling.

Keywords: High Strength Concrete, Beams, Flexural, Durability, Temperature.

1. Introduction

One of the most often used building materials in the world today is concrete. Concrete components can be found naturally anywhere in the world. Concrete has long been utilized to construct long-lasting commercial structures, roads, water supply systems, bridges, and residences in order to promote social cohesion, economic recovery, and practical infrastructure. [1, 2].

Its tensile strength is somewhat lower, though. Researchers have looked into using reinforcing fibers, which come in two varieties—organic and inorganic—to enhance the qualities of concrete. Concrete's mechanical qualities, including bending, tensile, and fatigue stresses, are enhanced by the addition of fibers. Numerous research have shown that concrete improves its toughness, ductility, and nonlinear behavior. [3-7].

A common material in building is high-strength concrete (HSC). Although the compressive strength of high-strength concrete is strong, the material's flexural strength and cracking are issues. Composite materials based on strain-hardening cement have recently been developed as a means of enhancing flexural strength and crack management. [8].

In order to guarantee a long service life, RC buildings must be durable. This reduces waste, conserves resources, and lessens the environmental effects of replacement and maintenance. Current design and construction rules place a strong emphasis on durability; therefore, all strengthening and repair work should be durable. The durability of reinforced concrete structures is negatively impacted by steel reinforcement corrosion. [9]. The working environment has a big impact on how long steel RC constructions last. Steel reinforcement is susceptible to corrosion, especially in hostile environments, which can lead to concrete fractures and a decrease in the steel RC structures' ability to support loads. As a result, maintaining damaged steel reinforced concrete structures comes at a huge cost. Fiber-reinforced polymer (FRP) bars have been used in place of steel reinforcement in RC structures to extend their durability due to their high strength, nonmagnetic properties, and corrosion resistance. Unidirectional fibers inserted in a polymer matrix are used to make FRP bars. Compared to the manufacture of steel, the production of FRP bars utilizes less energy and produces less pollution. [10, 11]

Fire affects reinforced concrete (RC) members because it increases the bulk temperature of the concrete. This rise in temperature significantly reduces the mechanical qualities of concrete and steel. Transient creep, thermal creep, and other strains are also brought on by fire temperatures. Additionally, they could produce explosive concrete member surface fragments.[2]. Concrete resists fire because it is non-flammable and has a low heat conductivity. In the rush to consider every design aspect, concrete's fire resistance is occasionally disregarded. Because fire raises the bulk temperature of reinforced concrete (RC), it affects RC members. In concrete and steel, this temperature increase significantly reduces their mechanical qualities. Additionally, thermal creep, transient creep, and other strains are brought on by fire temperatures. Additionally, they may result in concrete members with explosive surface fragments. Because concrete is non-combustible and has a low heat conductivity, it resists fire. The fire resistance of concrete is occasionally overlooked in the haste to take into account every architectural detail. [4]. [1, 12, 13, 14]

The world's temperatures are steadily rising due to global warming, which is causing an increase in fire incidences. With the increasing number of construction and fire incidents worldwide, it is necessary to examine the durability of reinforced concrete components at fire-induced high temperatures. Understanding how high temperatures impact the strength of the connection between concrete and reinforcement is essential to fully comprehending the fire resistance of reinforced concrete structures.. [15]

Reviewing previous research on the impact of high temperatures on the flexural strength and durability of high-strength concrete beams is one of the study's goals.

2. High Strength Concrete

High-strength concrete is made by carefully selecting premium ingredients and modifying mixing techniques. Superplasticizers are required to provide proper workability because such concrete frequently has low water-binder ratios due to its extremely low w/b ratio of 0.25 to 0.35. The use of a mineral supplement is also strongly recommended. The coarse aggregates must be spherical or square. A high strength concrete (HSC) requires the use of concrete that is more robust and long-lasting than ordinary concrete. This concrete typically contains a super plasticizer in addition to one or more cementitious ingredients, such as fly ash, silica fumes, or powdered granulated blast furnace slag. The design of the concrete mix requires a thorough grasp of the various characteristics of these component constituents. An important advancement in concrete technology has been the creation of high strength concrete. The development of high strength concrete is a major breakthrough in concrete technology. High strength concrete (HSC) is defined as concrete with a certain characteristic cube strength between 40 and 100 N/mm2, even though higher strengths have been achieved and used. Strength levels of 80 to 100 N/mm2 or more are being used for both precast and in situ projects. High strength concrete is used when weight reduction is essential or when design concerns need fewer load-bearing components. [15]

Although a variety of aggregates can be used to create high-strength concrete, rounded and/or smooth aggregates may have a tendency to show aggregate bond failure at relatively low strengths. It is best to use crushed rock aggregates that are between 10 and 20 mm in size, not too lengthy or sharp. Nonetheless, it has been discovered that the link strength between smaller aggregates is stronger than that between bigger aggregates; as a result, smaller aggregates typically produce better outcomes. The ratio of water to cement (or water-binder) is the foundation for the creation of high strength concrete. The w/c ratio should be kept low for high strength concrete. Superplasticizers based on polycarboxylate-ether are required when using cementitious materials and low water-to-cement ratios. While plasticizers might be sufficient for reduced strength, superplasticizers are recommended for maximum water reduction. Strength may not necessarily increase with an increase in cement content. It might not have much of an impact above a certain point. Concrete with high strength is frequently regarded as a novel material. It was developed many years ago. In 1950, concrete with a compressive strength of 34 MPa was considered extremely durable in the United States. By 1960, concrete with a compressive strength of 41 to 52 MPa was being utilized commercially. Concrete with a strength of 62 MPa was created in the early 1970s. Over the past three decades, extremely strong concrete has been used in the construction of long-span bridges and high-rise skyscrapers. While IS 456-2000 states that concrete that has a compressive load capacity above 110 MPa has been considered for use in prestressed concrete members and cast-in-place buildings, reactive concrete has recently been shown to have a compressive strength of almost 250 MPa. The foundation of it is pozzolanic materials. [16]

Special materials may or may not be needed for the production of HSC, but materials of the highest caliber and with the best possible qualities are unquestionably needed. Compared to lesser strength concrete, the manufacture of HSC that continuously satisfies the workability and strength development requirements imposes stricter material selection requirements. Laboratory mixtures are used to test the creation of a high-strength, high-performance concrete with large amounts of industrial by-products. Electric arc furnace slag is utilized as an aggregate, whereas high-calcium fly ash and ladle furnace slag are utilized as binders. Ladle furnace slag makes up 30% of the overall mass of the binder, while fly ash makes up 50%. Coarse aggregates or both fine and coarse aggregates can be substituted by slag aggregates. The resulting concrete exhibits high strength (>70 MPa), strong abrasion resistance, and fracture toughness in combinations that contain both slag aggregates and other cementitious elements. [17, 18, 19]

3. Past Related Studies

The experimental study on the application of steel fibers (SF) and basalt fibers (BF) and their impact on the flexural, tensile, and compressive behavior of reinforced concrete beams at both normal and high temperatures was presented by Ahmed et al. in 2024. To determine the ideal percentage of fibers, tests were conducted on 19 beams, 114 cubes, and 114 cylinders. By cement weight, BF was utilized in percentages of 1%, 2%, and 3.5%, whilst SF was utilized in percentages of 0%, 0.5%, 1%, and 1.5%. Before testing, heated samples were exposed to 600 °C for three hours and allowed to cool naturally. The test findings demonstrate that the tensile strength of unheated cylinders was considerably enhanced by the use of BF and SF, with the ideal fiber content of 1% BF to 1.5% SF yielding a 163% improvement over the control. The ideal fiber content for heated cylinders was between 2% BF and 1.5% SF, which resulted in a 175% increase. The improvement in compressive strength was less pronounced for the majority of the fiber content ratios that were employed; the ideal blend of 1% BF and 1% SF produced improvements of 27% and 44% for unheated and heated environments, respectively. According to flexural data, beams using a combination of 2% BF and 1% SF produced the best results at room temperature, increasing capacity by 27% above the control. Using the ideal mixture of 1.5% SF and 1% BF at high temperatures resulted in a 27.2% increase over control. It has also been demonstrated that adding BF and SF to concrete increases the ductility of the beams and shifts the failure mode from shear to flexural. [3]. The compressive test results are displayed in Figure 1, the tensile strength findings are displayed in Figure 2, the flexural capacity of the beams at normal temperature is shown in Figure 3, and the flexural capacity of the beams at elevated temperatures is shown in Figure 4.

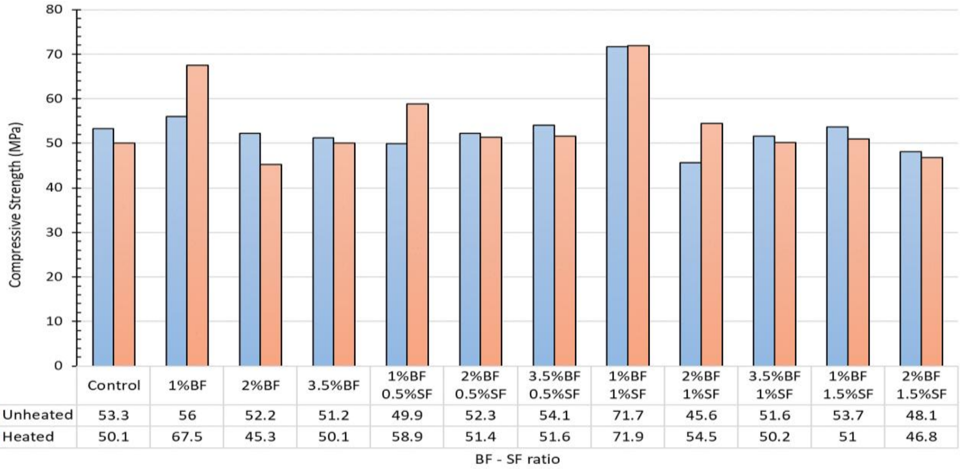

Figure 1. Results of compressive tests [3]

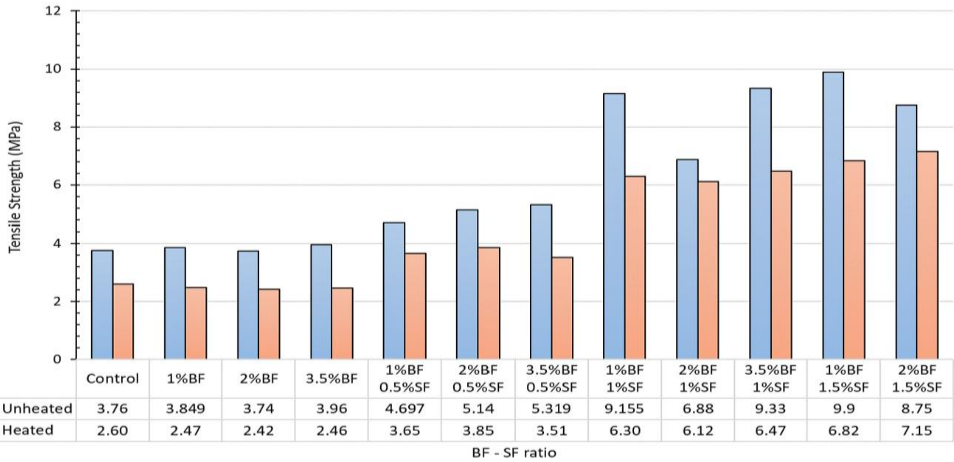

Figure 2. Results of Tensile strength [3]

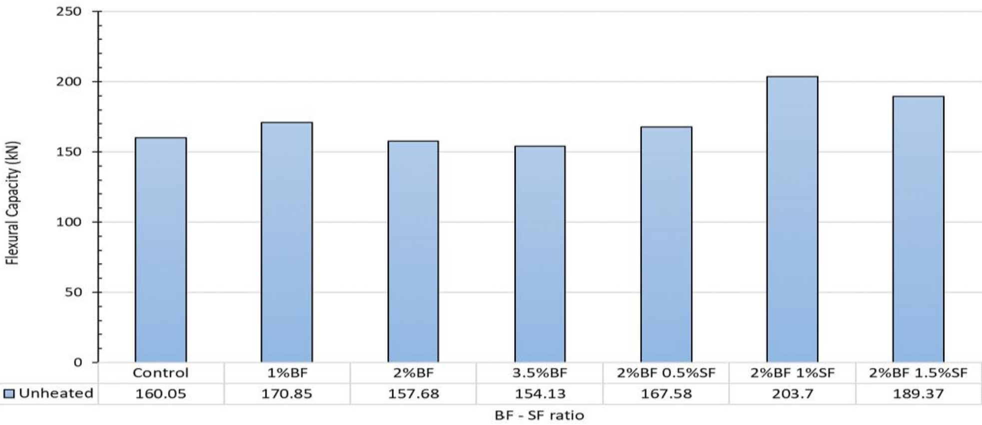

Figure 3Beams' flexural strength at room temperature [20]

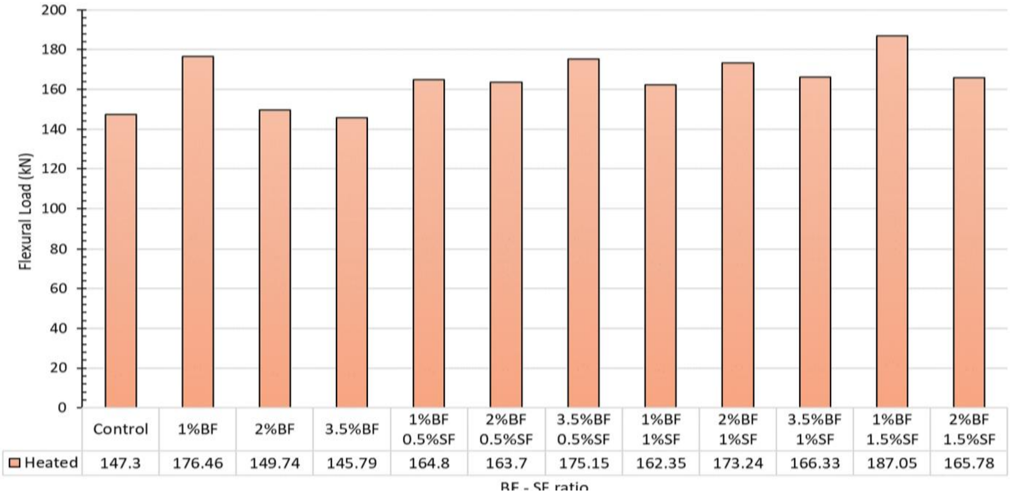

Figure 4. Beams' flexural strength at elevated temperatures [3]

Of the 56 reinforced concrete beams used by Kiute et al. (2014), 28 had a compressive strength of 20 MPa, and the other 28 had a compressive strength of 25 MPa. The study's goal was to find out how high temperatures affected the reinforced concrete beams' flexural strength. According to the results, RC beam specimens with a compressive strength of 20 MPa lost a maximum of 20.1% of their strength after an hour at 250°C, and after two hours, the strength loss increased to 24.88%. The results demonstrated that the coolant at room temperature is more than equal to the flexural strength lost throughout the heating and cooling process with cold water during quenching. Additionally, the results of the trials have demonstrated that flexural strength declines with increasing exposure time and temperature. [20]

Fathi and Farhang (2015) investigated the behavior of heated reinforced concrete beams with self-compacted concrete (SCC) at six different temperatures: 23°C, 100°C, 200°C, 400°C, 600°C, and 800°C. The beam was heated at a rate of 01°C per minute. Uniaxial loading was applied to RC beams at a loading rate of roughly 5 KN/s. The outcomes presented that (RC's) flexural strength decreased with increasing temperature. Furthermore, the results demonstrated that the maximum yield strength of the RC beam decreased as the temperature rose. The depth and shape of fractures in heated concrete are also influenced by the temperature and the compressive strength of the concrete. Concrete with a high compressive strength was more affected by a greater temperature. [21]. The percentage decrease in compressive and flexural strengths brought on by increased temperatures is displayed in Figure 5. Figure 6 displays the experimental data as discrete points and the suggested moment-curvature diagram for heated RCBs in linear form.

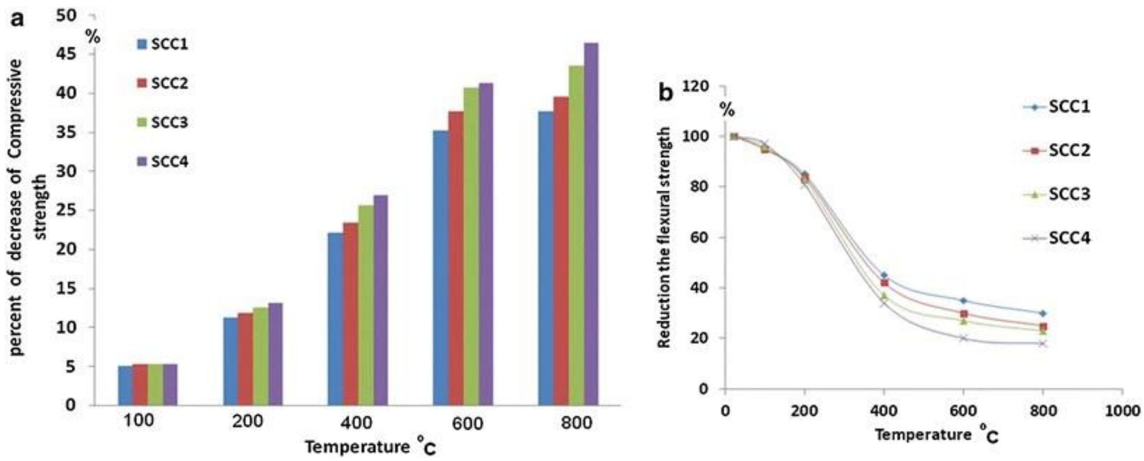

Figure 5. percentage of compressive and flexural strength loss brought on by temperature increases [21]

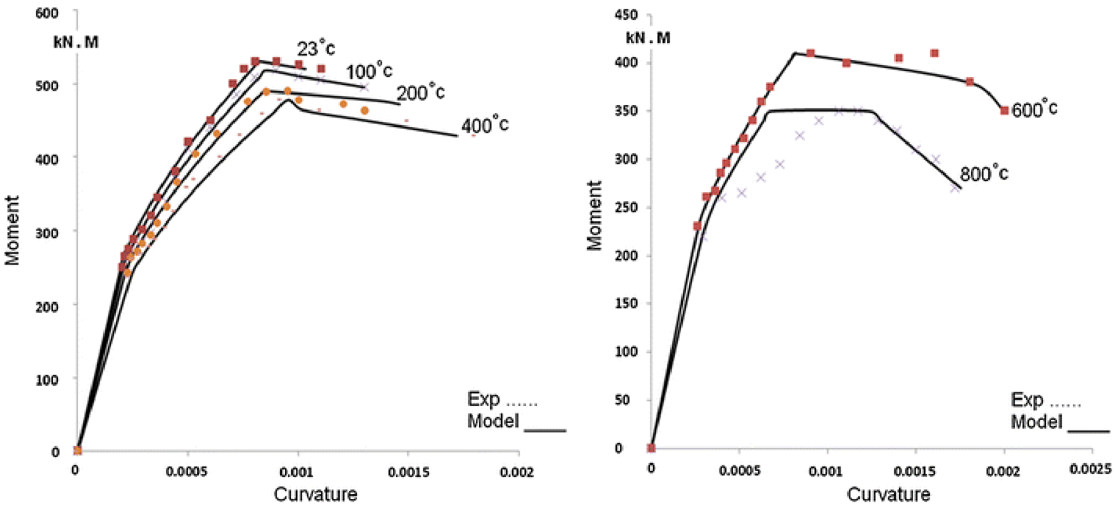

Figure 6. The linearly presented moment-curvature diagram for heated RCBs and the discrete points that represent the experimental results [21]

In 2003, Kadhum et al. investigated how fire flame affected several mechanical properties of rectangular reinforced normal weight concrete beams, such as compressive strength, drying shrinkage, and load-deflection behavior. The residual compressive strength ranged from 67–76% at 400°C to 58–66% at 600°C to 28–51% at 800°C, per the results. The researcher then went on to examine how the shrinkage values grew as the temperature rose. Results show that after being exposed to a fire flame, two types of cracks developed in strengthened concrete beams showing to high temperatures in both strained and unstressed conditions. The first cracks appeared as a honeycomb pattern across the entire surface and were brought on by heat. The applied force caused by bending caused the second kind of cracks, called flexural cracks, to begin at the mid-span area. In contrast, when concrete is subjected to fire flame temperature, the modulus of elasticity is more affected than the compressive strength. [22]. The impact of the fire flame on the compressive strength at a 1.0-hour exposure period is depicted in Figure 7, and the impact at a 2.0-hour exposure period is evident in Figure 8.

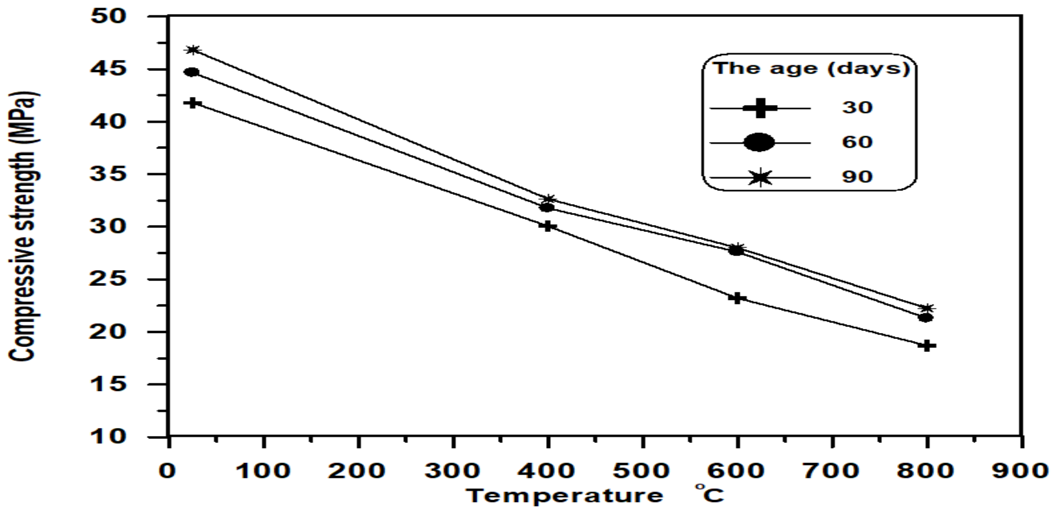

Figure 7. Impact of fire flame on compressive strength after one hour of exposure [22]

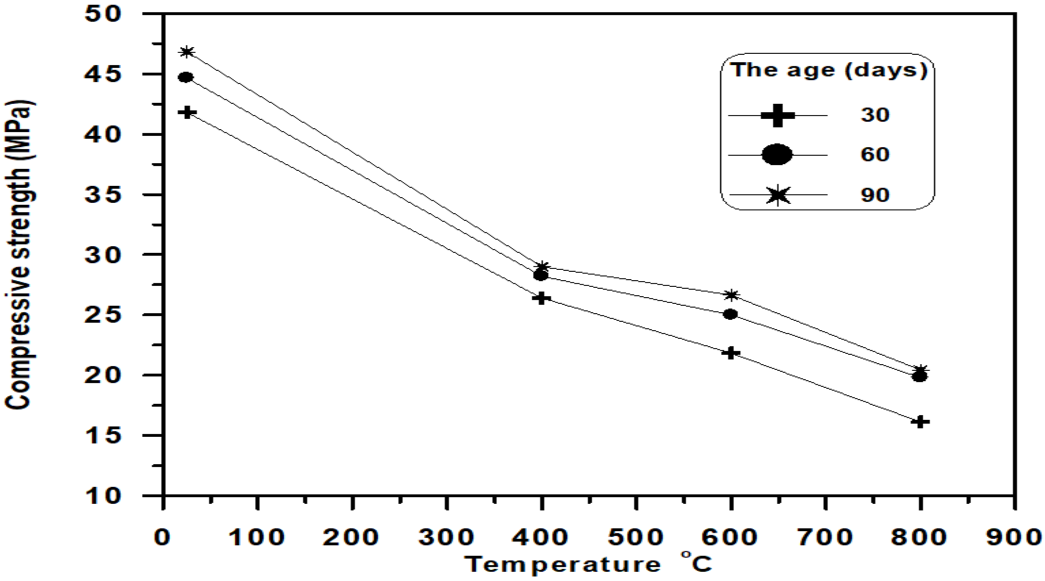

Figure 8. Fire flame's impact on compressive strength after two hours of exposure [22]

Kodur and Phan (2007) synthesized data from previous studies to understand how numerous factors affect the fire behavior of high-strength concrete materials. These findings demonstrated that a high heating rate can result in concrete spalling. Because of the material's limited permeability and higher build-up pore pressure, concrete spalling is more likely to occur when the compressive strength surpasses 70 MPa. Moreover, considerable spalling was found to be caused by a high moisture content. Additionally, it was shown that the probability of spalling increased with specimen size since large structures have a greater capacity to store energy. [23]

According to Mahmud Yağan et al. (2024), steel yield strength and concrete compressive strength values decline at higher temperatures in a predictable manner. These results can be attributed to well-known phenomena, such as the enlargement and shrinkage of cement mixtures and aggregates in concrete and the degradation of steel rebars' molecular construction in response to high temperatures. This study also found comparable results. Even though the declining tendency of the compressive strength of concrete impacted by raising the temperature from 100 degrees Celsius corresponds with previous research, more depressing results were discovered. The duration of heating and the higher degree of thermal expansion that occurred during this period had an effect on the previously reported decline. Steel bar's yield strength did not significantly decline up to 600 °C, although strength declines beyond that point are in line with previous research. Additionally, test findings showed that the concrete's compressive strength is the primary factor affecting the bond strength among concrete and steel reinforcing. The primary cause of the loss of load-bearing strength in both flexural and shear groups is degradation of concrete's compressive strength and concrete-steel bonded efficiency. This is particularly true when steel remains constant and concrete compressive strength drops by 55% and bond strength drops by 41% up to 600 °C. This impact is most noticeable around 800 °C. Due to the substantial In the flexural group specimens, shear flaws and a reduction in concrete strength were also noted, particularly after 200 °C. [24]. The strength of concrete exposed to high temperatures during compressive is depicted in Figure 9. The yield strength of steel subject to extreme temperatures is depicted in Figure 10. The capacity of the failing flexural category to support loads is depicted on Figure 11. The load-bearing capacity of the shear failure group is displayed in Figure 12. The bending and ruptured load-bearing capacities during shear groups are displayed in Figure 13.

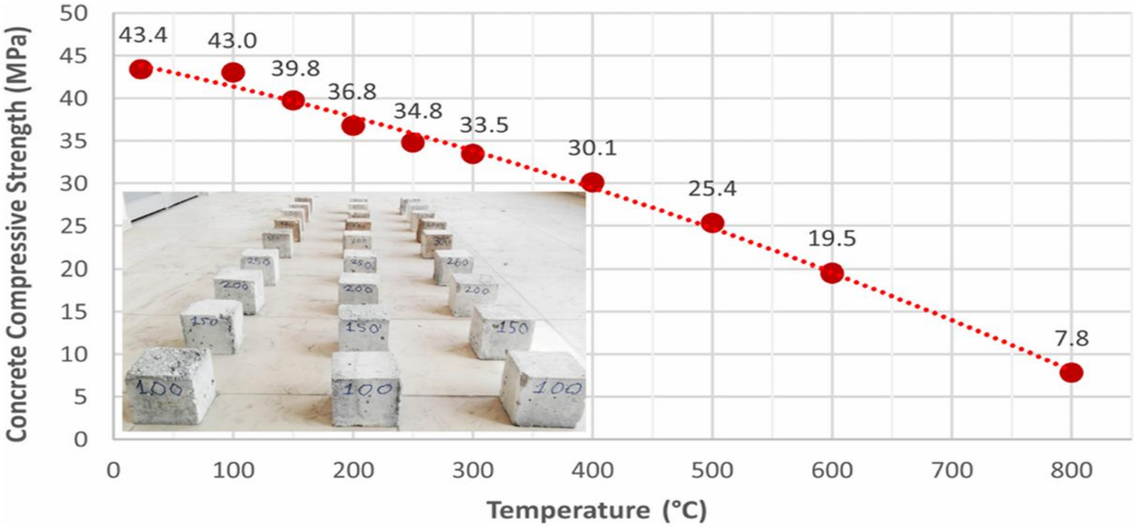

Figure 9. Concrete's compressive strength after exposed to higher temperatures [24]

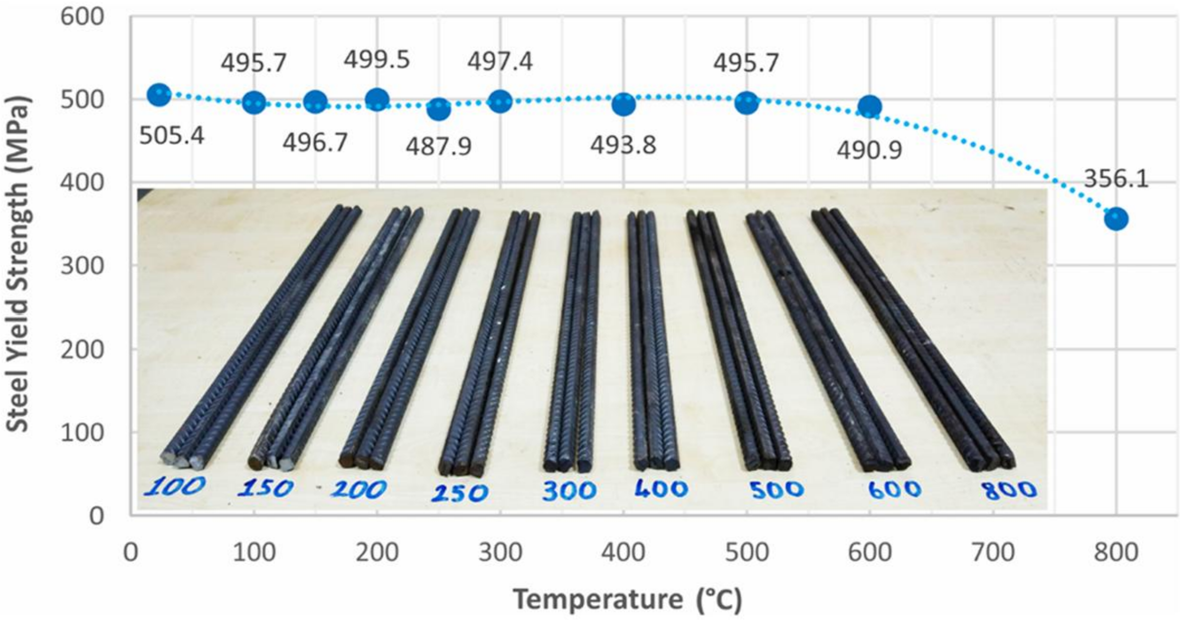

Figure 10. Steel's yield strength after exposed to higher temperatures [24]

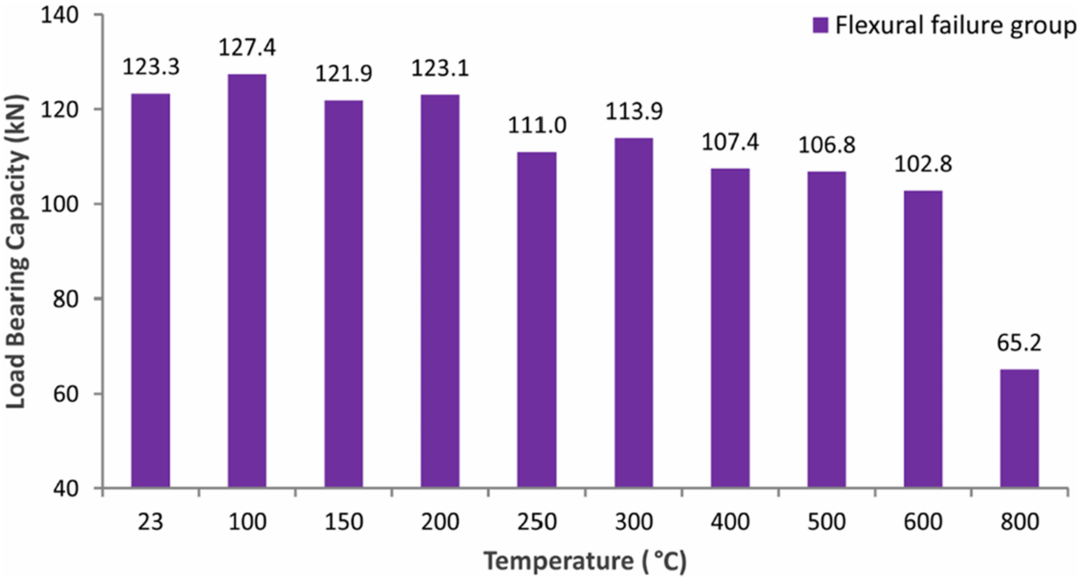

Figure 11. Capabilities of the flexural failure group to support loads [24]

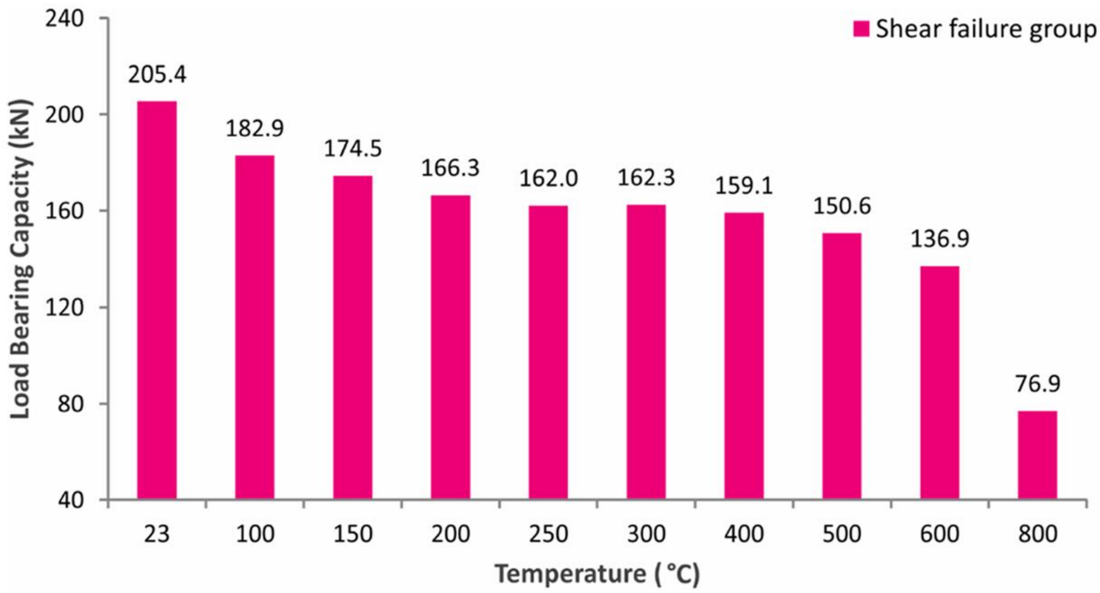

Figure 12. Capabilities of the shear failure group to support loads [24]

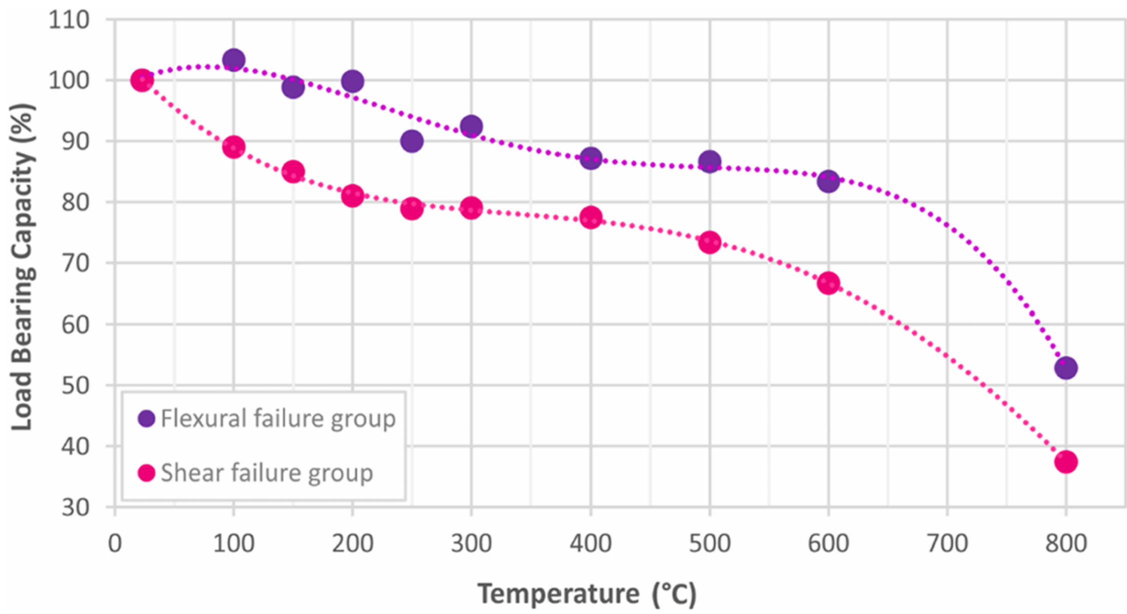

Figure 13. Capabilities of flexural and shear failure groups to support loads [24]

According to research by Xiao and Koenig (2004), steel strength does not rise and flexibility diminishes when the temperature rises from a room temperature to 400 °C.At increasing temperatures, steel's strength gradually decreases; by 700 °C, just 20% of its initial strength remains. Furthermore, when the temperature increases, steel's modulus of elasticity steadily decreases. Because concrete's thermal elongation at elevated temperatures is significantly smaller compared to that of the reinforcing steel, the denseness of the concrete next to the reinforcement increases the roughness between the two. On the other hand, some of the tensile strength of concrete is lost. Therefore, the bond that exists between the concrete and the reinforcement, which has been changed by the effects of high temperatures, affects the crack, cracking, and load-bearing capabilities of the reinforced concrete portions subjected to fire. One may argue that the effects of the high temperature led to a very obvious change in the relationship between the reinforcement and the concrete. The quantity of bond deterioration outweighs the decrease in the compressive force of the concrete. [24, 25]

In 2014, Xiao et al. conducted a laboratory study of the shear transferring effects of high-strength concrete along a precast fracture following exposure to extreme temperatures. The primary goal of the study was to assess two crucial variables: the amount of elevated temperature and the compressive strength of the concrete. The shear capacity of concrete with regard to crack formation and displace under high temperatures was investigated by pressure experiments utilizing samples free of cracks. Consequently, it has been noted that while the final shear strength of high-strength concrete declines at temperatures above 200 °C, the corresponding deteriorating form (fracture slip and crack wideness) rises via temperature. [24, 26]

A 2019 study by Hassan et al. examined how high temperatures affected concrete and how various reinforcement methods affected the ability of reinforced concrete beams to regain their capacity. Using various types of concrete, experiment samples were exposed near temperatures of 400 plus 600 °C for 60 plus 120 minutes in order to assess the behavior of the beams under fire conditions. It was determined that prolonged exposure to high temperatures and various concrete types works well for reinforced concrete parts, but that there is a noticeable lossing of strength, particularly in sampling made with regular concrete that is heated to 600 °C for two hours. [24, 27]

An investigation into the shear properties of concrete beams with reinforcement after exposition to extremely high temperatures was conducted in 2020 by Xing et al. After two hours of being exposed to ISO 834-1 standards fire on each side of each beam, shear stress was put on on the beams. According to test data, the ultimate deformations of the beams rise with temperature, whereas shear-bearing capability and shear toughness decrease. Furthermore, they found that when the pressure zone became subjected to high temperatures, the beams' flexural bearing ability decreased more than their bearing shear capacity. [24, 28]

In 2020, Ahmad et al. conducted tests on concrete samples to see how high temperatures affected the shear capability. After being heated to 350, 550, and 750 °C, the samples made with 40 MPa concrete stayed allowed to naturally cool to ambient temperature before undergoing the shear tests. The investigation's findings showed that concrete revealed to high temperatures lost 18.85% of its shear capacity at 350 °C, 29.6% at 550 °C, and 52.74% at 750 °C. [24, 29]

Abdulaziz Alaskar 2025 reviewed the frame of studies on the effects of excessive heat the mechanical properties of HPC mixtures, including mass loss, compressive strength, splitting tensile strength, modulus of elasticity, concrete spalling, and durability performance. The mechanical properties of HPC at high temperatures are methodically compiled in this study. It also describes HPC's spalling attitude at high temperatures. Additionally, it describes the methods and techniques for enhancing HPC's performance when exposed to high temperatures. According to the findings, concrete spalling, mass reduction, and durability are critical markers for assessing HPC's mechanical behavior at high temperatures. HPC's mechanical performance declined as the exposure temperature rose. Furthermore, mass defeat nonlinearly with the maximum temperature, and concrete's strength decreased with abrupt cooling. It was discovered that one of the main causes of HPC degradation was specimen size. Each test result presented in this study is the standard deviation of all three samples of mixture of concrete examined under each temperature exposition scenario. Compressive strength loss is lessened when specimen size is increased. The water content of HPC has no effect on its compressive strength when exposed to temperatures above 800 °C. The efficiency of the mechanically of HPC at high temperatures is influenced by a number of variables, including heating conditions, concrete quality, fiber volume and type, and replacement levels. A number of variables, including as the quantity and kind of reinforcing fibers, the quality of the concrete, the Degrees of substitution, and the heating circumstances, affect HPC's mechanical performance at high temperatures. Future developments in this field of study are also highlighted in this article. Finally, suggestions for improving HPC constructions' fire safety are made. [30]. The comparison of experimental strength loss curves with design curves is displayed in Figure 14. The spalling of an HPC beam exposed to a prolonged fire is depicted in Figure 15.

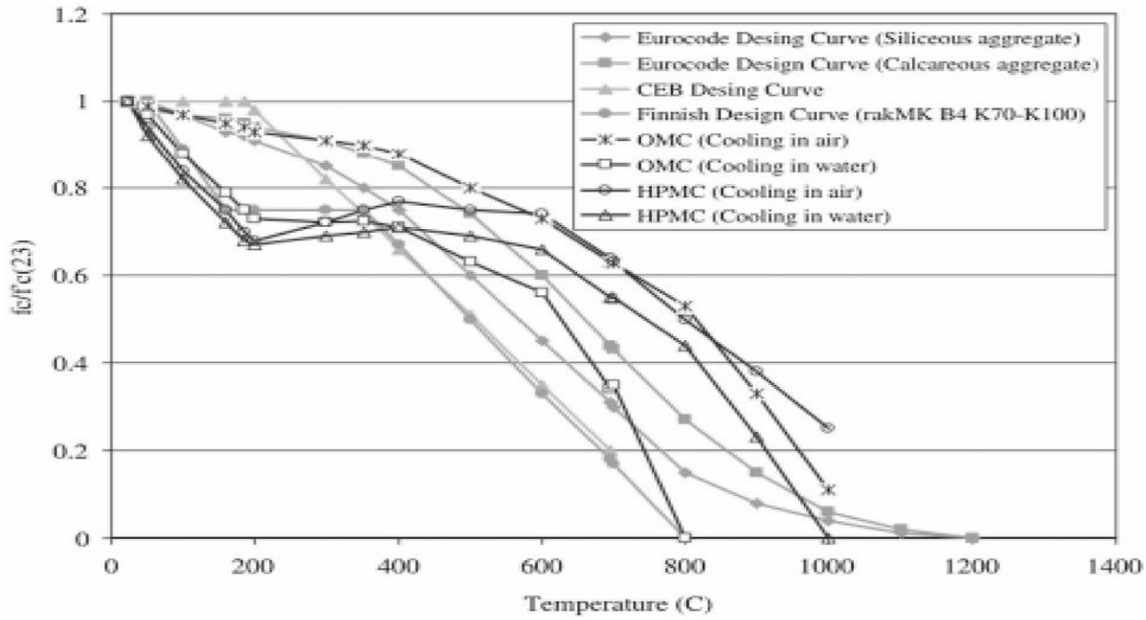

Figure 14. Experimentation strength degradation curves and designing curves are compared [30]

Figure 15. HPC beam spalling exposed to a prolonged fire [30]

In order to investigate the effects of sample size, water content, fire profiles, and strength grading on bending, splitting tensile, and compressive strengths, Li et al. 204 conducted an HPC investigation. HPC samples of grades C40, C60, and C70 were used in the investigation. Concrete's compressive strength decreased by 17.7%, 36.8%, 41.9%, and 72.7%, respectively, as temperatures rose to 200 °C, 400 °C, 600 °C, and 1000 °C. Likewise, The bending strength decreased by 15.5%, 56.3%, 83.7%, and 92.6%, accordingly, while split tension strength decreased by 14.3%, 18.2%, 48.1%, and 83.6%. The researchers also discovered that water content decreased no discernible effect on compressive strength at 800 °C and that bigger sample sizes might lead to a smaller amount lossing in compressive strength. [30, 31]

Al. Sheikh looked at how high temperatures, equal to 1000 °C, affected the mechanical performance of high-performance concrete in a 2011 study. Using ordinary Portland cement, the study focused on the residual compressive and tensile strengths of the HPC mixtures. Concrete samples were either rapidly cooled in water or progressively chilled in air after being exposed to a variety of temperatures. Tension and compression strengths, rebounding number, and the velocity of ultrasonic pulses all dropped as exposed temperatures rose, according to the research. Concrete's strength was reduced by rapid cooling, and its weight loss non linearly with temperature. [30, 32]

In a 2013 study, Akca and Zihnioğlu used PP fibers and air entraining additive (AEA) in an HPC mixture to improve fire resistance by forming interconnected reservoirs in the concrete. They created nine distinct HPC mixes with varying amounts of AEA and PP and 0.24 w/c blast furnace slag. 18 specimens were used in the study to evaluate the effect of specimen size. In order to ascertain the remaining mass and compressive strength, the temperatures were raised to 300, 600, and 900 degrees Celsius at a rate of 10 degrees Celsius per minute, followed by air cooling. Cracking, spalling, and color changes were assessed at different temperatures using both macroscopic and microscopic analyses. According to the study, adding AEA assisted alleviate the loss of residual strength; however, for thicker specimens, this impact changed at 300 °C. By combining AEA with PP fibers, the probability of spalling in HPC can be decreased. Additionally, the specimen's size played a significant role in HPC deterioration; smaller specimens lost more strength at higher temperatures, probably as a result of quicker temperature increases. [30, 33]

Research on the effects of high temperatures on HPC's mechanical properties was conducted by Tahwia et al. in 2024. In a furnace, samples containing and without polypropylene fibers (PPFs) were heated to 200, 400, and 800 degrees Celsius for one hour. The concrete was heated and then allowed to cool to room temperature in a laboratory setting. [30, 34]

The structural recital and remaining moment capability of surfaced and un surfaced -reinforced concrete (RC) beams exposed to varied fire exposure times were investigated by Naila Hisbani et al. in 2025. Two reinforcement configurations were tested for plastered and unplastered beams: one with two reinforcement bars of 10 mm in diameter at the top and bottom, and another with two bars of 10 mm in diameter at the top and three at the bottom. Concrete having a compressive strength of 20 MPa at room temperature was used to make both plastered and unplastered beams. With a peak temperature of 800 °C, they were exposed to fire for 0, 3, and 6 hours, mimicking actual fire conditions. The moment capability of fire-exposed beams reduced by roughly 20–36%, depending on the reinforcement. The results emphasize how crucial it is to take plaster into account as a protective layer when designing RC beams in order to improve fire resistance and post-fire structural performance. The results highlight the need for fire-resistant techniques, like plaster coatings, to reduce structural deterioration and improve RC beam performance and safety after fire. [35]. The structure of the beams under fire throughout the experiment is depicted in Figure 16, and the beams' spalling following fire exposure is shown in Figure 17.

Figure 16. Beams exposed to flames during the experiment [35]

Figure 17. Beam spalling following exposure to fire [35]

In 2023, Joseph O. et al. investigated how high temperatures affected the remaining structural features of concrete that contained unconventional fine aggregates such laterite and quarry dust. Concrete's structural integrity may be weakened by exposure to high temperatures in areas that frequently experience high temperatures, such as tropical climates. High temperatures (250 °C) were applied to concrete samples, and the results were compared to control samples that were evaluated normally. In this study, varied proportions of laterite (Lat) and pit dust (QD) were extra to the concrete mix in place of fine aggregates. 90%Lat:10%QD, 75%Lat:25%QD, 90%Lat:10%QD, 50%Lat:50%QD, and 25%Lat:75%QD. An experimental mix was created after the physical characteristics of the component aggregates—which included granite, sand, laterite, and quarry dust—were evaluated. After the concrete samples were cured for 3, 7, 14, and 28 days, their mechanical characteristics—more especially, their flexural and compression strength—were examined. The findings showed that recital in terms of density, sorptivity, and strength gain improved linearly with the proportion of laterite in the concrete environment. At 90% laterite replacement, the highest compressive strength was 32.80 N/mm2. The flexural strength, on the other hand, responded differently. It peaked at 5.99 N/mm2 at 50% laterite replacement, and then it decreased as the laterite ratio increased. The impact of heating on the 28-day-old concrete samples is depicted in Figure 18. The impact of heating on 28-day compressive strength is depicted in Figure 19. The impact of warming on 28-day flexural strength is depicted in Figure 20. [36]

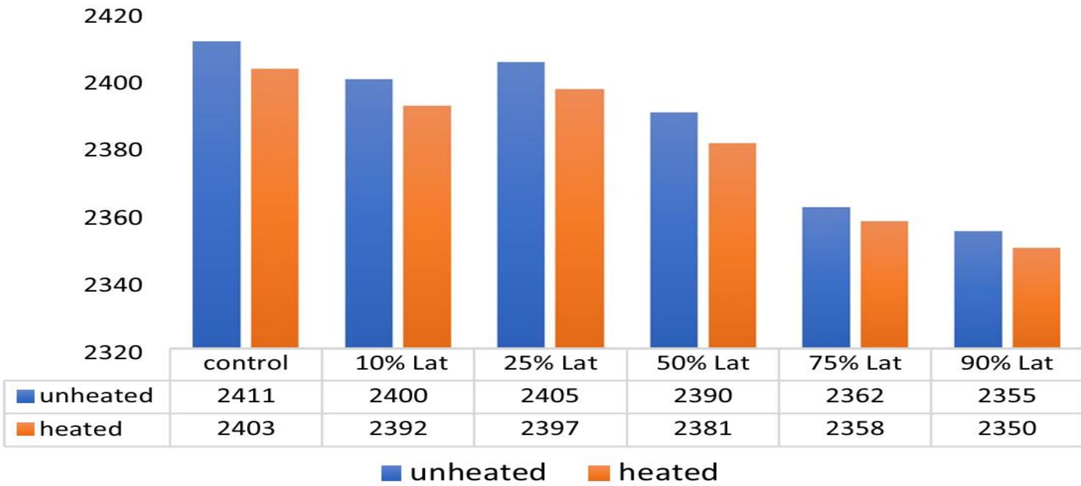

Figure 18. Impact of heating on samples of hardened concrete after 28 days [36]

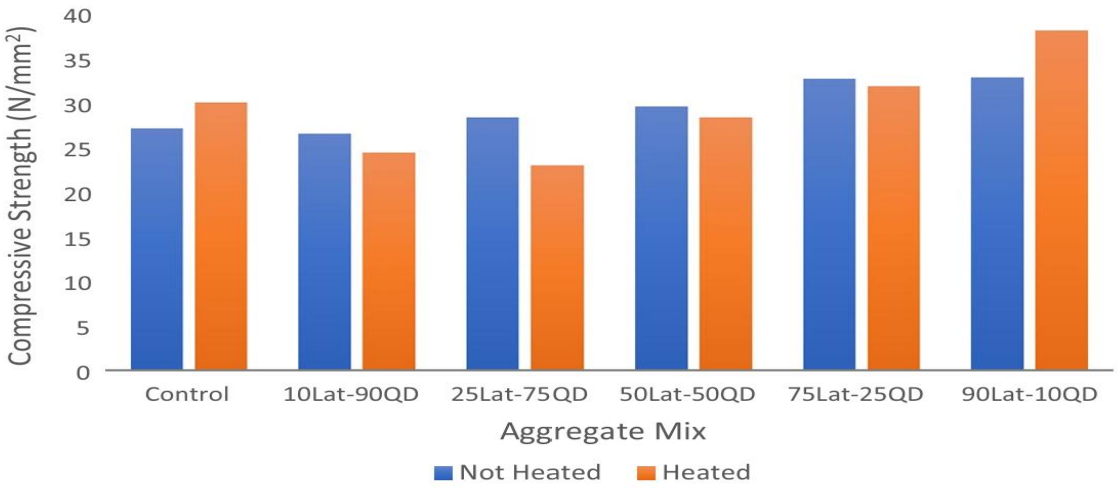

Figure 19. Impact of heating on compressive strength after 28 days [36]

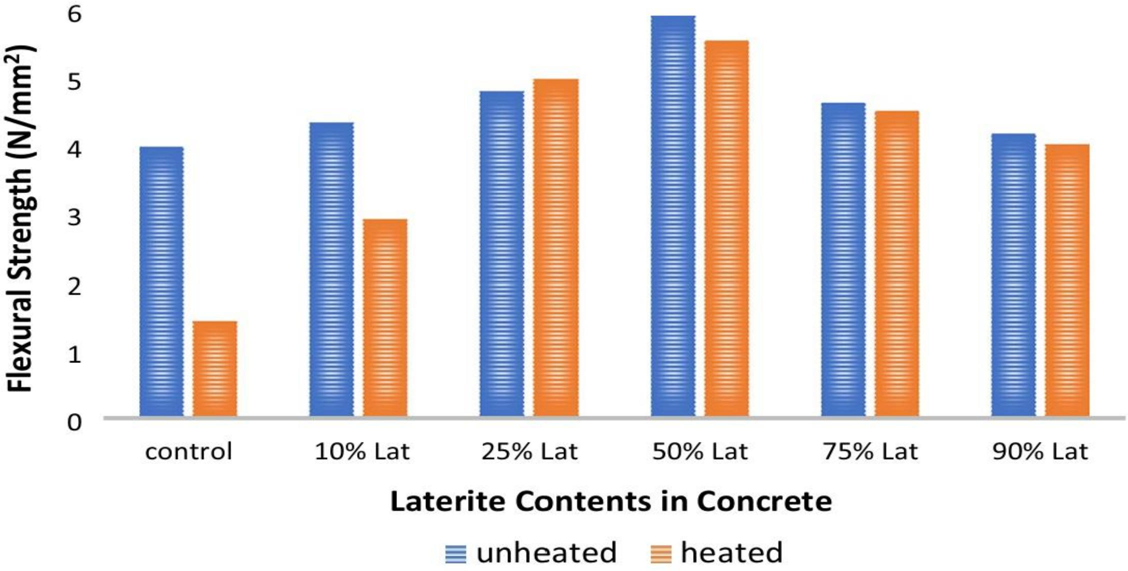

Figure 20. Heating's impact on 28-day flexural strength [36]

In a thorough experimental study published in 2020, Nabil Abdelmelek and Eva Lubloy evaluated the endurance of high-strength paste when exposed to temperatures that were as high as 900 °C. At 90 days of age, a number of parameters have been studied, including the water to binder ratio (w/b), increased temperatures, and metakaolin (MK) dosages. In comparison to pure cement paste in the instance of 0.3 w/b, the results shown that MK increases the proportional remaining compression force and comparison residual bending strength by up to 52% and 71% at 500 °C, respectively. The ideal dosages were 9, 12, and 12% of MK equivalents for 0.3, 0.35, and 0.4 w/b, respectively. The maximum quantity of MK that can be utilized is 12%. When the w/b ratio varies according to the density of the microstructure—which is determined by the w/b ratio and its packing effect induced by MK amount—the optimal dose may change... Apart from the mechanical characteristics, the use of MK reduces the specimens' tendency to break at high temperatures. SEM studies demonstrate that MK's specific surface area, chemical makeup, and physical shape all contribute positively to reducing the Ca(OH)2 impact. TG analysis shows the several phases that developed during temperature elevation. The results demonstrated why MK was used to improve mechanical characteristics and cracking after exposure to high temperatures. The optimal MK doses that were obtained at room temperature, however, differed from those that were acquired at higher temperatures. [37]. The relative residual compressive strength of HSP integrated by MK of 0.3 w/b is plotted vs temperature in Figure 20. The relative residual compressive strength of HSP integrated with MK of 0.35 w/b is plotted vs temperature in Figure 21. The relative residual compressive strength of HSP integrated by MK of 0.4 w/b is plotted vs temperature in Figure 22.

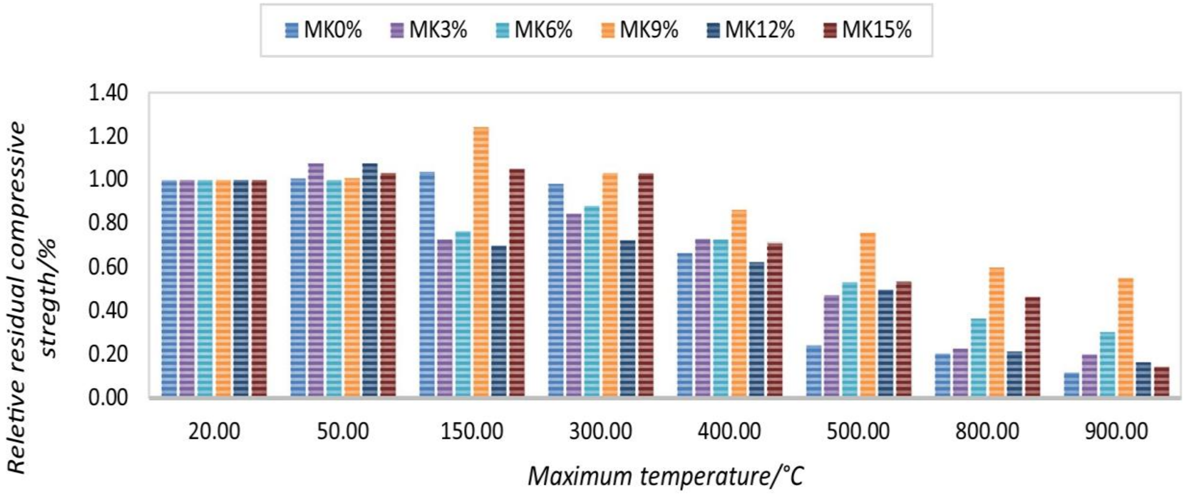

Figure 20. Temperature-dependent comparative residual compressive strength of HSP combined with 0.3 w/b MK [37]

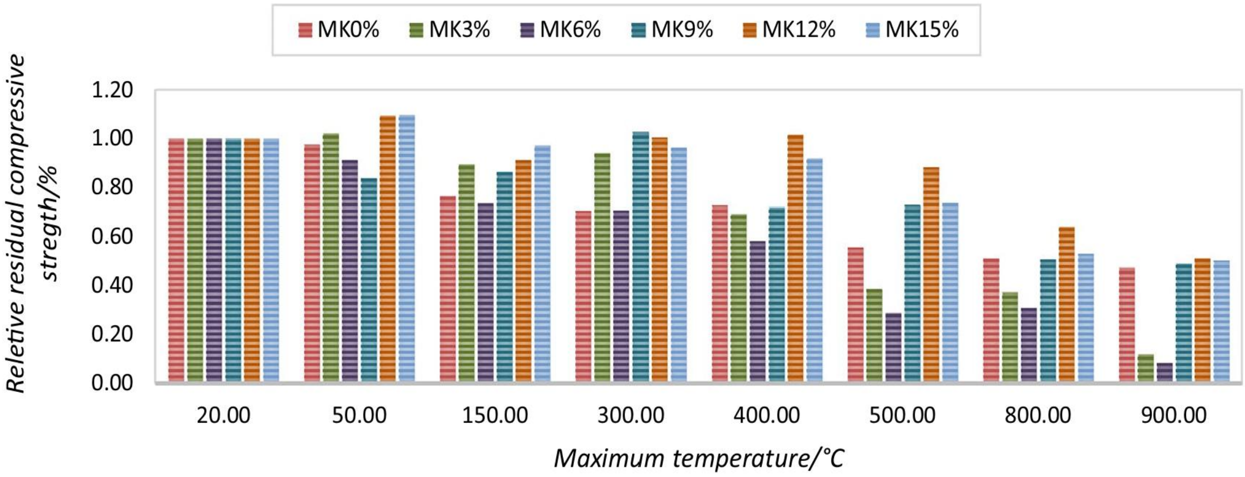

Figure 21. Temperature-dependent comparative residual compressive strength of HSP combined with MK of 0.35 w/b [37]

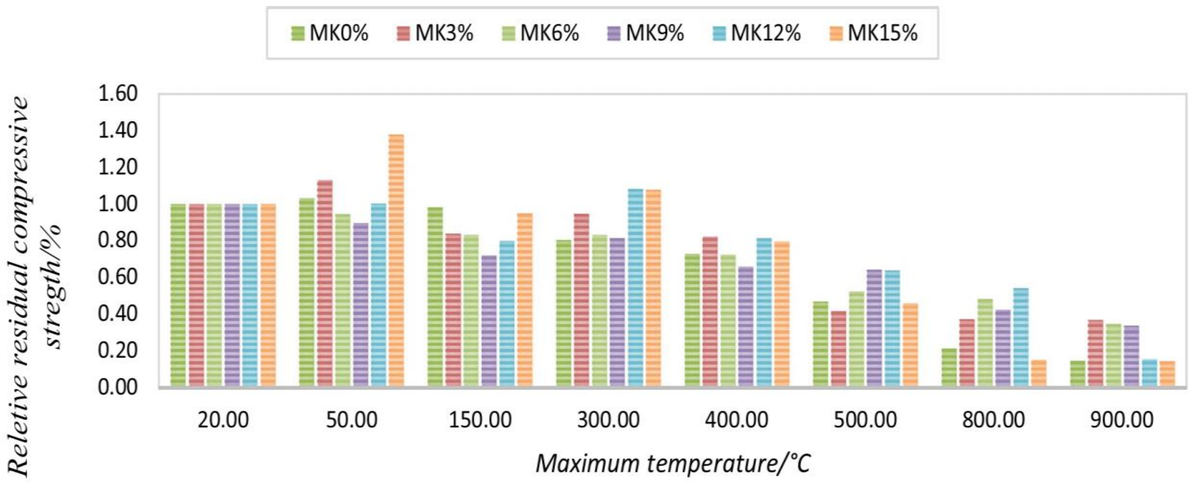

Figure 22. Temperature-dependent relative residual compressive strength of HSP combined with 0.4 w/b MK [37]

4. Conclusions

This study reviewed previous research on the impact of high temperatures on the flexural strength and durability of high strength concrete beams. High performance concrete (HPC) is used all over the world, although it may be exposed to higher fire risks, which could affect how it behaves. To learn more about HPC's mechanical performance at high temperatures, researchers have conducted a number of studies. According to the findings, concrete spalling, mass reduction, and durability are critical markers for assessing HPC's mechanical behavior at high temperatures. HPC's mechanical performance declined as the exposure temperature rose. Furthermore, weight loss rose nonlinearly with the maximum temperature, and concrete's strength decreased with abrupt cooling. It was discovered that one of the main causes of HPC degradation was specimen size. The water content of HPC has no effect on its compressive strength when exposed to temperatures above 800 °C. The mechanical performance of HPC at high temperatures is influenced by a number of variables, including heating conditions, concrete quality, fiber volume and type, and replacement levels. A number of variables, including as the quantity and kind of reinforcing fibers, the quality of the concrete, the replacement levels, and the heating circumstances, affect HPC's mechanical performance at high temperatures.

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