



A REVIEW ON FIRE-INDUCED RISKS IN REINFORCED CONCRETE BEAMS

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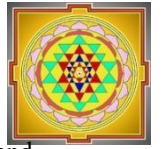
Abstract

Reinforced concrete (RC) beams are essential elements in structural systems, valued for their strength, durability, and inherent fire resistance; however, their performance can be severely compromised during fire events due to several critical factors. High temperatures cause thermal degradation of concrete, leading to a loss of compressive strength and microstructural damage, while the bond between concrete and steel reinforcement weakens, reducing the composite action vital to beam behavior. Spalling—where surface layers of concrete explosively break off due to thermal and pore pressure—exposes inner layers to heat, accelerating damage. The yield strength and stiffness of steel reinforcement also diminish with rising temperatures, further lowering load-carrying capacity and increasing the risk of collapse. Experimental studies and numerical simulations have been instrumental in identifying these failure mechanisms and understanding the impact of parameters such as heating rate, duration, load level, and cross-sectional size. Post-fire assessments provide real-world insights into residual capacity and damage patterns. To mitigate these risks, research has focused on improving fire-resistant design through advanced materials, protective coatings, and predictive fire modeling tools. Nevertheless, challenges remain in accurately simulating fire-structure interactions and understanding long-term post-fire performance, highlighting the need for further research to develop more resilient RC beam systems in fire-prone environments.

Key Words:- Reinforced concrete (RC), High temperatures, Thermal degradation, Experimental studies, numerical simulations, fire modeling tools

Introduction

Fire exposure significantly compromises the structural integrity of reinforced concrete (RC) beams through the degradation of both concrete and steel materials. Although concrete is inherently non-combustible, its mechanical properties—particularly strength and stiffness—deteriorate considerably at elevated temperatures; for example, compressive strength can reduce by more than 50% beyond 500°C. Simultaneously, reinforcing steel within the beam loses its yield strength and elasticity, typically starting around 300–400°C, which undermines the beam's load-bearing capacity. Prolonged exposure to high temperatures can also lead to spalling, where surface layers of concrete explosively detach, further exposing the inner reinforcement to heat. The severity of the damage depends on various factors, including fire duration, peak temperature, and thermal gradients within the cross-section. Additionally, the presence of structural restraints (like fixed supports or adjacent members) can induce thermal stresses and cracking, exacerbating deformation and reducing overall stability. Interestingly, although ductility may increase as materials soften, this gain is offset by the significant



loss in strength and stiffness, leading to potential structural failure if the beam is not adequately assessed and rehabilitated after a fire event.

Standard time-temperature curve

One common representation of the flashover and fully developed fire stages is the standard fire curve that represents the post-flashover stage, as shown in Figure 2.3. The most common standard time-temperature curves are ASTM-E119 and ISO-834 (or BS- 476). Figure 2.4 shows that the two standard fire curves are almost identical.

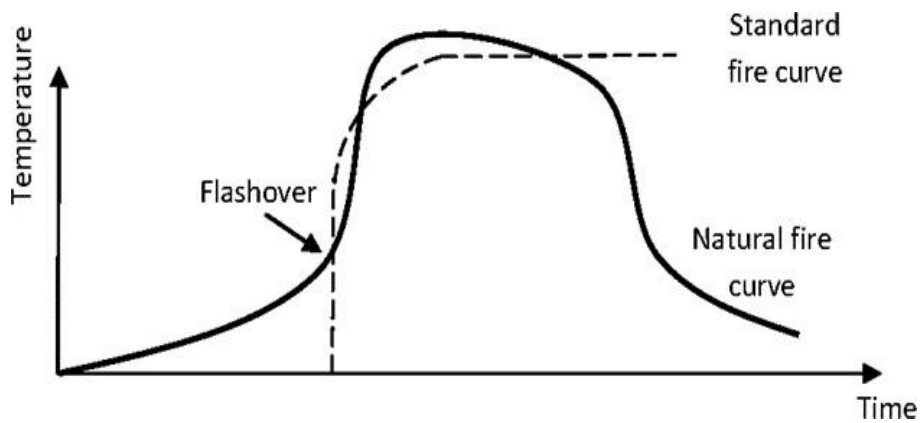


Figure 1 The standard fire curve as compared to a natural fire (Wit, 2011).

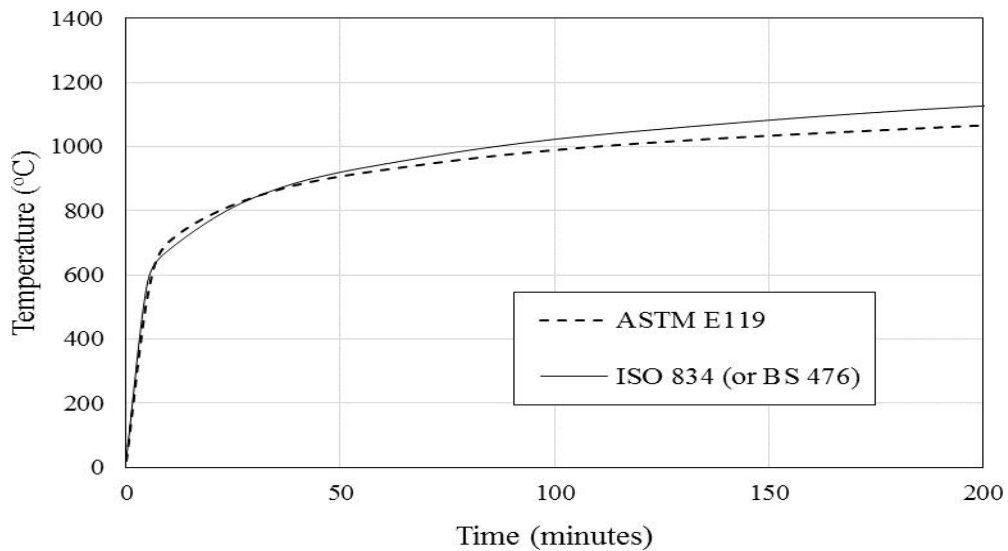


Figure 2 Standard fire curves.

Literature Review



Ali S.Alqarni et al (2022) was described experimental tests of the shear performance of high-strength reinforced concrete deep beams produced with different coarse aggregates, conducted at an ambient temperature of 25 °C and after heating to 600 °C. Three types of coarse aggregates of 10 mm maximum size were considered: limestone-based normal weight aggregate, quartzite-based normal weight aggregate, and steel slag-based heavyweight aggregate. Additionally, 20 mm maximum size aggregate was used for the steel slag concrete only. Eight beam specimens were designed to fail in shear, eliminating the possibility of flexural failure. Four beam specimens were tested at ambient temperature, and the corresponding four specimens were exposed to a temperature of 600 °C for 3 h. The results showed that the shear capacity of the deep beams tested at the ambient temperature was closely correlated with the abrasion resistance of the coarse aggregate. Exposure to an elevated temperature led to variable reduced shear strength, depending upon the type of aggregate. Compared to the beams tested in ambient conditions, the best performance was achieved by the limestone aggregate, followed by steel slag aggregate then quartzite aggregate, recording shear strength losses of 23.1%, 37.9% and 40.5%, respectively. This reduction in shear capacity was due to the reduction in compressive strength by 53–61% for the concrete exposed to 600 °C. The mid-span deflection at peak load was in general reasonably comparable for the beams tested at 25 °C and after exposure to 600 °C. The trend of stiffness loss after elevated temperature exposure for the various types of aggregate was very consistent with shear strength.

Seyed Bahram Beheshti Aval et al (2022) studied presents the results of long-term field measurement of two RC beams under the simultaneous effect of medium to high temperature, shrinkage, and self-weight creep. In industrial complexes such as steel making plants, these members may, in addition to creep and shrinkage, be exposed to high temperature. However, less attention has been paid to the simultaneous effect of creep, shrinkage, and temperature in a case study framework. In this regard, two RC beams with the same geometric properties in a pelletizing plant located in Kerman, Iran, were studied. In addition, in order to establish a powerful numerical method for these effects, numerical results were compared with the field measurement data. The results showed that an average increase by 50% in temperature would increase the maximum deflection of RC beam by 37%. In the case of the environment temperature, grate machine temperature increased the maximum deflection of RC beam by 61%. Moreover, field measurements showed that for self-weight creep level, shrinkage, temperature, and cracking strains covered more than 80% of the total strain. Similarly, such as this case study, simultaneous effects of these triple factors can change the long-term serviceability of structural elements exposed to harsh environmental conditions.

Tieming Zhou et al (2022) was observed in recent decades, reinforced-concrete bridges have experienced premature deterioration and other problems during service due to severe environmental effects such as fire and corrosion. Previous studies have shown that the use of ultra-high-performance concrete (UHPC) can improve the durability of bridge structures. In this study, four-point bending tests were conducted on twelve UHPC–NC laminated beams with different UHPC-layer heights and at different temperatures in order to evaluate their flexural performance under fire conditions. The test variables were the UHPC heights (20 mm, 50 mm, 80 mm) and temperatures (20 C, 200 C, 400 C, 600 C), and the effects on the flexural load capacity of UHPC–NC laminated beams under the influence of these factors were investigated. The test results show that the increase in temperature causes the concrete color to change from grayish blue to white and leads to a significant decrease in



the flexural load capacity of the stacked beams. The height of the UHPC layer has an important effect on the stiffness of the stacked beams and delays the formation of local cracks, thus improving the durability of the stacked beams

Zainab M.R.Abdul Rasoul **et al (2020)** was examined three of these beams were prepared with volume fraction of WPPF ratios 0%, 0.5%, and 1% to test under two-point loads without exposure to fire, while the other beams were prepared with same conditions to test after exposure to fire. The results showed that the reinforced concrete beams without fibers suffered significant reduction in overall performance and mechanical properties, when subjected to fire for enough time to reach elevated temperatures (400 C⁰). Both 0.5% and 1% of WPPF ratios didn't affect the flexural capacity before the fire, however, reduction in compressive strength occurred. On the other hand, the fiber improved the tensile strength and the first cracking load, and also reduced the loss in compression strength after the fire. Finally, the recommended optimal ratio of WPPF is not more than 0.5%.

Terro (1998) developed finite element computer programs to predict the behavior of three-dimensional reinforced concrete structures in fire. The programs were validated by comparing their predictions with the results of experimental testing. Lie (1992) described the utilization of numerical tools to determine the temperature distribution within cross-sections of structural elements and outlined how these numerical tools are used to calculate fire resistance. The detailed thermal and mechanical properties of concrete and steel were also detailed

Kodur and Dwaikat (2009) presented a macroscopic finite element model for tracing the performance of RC structural members during fire. Their model was validated by comparing its predictions with the results of full-scale experimental tests. The study suggested that a fire scenario has a noticeable effect on the fire resistance of structural elements. Kodur and Wang (2004) conducted a similar study to predict the fire resistance of high strength concrete columns. The predictions of this study showed a good agreement with the results of full-scale experimental tests.

Wisena Perceka et al (2019) Conducting research on steel fiber-reinforced concrete (SFRC) beams without stirrups, particularly the SFRC beams with high-strength concrete (HSC) and high-strength steel (HSS) reinforcing bars is essential due to the limitation of test results of high strength SFRC beams with high strength steel reinforcing bars. Eight shear strength prediction equations for analysis and design of the SFRC beam derived by different researchers are summarized. A database was constructed from 236 beams. Accordingly, the previous shear strength equations can be evaluated. Ten high-strength SFRC beams subjected to monotonic loading were prepared to verify the existing shear strength prediction equations. The equations for predicting shear strength of the SFRC beam are proposed on the basis of observations from the test results and evaluation results of the previous shear strength equations. The proposed shear strength equation possesses a reasonable result. For alternative analysis and design of the SFRC beams, ACI 318-19 shear strength equation is modified to consider steel fiber parameters



Rajai Z et al (2021) was examined exposure of concrete structures to elevated temperatures causes a severe deterioration because of decomposition of cement hydration products, generation of vapor pressure, and the inhomogeneous volume changes of concrete's ingredients and beyond a temperature of 500 °C. The most Retrieval the structural performance of severely heat-damaged structural concrete members would be most significantly achieved using carbon fiber-reinforced polymer (CFRP) composite materials. Nevertheless, deboning and anchoring problems remain a challenge for the success of this technique. In this study, an innovative application was implemented in which CFRP strips were integrated as external shear reinforcement for reinforced concrete (RC) beams by using the groove technique. The intent was to assess the CFRP strips' contribution to the shear strength and thus evaluate the effectiveness of using them as main or supplemental shear reinforcement before and after exposure to elevated temperature. The investigated parameters include the area and number of layers of CFRP strips and different elevated temperatures. By demonstrating an outstanding structural performance with significant enhancement in the ultimate strength, ultimate deflection, stiffness, and toughness, this paper's findings strongly attest that CFRP strips can be effectively utilized as external shear reinforcement in reinforced concrete beams exposed to elevated temperatures. New guideline and proposed empirical model are developed to predict the damage level and shear strength of heated damaged RC beams externally reinforced with CFRP composites considering the influence of the number of CFRP strips and elevated temperature as groove technique.

Simret T Deresa et al (2020) this article presents a comprehensive and critical review of the structural performances of reinforced recycled aggregate concrete beams and columns based on experimental results reported in the literature. Extensive data sets collected from the literature are categorized to investigate the effects on the local and global structural behavior. First, the flexural and shear response of reinforced recycled aggregate concrete beams is discussed. The structural performances are reviewed focusing on the main geometric and material variables such as the recycled concrete aggregate replacement ratio, the longitudinal reinforcement ratio, the transverse reinforcement ratio, and the shear span-to-depth ratio. Then, the behavior of reinforced recycled aggregate concrete columns under concentric and eccentric compressive loads and the seismic performance under low cyclic loading are discussed. The similarities and the differences between reinforced recycled aggregate concrete and reinforced natural aggregate concrete beams and columns are highlighted. The need for further research is pointed out at the end of the article. The results reported in this review clearly indicate that reinforced recycled aggregate concrete beams and columns with various recycled concrete aggregate replacement ratios have comparable or slightly lower structural performances to the reinforced natural aggregate concrete ones indicating the feasibility of recycled concrete aggregate for structural applications.

Dia Eddin Nassani et al (2020) it focuses primarily on beam deformation and stress at an equivalent size of 1500x150 x200 mm. Using software, a nonlinear FE model was developed to analyze the two hybrid RC beams. The experimentally and analytically obtained findings were compared and close associations between them found. In addition to initial and progressive cracking of FE and experimental analyses, deflection and stress at the centerline were compared and strong associations between them were found.



Chittaranjan B. Nayak et al (2020) using software to authenticate the experimental results and numerical results such as deflection and overall load carrying capacity for the various reinforcement patterns, the beam was modeled in order to authenticate the experimental results. Finally, this analysis concluded that different modes of experimental failure were seen and the numerical results were compared. The outcome of this research is expected to be of great help to improve the structure.

Sougata Chattopadhyay, et al. (2018) in this analytical study, twenty-four concrete beams of dimensions, 150 mm in width, 200 mm in depth and 1200 mm in length, reinforced with steel and GFRP, were modeled and analyzed until failure under the four point bending test using the Software. Solid65 is used as a concrete model and LINK180 as a steel and GFRP reinforcement test. They were analyzed using software tender four point loading. Mid-span deflection, stress, strain and concrete failure patterns were studied for six different levels of reinforcement ratio and four different grades of concrete.

Kiran Kumar Poloju et.al (2018) an elevated temperature test was performed on concrete grade cubes M20, M40 and M60, respectively. The specimens were held inside the oven and reached the necessary temperatures of 200⁰c, 400⁰c, 600⁰c and 800⁰c for constant 1-hour exposure to temperature. Specimens cooled under air-cooling and it is noted that concrete of the M20 grade had a slight increase in strength at 200 to 400⁰c, a drastic decrease in almost 50 percent of strength after 600⁰c -800⁰c is observed. Concrete sapling is mostly due to crack width expansion and it is observed that when concrete is exposed to 800⁰c, sapling begins. The color of the surface of the concrete was found to be light pink at 600⁰c and red-hot. At 800⁰c color. Even after the concrete surface was cooled, it was found to be a faint pink color. The magnitude of cracks reaches to 400⁰c and it contributes to concrete sapling at high temperatures.

Tomasz Drzymala et al (2018) the test was performed on three high-strength concrete types: air-trained concrete, fiber-reinforced polypropylene concrete and reference concrete with a constant w/c ratio of 0.3. The ISO 834 standard fire curve was followed by the heat treatment process in the furnace Compressive Reference concrete strength 21 percent gain at 300⁰c at elevated temperature, 12.5 percent gain at 450⁰c and 18 percent loss at 600⁰c, with reference to ambient temperature strength. With increasing temperature, the flexural strength decreased and showed a 6 percent loss at 300⁰c. Tensile intensity increased to 300⁰c by 5.2 percent, with terms starting to decrease by around 8.5 percent and 57 percent at 450⁰c and 600⁰c respectively. The young high-strength concrete module decreased at a rate of 34 percent, 58 percent and 83.5 percent at a temperature of 300⁰c, 450⁰c and 600⁰c, respectively.

Fatma Eid et.al (2017) the action of the Reinforced self- compacted Concrete Beam-Column attachment for 1 and 2 hours under standard fire was studied. 1/3rd scaled down test samples divided into three types based on the supplied reinforcement. Details of reinforcement- 4 16, 4 12, 4 12 longitudinal bars and minimum shear reinforcement for Case 1,2 and additional shear reinforcement for Case 3, respectively. The appropriate 600⁰C temperature is achieved in 6 minutes in the furnace and the 2018-19 Department of Civil Engineering, NIE Mysore 9 peak temperature analysis on reinforced concrete beam subjected to elevated temperature for 1 and 2 hours was maintained. A special loading arrangement was carried out to load the specimen under fire. The



temperature distribution inside the specimens was measured using a K-type thermocouple (900°C direct fire capacity), a furnace specifically designed for testing beam column connections. As the fire exposure period increased, the cracks increased and it was found that more cracks appeared on the specimen with additional stirrups than on other specimens. In case 1, the center of the specimen reached a temperature of 202 and 428 respectively after exposure to 1h and 2h of fire. The inside temperature of the specimens depends on the reinforcement ratio present, the temperature is high and the reinforcement is higher, and vice versa. [6]

Methodology

The methodology for reviewing fire-induced risks in reinforced concrete beams involves a systematic assessment of experimental studies, numerical simulations, and analytical models that explore the behavior of beams under elevated temperatures. Key parameters such as temperature distribution, material degradation (especially of concrete and steel reinforcement), structural failure modes, and fire exposure duration are evaluated. Experimental data from fire tests provide empirical insights, while finite element analysis (FEA) tools are used to simulate thermal and structural responses under standardized fire scenarios. The review also considers the influence of cross-sectional dimensions, reinforcement detailing, load conditions, and fire protection measures. Comparative analysis of existing design codes and guidelines (e.g., Eurocode, ACI) further aids in identifying gaps in current practices and potential areas for improvement.

Conclusion

Fire-induced risks in reinforced concrete (RC) beams pose significant threats to structural integrity, primarily due to the deterioration of both concrete and steel reinforcement under elevated temperatures. Fire exposure reduces the mechanical properties of concrete, such as strength and stiffness, and leads to spalling, which exposes the reinforcement to direct heat, accelerating the loss of yield strength and ductility in steel bars. These effects can compromise the load-bearing capacity and serviceability of RC beams, making early detection, fireproofing measures, and post-fire assessments critical. The severity of damage depends on factors such as fire duration, peak temperature, beam geometry, loading conditions, and the type and arrangement of reinforcement. Therefore, understanding the thermal and mechanical responses of RC beams under fire scenarios is essential for developing robust design codes, enhancing fire resistance through material innovation (like fiber-reinforced concrete or intumescent coatings), and improving structural resilience and safety during and after fire events..

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