

Effects of Elevated Temperatures on RCC Beams: Damage Assessment & Performance Evaluation

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Abstract:

This study examines how high temperatures affect reinforced concrete (RCC) beams, emphasizing how thermal stresses alter material characteristics and structural performance. According to experimental findings, there is no discernible harm up to 300°C to 400°C; nevertheless, at 500°C, discoloration starts, mild spalling starts at 600°C, and large fractures with light brown discoloration start to emerge at 700°C. Between 300°C and 700°C, compressive strength drastically decreases, ranging from 20% to 80%. Finding fractures, spalling, and strength loss in steel reinforcing is crucial, according to post-fire damage assessment. Remaining strength and structural integrity were assessed using non-destructive testing instruments including the Ultrasonic Pulse Velocity meter and Rebound Hammer. In order to restore fire-damaged RCC elements and guarantee structural integrity and load-bearing capability, strengthening techniques such as the use of GFRP sheets were also investigated. This comprehensive analysis provides insights into performance evaluation and effective repair techniques for fire-exposed RCC structures

Keywords: RCC beams, elevated temperatures, thermal stresses, compressive strength, damage assessment, spalling

1. Introduction

The foundation of contemporary infrastructure is made up of reinforced concrete (RCC) constructions, which offer stability, strength, and longevity. However, these constructions have serious difficulties in the event of a fire, which may jeopardize their safety and integrity. RCC beams must undergo post-fire strengthening and retrofitting in order to regain their structural strength and guarantee continuous operation. In order to provide light on successful approaches, difficulties, and potential future directions in this area, this thesis examines these processes through a thorough analysis of the body of current research. RCC beam damage from fire results from a confluence of material behavior and thermal factors. During a fire, high temperatures can cause steel reinforcing to deteriorate and concrete qualities like strength and modulus of elasticity to deteriorate. According to the literature, a number of variables, including temperature, the length of the fire, and the beams' structural arrangement, affect how severe the damage is.

Researchers and engineers have created a variety of strengthening and retrofitting methods to increase the durability of RCC beams in response to damage caused by fire. Because of its high strength-to-weight ratio, resistance to corrosion, and ease of use, fiber-reinforced polymer (FRP) composites have become a popular option. Research has demonstrated that externally attached fiber-reinforced polymer (FRP) sheets or wraps may successfully repair fire-

damaged beams' flexural and shear capabilities, offering a practical rehabilitation alternative.

Reinforced Cement Concrete (RCC) beams are fundamental elements in modern construction (Carlos et al., 2018), providing essential structural support for buildings, bridges, and other infrastructure (Shang et al., 2020). The combination of concrete's compressive strength and steel reinforcement's tensile strength allows RCC beams (Amin et al., 2022) to withstand various loads and stresses (Abdulrahman & Kadir, 2022), ensuring the stability and safety of structures. RCC beams are preferred due to their durability, versatility (da Costa et al., 2023), and ability to be molded into various shapes and sizes, making them suitable for a wide range of applications (Jafarzadeh & Nematzadeh, 2022). They play a crucial role in maintaining the integrity of multi-story buildings (Mathews et al., 2021), industrial facilities, and transportation infrastructure (Mohammed & Said, 2022), contributing to the overall resilience and longevity of these structures (Mejía et al., 2024).

Fire exposure significantly affects the structural integrity and material properties of RCC beams (Firmo, Correia, et al., 2015). High temperatures can cause severe damage to both concrete and steel reinforcement. Concrete (Dai et al., 2015), when subjected to intense heat, experiences thermal expansion and spalling (Lenwari et al., 2020), leading to the loss of material from the surface. This results in a reduction in cross-sectional area (Kodur & Yu, 2016), compromising the beam's load-bearing capacity. Additionally (Thanaraj et

al., 2020), the dehydration of cement paste at elevated temperatures weakens the bond between the concrete and the aggregate (Abdulrahman & Kadir, 2022), further diminishing the concrete's mechanical properties (Zhang et al., 2018b).

The steel reinforcement within RCC beams is also adversely affected by fire (Ma et al., 2019). As temperatures rise, the steel loses its yield strength and stiffness, making it more susceptible to deformation under load (Zhang et al., 2018a). The differential thermal expansion between concrete and steel can cause cracking and debonding at the interface (Yu et al., 2018), further compromising the structural performance of the beam (Alshannag & Alshenawy, 2020). Prolonged exposure to high temperatures can lead to significant reductions in the overall structural capacity of RCC beams, necessitating urgent rehabilitation and strengthening measures (Firmo, Arruda, et al., 2015).

The concrete and reinforcing characteristics of RCC beams vary as a result of thermal stresses during fire exposure. For steel reinforcement to show signs of cracking, spalling, or strength loss, damage evaluation is essential. Performance evaluation establishes the load-bearing capability and residual strength. Repair techniques that restore structural integrity and aesthetics include shotcrete, epoxy injection, and jacketing. By assessing compressive strength, structural integrity, failure load, and deflection using NDT instruments like the Rebound Hammer and Ultrasonic Pulse Velocity meter at different temperatures, this study investigates the impact of fire on RCC elements. For RCC elements damaged by fire, it also looks at reinforcing techniques with GFRP sheets.

2. SYSTEM DEVELOPMENT

2.1 Introduction

The foundation of contemporary infrastructure is made up of reinforced concrete (RCC) constructions, which offer stability, strength, and durability. However, these constructions encounter serious difficulties in the event of a fire, which may jeopardize their safety and integrity. RCC beams must undergo post-fire strengthening and retrofitting in order to regain their structural strength and guarantee continuous operation. In order to provide light on successful approaches, difficulties, and potential future directions in this area, this thesis examines these processes through a thorough analysis of the body of existing research.

RCC beam damage from fire results from a confluence of material behavior and thermal factors. During a fire, high temperatures can cause steel reinforcing to deteriorate and concrete qualities like strength and modulus of elasticity to deteriorate. The length of the fire, the temperature, and the beams' structural arrangement are some of the variables that affect how severe the damage is, according to the literature.

3. Specimen Description

To ascertain the new composite's textural behavior, $150 \times 100 \times 150$ mm beam specimens were evaluated. The ten M25 grade no beam specimens exhibited identical failure mechanisms and had the same tension reinforcement ratio (ρ_t) and 8mm dia stirrup spacings of 100mm c/c. In the compression face, the concrete crushed the two beams. the concrete's mixing percentage. is used as mixing water here. A summary of the mechanical characteristics of hardened concrete after 28 days of moisture curing is provided. After the usual 28-day curing period, cyclic wet and dry conditions were used to mimic the corrosion process under salt attack.



Figure 1: beam Specimen

Materials Use:

A vital ingredient in contemporary building, cement is essential to the production of concrete. Based on the ratios of its main components—cement, sand, and aggregate—concrete is divided into three categories: ordinary, standard, and high-strength. One of the most widely used concrete grades is M25, where "M" refers for "mix" and the number represents the concrete specimen's typical compressive strength in megapascals (MPa) after 28 days. Knowing the M25 mix ratio offers information on its composition and uses. A naturally occurring substance, river sand is taken from riverbanks and riverbeds. Its fine, spherical grains are the result of long weathering processes that eroded rocks and minerals over millennia. River sand is a popular resource in many construction projects because of its reputation for quality and consistency. Granular materials like crushed stone, gravel, or natural sand are known as coarse aggregates in construction and are

essential to the creation of concrete. These aggregates, which are usually obtained from quarries or by mechanical crushing, need to be cleaned before use in order to guarantee quality. Their strength, size, and angular shape have a considerable impact on the characteristics of concrete. Because coarse aggregates can range in size from 4.7mm to 63mm and are often kept on a 4.7mm screen, their precise selection is essential to guaranteeing the end product's strength and longevity.

3.4 Equipment Use:

The steel mold that was used in the creation is 60 cm by 100 cm by 150 cm. To guarantee the placement of the reinforcement, cover blocks are positioned at the sides and bottom of the mold. For added strength and stability, the beam is strengthened with two bars of 12 mm in diameter at the top and bottom, as well as stirrups of 10 mm in diameter.



Figure 2: mould

2. Stirrups: To properly hold reinforcement, stirrups with a diameter of 10 mm are used. Four stirrups spaced 40 mm apart are used in a single beam.



Figure 3: Stirrups

Depending on what kind of heating elements are employed in its construction, a muffle furnace can reach a variety of maximum temperatures. With a typical temperature range of 0°C to 1200°C, these furnaces are frequently used for high-temperature applications and can be used for a range of industrial and laboratory activities.



Figure 4: Muffle Furnace

4. Universal Testing Machine (UTM): A UTM is a multipurpose mechanical testing device that is used to assess the mechanical characteristics of materials under bending, torsion, compression, and tension. Tensile strength, compressive strength, modulus of elasticity, and other

properties can be determined by applying controlled loads to specimens and monitoring their reaction. UTMs are frequently used in manufacturing facilities, research institutes, and materials testing labs to evaluate the quality and performance of materials in a variety of industries.



Figure 5: universal testing machine

5. Dial gauge: Two pointer arms, A1 and A2, are carried by the dial gauge's clock-like graded dial (Fig.). Each of the 100 equal divisions on the dial corresponds to a spindle movement of 0.02 mm. The arm A1 completes one full turn on the dial for every 1 mm of spindle movement. The number of

complete rotations done by the longer arm A1 is recorded by the smaller arm A2.

4. PERFORMANCE ANALYSIS

4.1. Testing On beam Expose To Fire:

4.1.1 Reference Specimen One (RS1):

This reference specimen serves as a point of reference. The fired beam is compared to this reference specimen. Following testing, all findings are compared to RS1, and the remaining beams are fire supplied differently utilizing a muffle furnace.



Figure 6: Reference Specimen one

4.1.2 Temperature Specimen One (TS1 Fired At 300°C):

There would probably be serious repercussions if a specimen was exposed to 300°C, such as heat stroke, burns, and equipment damage. Although spacesuits are made to endure extremely high temperatures, they cannot function at 300°C. RC beams and other reinforced concrete (RC) structures are severely damaged by high temperatures. It has been documented that high temperatures cause RC beams to lose stiffness and strength with comparatively large permanent deformations.

Equipment Damage: The specimen's electronics, spacesuit, and any other equipment they may be carrying could all be harmed by the intense heat. The specimen's capacity to operate safely in space may be jeopardized if components melt or break.

4.1.2 Temperature Specimen One

4.1.3 Temperature Specimen two (TS2 Fired At 400°C):

Because of the high temperatures involved, operating a muffle furnace at 400°C necessitates accurate calibration and adherence to safety procedures. Deep tissue damage can result from instantaneous heat burns at 400°C. Heat shock, which overwhelms the body's thermoregulation and may result in organ damage, can be brought on by such intense heat. Functionality may be compromised by equipment failure or melting, including spacesuits. Furthermore, quick dehydration and electrolyte imbalance brought on by the extreme heat might raise the risk of heat exhaustion or heatstroke.



Figure 7: Temperature Specimen Two



Figure8: Temperature Specimen Three



Figure 9: Fired Process on Beam At (500°)

4.1.4 Temperature Specimen Four (TS4 Fired At 600°c):

It is true that exposing a specimen to 600°C would have disastrous results:
Immediate Burns: The specimen's skin and any exposed tissues would be immediately and severely burned upon contact with surfaces heated to 600°C, causing significant tissue damage and perhaps setting clothing or equipment on fire.

4.2. Rebound Hammer Test Result :

A concrete beam's strength and endurance may be significantly impacted by changes in its material qualities brought on by fire exposure. One popular technique for determining the strength of concrete is the rebound hammer test. After a concrete beam has been exposed to fire, the rebound hammer test can be used as follows.

Table 1: Rebound Hammer Test results

REBOUND NO					
Location-1	Location-2	Location-3	Average	Compressive strength	
36	32	31	33	25	Good
24	26	23	24.33333333	19.05	Fair
20	21	20	20.33333333	15.05	Fair
19	18	16	17.66666667	10	Poor

14	12	13	13	8	Poor
12	13	9	11.33333333	5	Poor



Figure 10: Rebound Hammer graph

4.2.2 Ultra Sonic Pulse Velocity Test Result :

Fire exposure can drastically change an RCC (reinforced concrete) beam's characteristics, especially its strength and integrity. Testing for ultrasonic pulse velocity (UPV)

following fire exposure can reveal important information about the beam's condition. The test findings could be interpreted as follows.

Table 2: Ultrasonic Velocity Test

TEMPRATURE COMPARISON						
UITRASONIC VELOCITY TEST						
SR	SPECUMEANS	TEMP	INDIRECT	SEMI DIRECT	DIRECT	(DIRECT) TIME Sec
1	RS1	0	6329m/sec	6157m/sec	1136m/sec	27.01
2	TS1	300	3267m/sec	4789m/sec	818m/sec	29
3	TS2	400	3274m/sec	4052m/sec	9677m/sec	32.02
4	TS3	500	108.6m/sec	802.3m/sec	187.2m/sec	34.8
5	TS4	600	1409m/sec	544m/sec	177m/sec	26.3
6	TS5	700	832m/sec	438m/sec	168m/sec	25.1

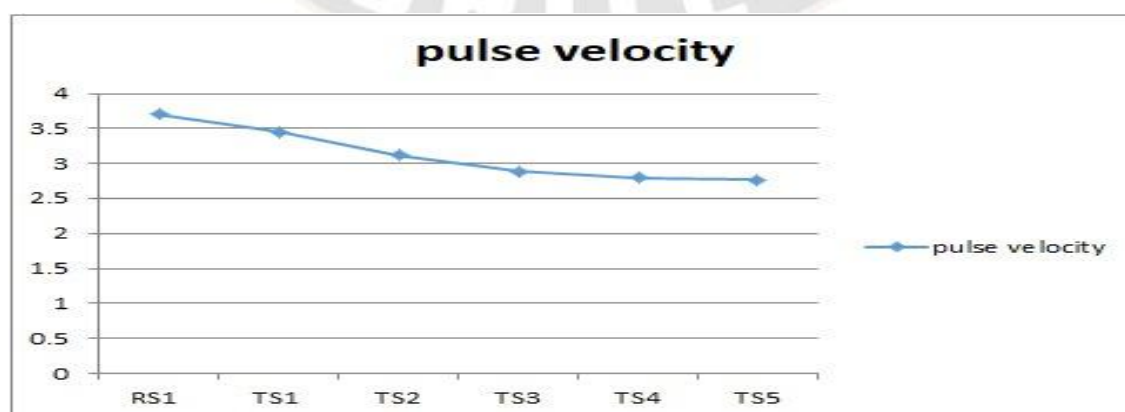


Figure 11: Ultra Sonic pulse velocity graph

Table 2: Load Test Result

	TEMPRATURE COMPARISION	
SR	SPECUMEANS	Failure Load KN
1	RS1	116.4
2	TS1 (300)	100.5
3	TS2 (400)	96.64
4	TS3 (500)	73.5
5	TS4 (600)	69.4
6	TS5 (700)	72.7

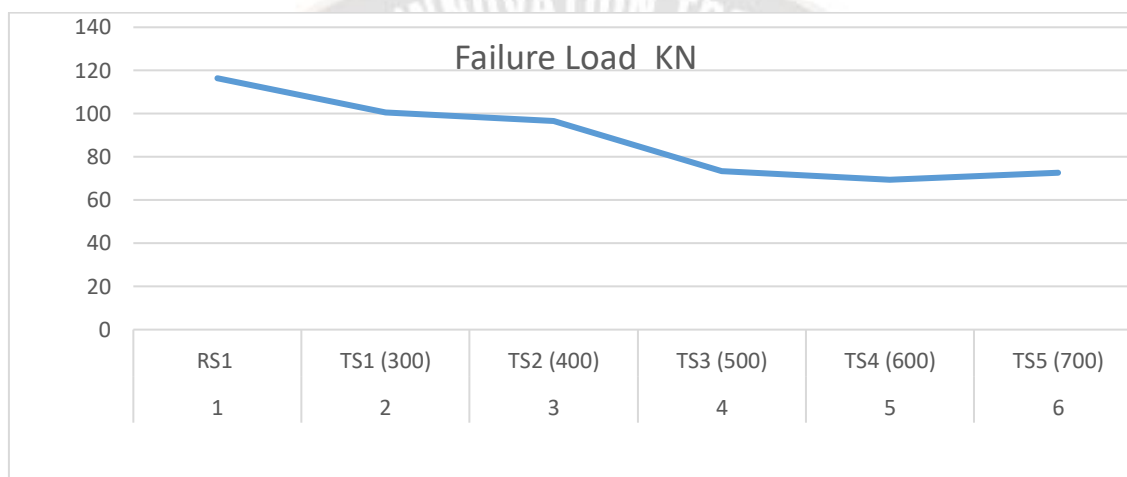


Figure 12: Failure load graph

In order to test a beam with a Universal Testing Machine (UTM), the specimen must be prepared in accordance with standards, fixed firmly in the UTM, and the machine must be configured with the proper test parameters. The UTM records data such load, displacement, and time while progressively applying load in tension or compression. In order to assess mechanical attributes such as ultimate strength, yield strength, and elasticity, engineers examine this data. To evaluate the structural integrity of the beam, the test is conducted repeatedly until failure or a predetermined endpoint is reached. The results are recorded in a comprehensive report.

5. CONCLUSION

In summary, the test results suggest that, up to 300°C to 400°C, beams do not exhibit any discernible temperature effects. At 500°C, however, discolouration happens without spalling. At 600°C, there is some spalling, but at 700°C, there are significant fissures and mild brown staining. Additionally, as temperatures rise, both rebound numbers and compressive strength decline. Between 300°C and 400°C, compressive strength decreases by 20% to 80%, and at 700°C, it decreases by 80%.

REFERENCES

1. Abdulrahman, A. S., & Kadir, M. R. A. (2022). Behavior and flexural strength of fire damaged high strength reinforced rectangular concrete beams after strengthening with CFRP laminates. *Ain Shams Engineering Journal*, 13(6), 101767.
2. Alshannag, M. J., & Alshenawy, A. (2020). Effective strengthening schemes for heat damaged reinforced concrete beams. *Journal of King Saud University-Engineering Sciences*, 32(4), 236–245.
3. Amin, A., Tamal, S., Bari, A. F., Mazumder, M., & Hasan, M. A. (2022). Strengthening of fire damaged reinforced beams by using ferro cement. *Turkish Journal of Engineering*, 6(3), 206–210.
4. Carlos, T. B., Rodrigues, J. P. C., de Lima, R. C., & Dhima, D. (2018). Experimental analysis on flexural behaviour of RC beams strengthened with CFRP laminates and under fire conditions. *Composite Structures*, 189, 516–528.
5. da Costa, L. M., de Carvalho Pires, T. A., & Silva, J. J. R. (2023). Shear strengthening of fire-damaged reinforced concrete beams using NSM CFRP laminates. *Engineering Structures*, 287, 116175.
6. Dai, J.-G., Gao, W.-Y., & Teng, J. G. (2015). Finite Element Modeling of Insulated FRP-Strengthened RC Beams Exposed to Fire. *Journal of Composites for*

- Construction, 19(2), 04014046. [https://doi.org/10.1061/\(ASCE\)CC.1943-5614.0000509](https://doi.org/10.1061/(ASCE)CC.1943-5614.0000509)
7. Firmo, J. P., Arruda, M. R. T., & Correia, J. R. (2015). Numerical simulation of the fire behaviour of thermally insulated reinforced concrete beams strengthened with EBR-CFRP strips. *Composite Structures*, 126, 360–370.
8. Firmo, J. P., Correia, J. R., & Bisby, L. A. (2015). Fire behaviour of FRP-strengthened reinforced concrete structural elements: A state-of-the-art review. *Composites Part B: Engineering*, 80, 198–216.
9. Jafarzadeh, H., & Nematzadeh, M. (2022). Flexural strengthening of fire-damaged GFRP-reinforced concrete beams using CFRP sheet: Experimental and analytical study. *Composite Structures*, 288, 115378.
10. Kodur, V. K. R., & Yu, B. (2016). Rational Approach for Evaluating Fire Resistance of FRP-Strengthened Concrete Beams. *Journal of Composites for Construction*, 20(6), 04016041. [https://doi.org/10.1061/\(ASCE\)CC.1943-5614.0000697](https://doi.org/10.1061/(ASCE)CC.1943-5614.0000697)
11. Lenwari, A., Thongchom, C., & Aboutaha, R. S. (2020). Cyclic flexural performance of fire-damaged reinforced concrete beams strengthened with carbon fiber-reinforced polymer plates. *ACI Structural Journal*, 117(6), 133–146.
12. Ma, W., Yin, C., Zhou, J., & Wang, L. (2019). Repair of fire-damaged reinforced concrete flexural members: A review. *Sustainability*, 11(19), 5199.
13. Mathews, M. E., Kiran, T., & Al-Jabri, K. (2021). Flexural behavior of fire damaged self-compacting concrete beams strengthened with fiber reinforced polymer (FRP) wrapping. *Journal of Structural Fire Engineering*, 12(4), 486–509.
14. Mejía, N., Sarango, A., & Espinosa, A. (2024). Flexural and shear strengthening of RC beams reinforced with externally bonded CFRP laminates postfire exposure by experimental and analytical investigations. *Engineering Structures*, 308, 117995.
15. Mohammed, H. R., & Said, A. I. (2022). Residual strength and strengthening capacity of reinforced concrete columns subjected to fire exposure by numerical analysis. *Journal of the Mechanical Behavior of Materials*, 31(1), 212–224. <https://doi.org/10.1515/jmbm-2022-0026>
16. Shang, X., Yu, J., Li, L., & Lu, Z. (2020). Shear strengthening of fire damaged RC beams with stirrup reinforced engineered cementitious composites. *Engineering Structures*, 210, 110263.
17. Thanaraj, D. P., Anand, N., Arulraj, P., & Al-Jabri, K. (2020). Investigation on structural and thermal performance of reinforced concrete beams exposed to standard fire. *Journal of Building Engineering*, 32, 101764.
18. Yu, J., Liu, K., Li, L., Wang, Y., Yu, K., & Xu, Q. (2018). A simplified method to predict the fire resistance of RC beams strengthened with near-surface mounted CFRP. *Composite Structures*, 193, 1–7.
19. Zhang, H. Y., Lv, H. R., Kodur, V., & Qi, S. L. (2018a). Comparative fire behavior of geopolymer and epoxy resin bonded fiber sheet strengthened RC beams. *Engineering Structures*, 155, 222–234.
20. Zhang, H. Y., Lv, H. R., Kodur, V., & Qi, S. L. (2018b). Performance comparison of fiber sheet strengthened RC beams bonded with geopolymer and epoxy resin under ambient and fire conditions. *Journal of Structural Fire Engineering*, 9(3), 174–188.