AN OVERVIEW ON FIRE DAMAGE QUANTIFICATION AND RETROFITTING OF LOW-RISE REINFORCED CONCRETE STRUCTURES

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***Abstract*:** Reinforced concrete (RC) structures are exceedingly susceptible to fire damage, which may induce substantial degradation of the material. Concrete does not ignite at ambient temperature; however, it can significantly alter its mechanical, chemical, and structural characteristics when subjected to elevated temperatures. The extent of a fire damage is primarily determined by its severity and duration. Small fires for short duration, burning, results limited damage, larger fires that persisting over time leads to substantial damage or even structural collapse. This study examines the response of concrete to fire, the potential damage that reinforced concrete buildings may sustain, and the retrofitting solutions that are currently available. Additionally, it contains an incident report regarding a textile market fire that was precipitated by a short circuit. This case study examines ecological retrofitting solutions and concentrates on reinforced concrete buildings on lower stories. In this investigation, we investigate the potential of natural fiber laminates to retrofit buildings and the ability of cement slurry to repair damaged concrete.

***Keywords*-**Bamboo fiber laminates, Concrete structures, Fire, Retrofitting techniques.

1 Introduction

The danger of fire causes a substantial risk to the structural stability of reinforced concrete (RC) buildings. Although concrete is categorized as a non-combustible substance, it can undergo physical and chemical alterations when subjected to high temperatures. These alterations can cause significant deterioration in the mechanical characteristics of the object, which may result in potentially disastrous structural failures [1,2]. The magnitude of harm sustained by concrete buildings during a fire occurrence is impacted by several aspects, such as the strength and length of the fire, as well as the distinct characteristics of the concrete and steel reinforcing [3].Concrete degradation when exposed to high temperatures is primarily caused by water vapor pressure, the breakdown of hydrated cement compounds, and the incompatibility between the thermal reactions of aggregate and hydrated cement [4]. At temperatures over 400˚C, concrete undergoes a process where water is expelled from the gel, capillary, and interlayer pores. Calcium hydroxide decomposes at around 400˚C, while combined water and C–S–H break down at temperatures ranging from 500˚C to 800˚C [5]. In most of the fire events, the intensity and length of the fire impair the structural integrity and rigidity of concrete structures to the extent that repairing them becomes a more practical and cost-effective alternative than dismantling and rebuilding the damaged structures [6].

Various deterioration and damage processes can affect RC structures, each with its own set of pros and cons. "Concrete jacketing" applies a new layer of reinforced concrete to enhance the strength and ductility of existing columns or beams. Modifications to the base can be required due to the method's effect on the enlargement and weight of structural parts [7]. Spending a significant amount of money on this could potentially change the appearance of the building. Installing steel braces or frames enhances the structural stability and lateral resistance of damaged constructions. The execution of this technique will determine whether altering the building's aesthetic is necessary or not. Factors such as the design of the building and the placement of the bracing determine the effectiveness of the retrofit. Furthermore, significant bracing may lead to financial concerns [8]. When choosing an appropriate retrofitting method for burnt concrete structures, one must carefully consider factors such as increased strength and stability, expenditures, structural alterations, and the type of damage.

This study investigates the behaviour of concrete when exposed to fire, the many forms of damage that can occur to reinforced concrete structures because of fire, and the retrofitting options that are now available. Visual inspections and non-destructive tests quantify reinforced concrete fire damage. The procedures measure material properties, internal flaws, and structural integrity. These approaches provide a comprehensive representation of the damage caused by fire in concrete buildings. The case study examines the harm inflicted on low-rise reinforced concrete structures due to a fire triggered by a short-circuit in a nearby fabric market. It also investigates retrofitting methods that are ecologically sustainable. Several natural fibers exhibit potential as laminate materials for concrete retrofitting; nevertheless, there is a lack of research on the recommendations for their use. The paper looks at the possibilities of natural fiber laminates in combination with cement slurry for the purpose of retrofitting, with the goal of restoring concrete stiffness and stability.

2 Concrete behaviour under fire

Concrete, a commonly utilized material in the construction industry owing to its strength and long-lasting properties, experiences substantial degradation when subjected to elevated temperatures. Comprehending the behaviour of concrete during fire situations is essential for evaluating harm and devising efficient retrofitting techniques. Concrete undergoes physical and chemical changes when exposed to high temperatures. Above 100°C, moisture evaporates, creating internal steam pressure that causes micro-cracking and spalling on the concrete surface [9]. Chemical decomposition begins at approximately 300°C, causing hydrated cement paste to dehydrate. This leads to the breakdown of calcium hydroxide into calcium oxide and water vapor, significantly weakening the cement paste and reducing its compressive strength [2]. Aggregate deterioration occurs when siliceous aggregates break down about 600°C, but calcareous aggregates maintain greater stability at higher temperatures, leading to further structural vulnerability [4].

Fire exposure drastically alters concrete's mechanical properties. Temperatures exceeding 300°C can reduce its compressive strength by around 50%, primarily due to moisture loss, chemical degradation, and the breakdown of the aggregate-cement bond [9]. The bad impact on tensile strength is greater than that on compressive strength, principally because of the development of micro-cracks and spalling, which undermine the material's capacity to endure tensile stresses [2]. The elastic modulus of concrete decreases with higher temperatures, increasing deflections and deformations under load. This poses risks to the structural integrity and load-bearing capacity of fire-exposed concrete elements [4]. Some of the common changes to concrete at high temperature are found in a study carried out by Osman et al. [l0] are shown in table below.

Table 1. The behavior of concrete at varying temperatures [10]

Temperature Range ◦C	Exposed Color	Surface Texture	Deterioration/Condition
Ambient-300◦C	Unaffected	Unaffected	Unaffected
(300–600) ◦C	Pink to red	Cracking, crazing, and aggregate pop-outs on the surface	Safe but capacity might be affected
(600–950) ◦C	Whitish grey	Exposure steel reinforcement and Spalling	Weakened
Above 950 ◦C	Buff	Extensive spalling	Significantly damaged

3 Fire damages to RC structures

Fire damages present a substantial risk to reinforced concrete (RC) structures, resulting in the deterioration of materials and a decrease in structural integrity. Crazing manifests as uneven, slender lines on the surface, signifying the early thermal harm caused by differential thermal expansion [9]. Rising temperatures result in thermal expansion and contraction, which in turn leads to the development of more severe fractures, including deeper structural fissures that weaken the connection between concrete and steel [2]. Spalling is the process in which the internal pressure of steam inside concrete becomes greater than the concrete's ability to withstand tension. This leads to the loss of surface material and exposes the underlying concrete and reinforcing to heat [4]. The loss of concrete cover results in the vulnerable exposure of reinforcing steel, causing a quick decline in strength and a considerable decrease in load-bearing capacity [11]. Fire exposure may significantly impair the load-bearing capacity of reinforced concrete (RC) structures, putting them at high danger of partial or full collapse. This is caused by the deterioration of concrete, loss of bond, and degradation of reinforcing steel [12].

A recent fabric market fire as an example of the devastating impact of fire on reinforced concrete structures located at lower levels. An electrical short-circuit started the fire, which moderately damaged the surface, with spalling and splitting as its main characteristics. When the structure experiences crack due to thermal expansion and contraction, the loss of concrete cover worsens its vulnerability. In severe weather, the cement that holds the aggregate together may dissolve or deteriorate, releasing the aggregate and weakening the building. The results of a moderate fire that occurred in a low-rise RC structure that was commercially oriented are depicted in Figure 1. The fire was initiated by an electrical short-circuit on the second floor. It raged for eight hours, resulting in the death of one individual, moderate structural damage, and a significant amount of property loss. The fire incident that was detailed resulted in Level III structural damage, which is defined as extensive concrete degradation and fracture. This underscores the importance of efficient retrofitting solutions.

Fig.1: Damages to RC structure: a) RC structure under fire, b) Crazing, c) Cracking and loss of cover, d) Exposure of aggregate

3 Retrofitting of fire damaged structures

The retrofitting approaches for fire-damaged reinforced concrete (RC) structures include both conventional and innovative technologies. One traditional approach is epoxy injection, which can seal fractures but does not much improve the structural load capacity, also bonding steel plates can enhance both flexural and shear strength. However, it is crucial to ensure exact installation in order to achieve optimal performance [13]. Carbon Fiber-Reinforced Polymers (CFRP) are preferred due to their superior strength-to-weight ratio and resistance to corrosion. They provide significant improvements in structural performance, although they are more expensive and require specialised application techniques [13,14]. Current study is centred around using natural fibre laminates, including jute, hemp, and bamboo, as sustainable alternative. These materials possess desirable mechanical qualities and have a reduced environmental effect compared to conventional options [11]. The renewable and biodegradable nature of these natural fibres makes them a cost-effective alternative.

Incorporating cement slurry with natural fibre laminates can improve adhesion to the concrete surface, therefore repairing cracks and voids and restoring rigidity and structural strength [4, 11]. Table 2 shows several retrofitting options available. Some of them have drawbacks as well, such as rising element cross-sections, expense, and brittleness. Restoring the ductility of beams that have been burned provides important information on how these structures failed, and BFRP laminates are great at this. BFRP laminates, an environmentally friendly alternative to conventional synthetic FRP composites, significantly increase the capacity of RC beams damaged by fire and subsequently reduce deflection, making them a viable retrofitting choice.

Table 2. Retrofitting techniques suggested by the researchers in their studies

Sr #	Member	Damage	Retrofitting Techniques	Reference
1	Columns	Severe	Jackets, RC concrete	[12]
2	Beams		Jacketing, Ferro cement (FC)	[15]
3	Beams	Moderate	Laminates, Bamboo fiber reinforced polymer (BFRP)	[11]
4	Beams		Glass fiber-reinforced polymer(GFRP)	[15]
5	Beams	Mild	Jacketing, Slurry-infiltrated fibrous concrete (SIFCON)	[16]
6	Columns		Wrap jackets, Carbon fiber reinforced polymer (CFRP)	[17]

5. Discussion

A recent fire in a nearby cloth market caused mild surface damage to a low-rise reinforced concrete structure due to a short-circuit. Post-fire evaluation revealed significant spalling, cracking, and slight steel reinforcement deformation, compromising structural stability despite the short duration of the fire. Retrofitting is recommended, starting with visual inspections and structural analysis. Cleaning damaged area, repairing with cement slurry for crack restoration and bonding, and reinforcing with natural fiber laminates (bamboo or jute) to enhance load-bearing capacity and structural performance.

6 Conclusions

Studying the effects of fire damage on reinforced concrete (RC) structures emphasises the need of comprehending material behaviour in extreme circumstances, since deterioration processes can greatly endanger structural integrity. Current progress in sustainable retrofitting methods, namely employing natural fibre laminates, provide lightweight, durable alternatives that are in line with environmental objectives. Although natural fibres help to decrease carbon footprints, their inherent variability requires standardisation in order to ensure consistent and dependable use. The transition to environmentally sustainable materials is crucial for tackling climate change and advancing the preservation of resources.

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