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THERMAL EFFECTS ON THE STRUCTURAL INTEGRITY OF REINFORCED CONCRETE BEAMS

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ABSTRACT :

Reinforced concrete structures are significantly affected by elevated temperatures, particularly in fire scenarios, which are becoming more frequent due to global warming and increased construction activity. This experimental study evaluated the structural performance of reinforced concrete beams after exposure to temperatures up to 800 °C, using concrete cubes, steel rebar's, pull-out test specimens, and full-scale reinforced concrete beams. After heating and air cooling, the specimens were tested according to standardized procedures. The results reveal that concrete compressive strength suffers a considerable degradation, decreasing by approximately 55% at 600 °C and reaching an alarming 82% reduction at 800 °C. While the yield strength of steel remains relatively stable up to 600 °C, it begins to deteriorate at higher temperatures, showing a nearly 30% reduction at 800 °C. This pronounced loss in compressive strength, combined with the decline in steel yield strength and the weakening of the concrete-steel bond, leads to a significant drop in the overall load-bearing capacity of reinforced concrete beams. The findings highlight the critical importance of assessing fire resistance and implementing fire-protective strategies in reinforced concrete design to ensure structural safety and durability under high-temperature conditions.

Key Words:- Reinforced concrete (RC), Elevated temperatures, Construction activity, Yield strength, Reinforced concrete design

Introduction

The provided paragraph discusses the vulnerability of *Reinforced Cement Concrete (RCC) beams* to fire damage and emphasizes the importance of *post-fire strengthening and retrofitting* methods to restore structural integrity. Below is a *detailed explanation* of the topic, expanding on key technical points.

Reinforced Concrete (RCC) and Fire Exposure

Reinforced concrete is widely used in modern construction due to its excellent *compressive strength*, *durability*, and ability to form complex structural elements. However, RCC structures are not immune to *fire hazards*. During a fire, the intense heat affects both the *steel reinforcement* and the *concrete matrix*, leading to degradation in their mechanical properties.

Concrete Damage: When exposed to high temperatures (typically above 300°C), concrete begins to lose its *compressive strength*. At temperatures around 500–600°C, significant spelling (breaking away of surface layers) can occur due to vapor pressure buildup, especially in dense concrete mixes. The *modulus of elasticity*, which is a measure of stiffness, also decreases substantially, leading to increased deflection under load.

Steel Reinforcement Damage: Steel reinforcement embedded in concrete begins to lose its *yield strength* and *ductility* at elevated temperatures. Around 600°C, steel can lose nearly 50% of its original strength, compromising the load-bearing capacity of RCC beams.

The *severity of the damage* depends on multiple factors:

- Maximum temperature reached during the fire
- Duration of exposure
- Cross-sectional size of the beam
- Cover depth (distance from surface to reinforcement)
- Original design and load conditions

Post-Fire Strengthening and Retrofitting Methods

To ensure safety and serviceability after a fire event, engineers must *retrofit or strengthen* the affected RCC members. This involves repairing damaged portions and enhancing the beam's performance to resist future loads. One of the most promising technologies in this area is the use of *Fiber-Reinforced Polymer (FRP) composites*.

Fiber-Reinforced Polymer (FRP) Composites

FRPs are made by combining high-strength fibers (e.g., carbon, glass, or aramid) with a polymer resin matrix. The resulting material is:

- *Lightweight* yet strong
- *Non-corrosive*, which enhances longevity
- *Easy to install*, even on existing structures

Application Techniques:

- *Externally Bonded FRP Sheets or Wraps:* These are applied to the surface of beams using epoxy adhesives. They improve the *flexural strength*, *shear capacity*, and *ductility* of fire-damaged beams.
- *Near-Surface Mounted (NSM) FRP Bars:* Involves embedding FRP bars into grooves cut into the concrete surface. This method is more durable in harsh conditions and provides better bond strength.
- *FRP Jacketing:* Involves wrapping the beam completely to confine and reinforce it against further deterioration.

Benefits of FRP Strengthening:

- Restores or even enhances the *original load-bearing capacity*
- Quick installation with *minimal disturbance*
- Suitable for irregular shapes and surfaces
- Can be designed for *specific load paths* (flexure, shear)

While FRP systems have shown significant promise, there are some *challenges*:

- *Bond performance* can deteriorate under high temperatures or if improperly applied
- Epoxy resins used for bonding may lose strength at elevated temperatures
- *Inspection and quality assurance* are crucial for ensuring long-term performance

Literature Review

Prof. S. V. Dhoke et al (2024) This study explores the impact of fire exposure on the structural performance of reinforced concrete (RC) beams by subjecting them to controlled high temperatures ranging from 300°C to 700°C and evaluating the resulting changes in compressive strength, surface condition, and internal microstructure. The degradation in performance, primarily due to the thermal breakdown of cement paste and aggregate, was quantified using non-destructive techniques such as the rebound hammer and Ultrasonic Pulse Velocity (UPV) meter, followed by two-point loading tests in a Universal Testing Machine (UTM). The results revealed a notable reduction in compressive strength with increasing temperature, accompanied by sapling, the development of surface cracks, and significant microstructural changes, including altered pore structures. To assess post-fire rehabilitation methods, selected beams were strengthened using Glass Fiber Reinforced Polymer (GFRP) sheets applied in two configurations: full U-shaped wrapping along the entire length and U-shaped wraps at specific intervals. These strengthened specimens were also tested under two-point loading, and the findings demonstrated that GFRP wrapping effectively restores structural capacity, with full U-shaped wrapping providing superior performance, indicating its potential as a viable solution for rehabilitating fire-damaged RC beams.

Dr. Mohammad Zuhair et al (2023) this study investigates the effects of high temperatures on reinforced concrete (RCC) beams, focusing on how thermal stresses impact material properties and overall structural performance. Experimental results reveal that RCC beams show no visible damage up to 300°C–400°C; however, discoloration begins at 500°C, minor sapling is observed at 600°C, and significant cracking with light brown discoloration becomes evident at 700°C. The compressive strength of concrete is notably affected between 300°C and 700°C, showing a drastic reduction ranging from 20% to 80%. The study highlights the importance of identifying post-fire damage indicators such as cracks, sapling, and loss of strength in both concrete and steel reinforcement. To evaluate the residual strength and structural integrity of fire-exposed RCC members, non-destructive testing methods like Ultrasonic Pulse Velocity (UPV) and Rebound Hammer tests were employed. Additionally, strengthening techniques using Glass Fiber Reinforced Polymer (GFRP) sheets were explored as an effective means to restore load-bearing capacity and ensure continued safety of the structures. This comprehensive evaluation provides valuable insights into the thermal behavior of RCC beams and effective post-fire rehabilitation methods.

Methodology

This study aims to experimentally investigate the effects of elevated temperatures on the structural integrity of reinforced concrete (RC) beams. The methodology comprises specimen preparation, controlled heating, and subsequent mechanical testing, as outlined below:

Specimen Design and Preparation

- *Beam Dimensions:* Standard RC beam specimens (e.g., 150 mm × 200 mm × 1200 mm) were cast based on IS 456:2000 guidelines.
- *Concrete Mix:* M25 grade concrete was used, prepared using OPC 43 grade cement, river sand as fine aggregate, and crushed stone as coarse aggregate.

- *Reinforcement Details:* TMT bars of Fe500 grade were used with 2 main bars at the bottom and stirrups placed at 150 mm c/c spacing.
- *Curing:* All specimens were water-cured for 28 days to ensure proper hydration and strength development.

Temperature Exposure

- *Heating Regimes:* Specimens were exposed to varying target temperatures (e.g., 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, and 700°C) in a programmable furnace.
- *Soaking Time:* Each specimen was held at the target temperature for 2 hours to simulate real fire scenarios.
- *Cooling:* After heating, some beams were cooled gradually (natural air cooling), while others were subjected to sudden cooling (water quenching) to study cooling effects.

Physical Observations

- After thermal exposure, visual inspection was performed to document surface discoloration, crack formation, sapling, and deformation.
- Changes in texture, color (pink, brown, gray), and surface cracks were recorded photographically.

Mechanical Testing

- *Flexural Test:* A two-point loading test was conducted on each beam to determine the ultimate load-carrying capacity after thermal exposure.
- *Deflection Measurement:* Dial gauges were used to measure the mid-span deflection throughout the loading process.
- *Compressive Strength:* Cube specimens were also tested at each temperature level to correlate concrete strength loss with beam performance.

Data Analysis

- Load-deflection curves were plotted for each temperature level.
- The percentage reduction in load-carrying capacity and stiffness was calculated.
- Structural degradation patterns were analyzed in relation to temperature and cooling method.

Safety and Standards

- All testing procedures complied with IS 516:2018 (Methods of Tests for Strength of Concrete) and IS 1608 for steel.
- Proper fire safety protocols and laboratory safety standards were maintained throughout the heating and testing process.

Result analysis

Shear failure in reinforced concrete (RC) beams is a type of brittle failure that occurs when the beam's shear strength is exceeded before flexural capacity is reached. This mode of failure is typically characterized by diagonal cracking, especially near the supports, where shear stresses are highest. The *load-bearing capacity in shear* refers to the maximum load that a beam can carry before failing in shear. Shear force in a beam arises due to transverse loading (perpendicular to the longitudinal axis), which tries to slide one part of the beam over the other. These internal shear forces generate shear stresses that must be resisted by both concrete and reinforcement. The *shear failure load* **or** *load-bearing capacity in shear* is the maximum load a beam can withstand before it fails due to shear stress. This failure is influenced by beam geometry, concrete strength, and the amount and detailing of shear reinforcement. Ensuring sufficient shear capacity is crucial for preventing sudden, brittle collapse and ensuring overall structural safety.

Table 1 Load-bearing capacities of the shear failure

Temperature in °C	load-bearing capacities (KN)
0	207.14
100	204.49
200	189.32
300	184.65
400	180.61
500	175.67
600	170.89
700	135.17
800	98.74
900	72.58

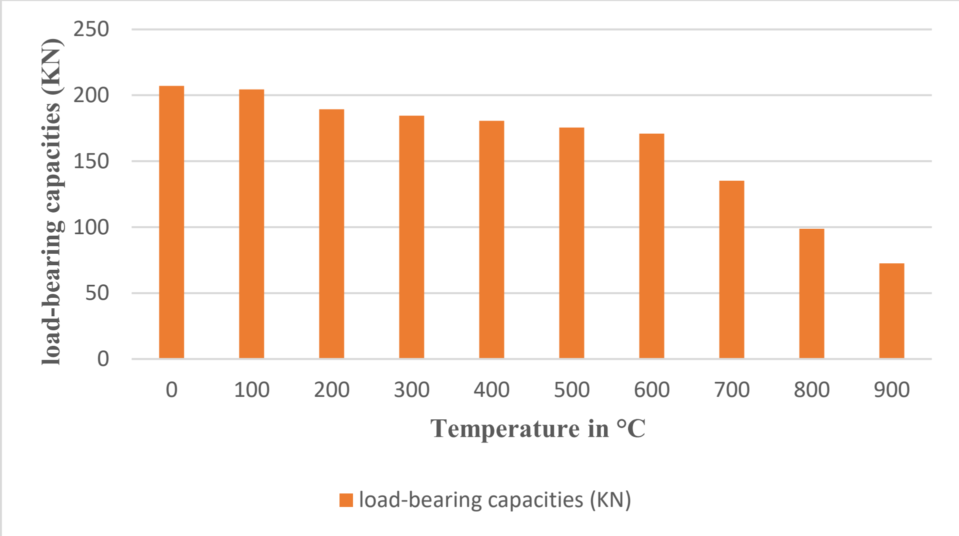

Figure 1 Load-bearing capacities graph

Conclusion

The study clearly shows that *elevated temperatures have a progressively destructive impact* on the shear capacity of reinforced concrete. While moderate heating cause's minimal strength loss, temperatures above *500°C* initiate significant structural deterioration. At temperatures *above 700°C*, the load-bearing ability becomes critically low, indicating that *structural safety is compromised* and post-fire assessment and possible retrofitting or replacement would be essential. These results emphasize the need for *fire-resistant design strategies* and the incorporation of thermal protection measures in critical structural elements. At *800°C and 900°C*, the structural integrity becomes severely compromised, with capacities falling to *98.74 kN* and *72.58 kN*, respectively—representing a *52.3% and 64.9% total reduction* from the initial value. These temperatures induce extensive *material decomposition*, such as the breakdown of calcium silicate hydrate (C-S-H) gel, and possible *melting of reinforcement surface layers*, making the structure unsafe under service loads.

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