Repairing Fire Damaged Concrete Column with Ultra High-Performance Fiber Reinforced Concrete. A Review

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ABSTRACT

This review paper explores the multifaceted realm of concrete, focusing on its critical role in construction as a structural material with exceptional durability, ease of fabrication, strength, and fire resistance properties. Concrete's low thermal conductivity renders it a robust choice for fire-resistant structures, despite fire incidents posing substantial risks to buildings. Adequately designed concrete structures with appropriate concrete cover can mitigate damage to reinforcement and core concrete, safeguarding structural integrity during fires. In Malaysia, the prevalence of fire incidents in 2012 with associated casualties and financial losses underscores the imperative of understanding concrete's behavior under fire conditions for enhancing fire safety standards. The review delves into concrete's response to fire, highlighting visual changes and mechanical effects, and the introduction of Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) as a promising solution for reinforcing and rehabilitating structures. Various rehabilitation projects utilizing UHPFRC are examined, shedding light on its versatility and potential to significantly enhance load-bearing capacity in fire-damaged reinforced concrete members. The paper contributes valuable insights into concrete technology and structural engineering.

Keywords: Concrete, rehabilitation, thermal conductivity, ultra high-performance fiber reinforced concrete, high temperatures, mechanical properties.

1. INTRODUCTION

The significance of concrete as a structural material in construction, emphasizing its durability, fabrication ease, strength, and fire resistance properties. Concrete's ability to withstand fire is attributed to its low thermal conductivity, making it an effective choice for fire-resistant structures [1]. Concrete's role in fire protection is crucial, as fire accidents pose a significant risk to structures. Adequately designed concrete structures with appropriate concrete cover can minimize damage to reinforcement and the concrete core, preserving the structure's integrity during a fire incident [2].

In Malaysia, fire incidents are a serious concern, with a substantial number of cases reported, leading to casualties and significant financial losses in 2012 [3]. Understanding how concrete behaves under fire conditions is essential for developing standards to enhance fire safety. However, despite the common belief in concrete's fire resistance due to its low heat conductivity, research has shown that concrete can suffer substantial damage and even catastrophic failure at high temperatures to the reinforced concrete (RC) structure. The mechanical properties of concrete and steel reinforcement can deteriorate considerably with prolonged exposure to high temperatures, affecting compressive strength, tensile strength, and stress-strain behavior of structural members [4][5].

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Because of that, it is often more cost-effective to repair damaged concrete structures than to demolish and reconstruct them. Partially fire-damaged buildings can be rehabilitated and used during the repair process. Extensive assessments are necessary before commencing repair work, with the choice of materials and repair methods based on the evaluation results [6][7].

2. THE EFFECT OF FIRE ON RC STRUCTURAL

Fire poses a significant threat to concrete construction. Despite this, concrete remains a preferred construction material due to its remarkable fire resistance properties, which enable it to withstand fire incidents effectively [8][9]. It is uncommon for entire concrete structures to collapse, even during prolonged fires. Notable examples include the Windsor Tower and Grenfell Tower, which experienced fires in 2015 and 2017 respectively, yet still stand today [10].

According to EN1992-1-2, the thermal conductivity of concrete decreases as the surrounding temperature rises. When exposed to high temperatures, concrete's mechanical strength and the characteristics of the embedded steel reinforcement bar deteriorate. Initial visual observations of fire-damaged concrete typically include color changes, cracking, and spalling of the surface. These changes become more pronounced as the temperature exceeds 500℃, with irreversible effects becoming evident [11] [12]. Additionally, concrete members exposed to elevated temperatures experience dehydration of the cement paste, increased porosity, high pore pressure expansion, creep, and spalling [13]. Figure 1 illustrates the variation in relative compressive strength of Normal Strength Concrete (NSC) with temperature [14].

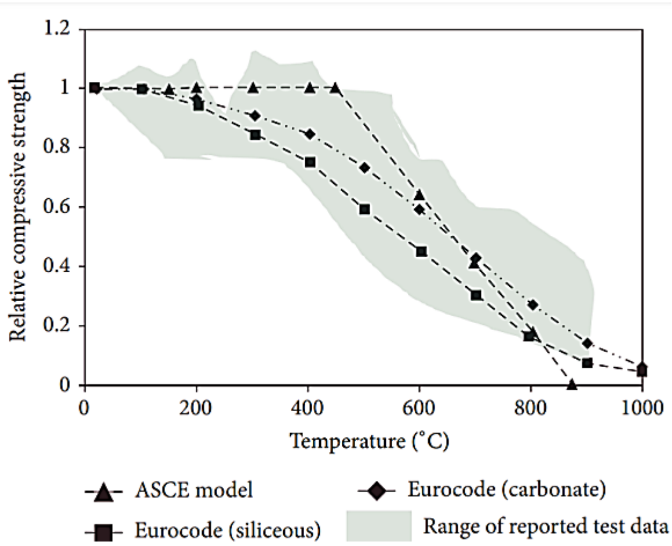

Figure 1. Variation of relative normal concrete compressive strength as a function of temperature [14].

The maximum compressive strength values in the Fire Damaged Concrete (FDC) are much lower than those in the NSC at the same axial load positions, as can also be seen in Figure 2. This observed disparity is mostly caused by the cement paste's and its constituent aggregates' considerable thermal expansion during the fire test. This resulted in increased porosity and microcracking in the FDC [15].

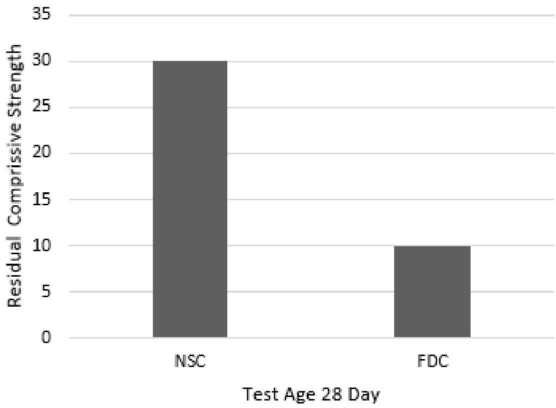

Figure 2. Average residual compressive strength of unheated NSC and FDC [15].

3. ULTRA HIGH PERFORMANCE FIBRE REINFORCED CONCRETE (UHPFRC)

The continuous development Ultra High-Performance Concrete (UHPC) by adding steel fibre reinforced concrete has resulted in the emergence of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) as potential repair material for reinforced concrete structures.

Advancements in concrete technology have yielded new types of concrete that offer superior strength and durability compared to conventional concrete [16]. However, the introduction of high-strength concrete has not fully addressed the challenge of preventing premature deterioration of reinforced concrete structures exposed to harsh environmental conditions and mechanical loads [17]. Additionally, the exposure of reinforced concrete structures to service loads, seismic damage, and degradation resulting from physical and chemical attacks in severe environments has become a significant concern. To address these issues, UHPFRC has emerged as a promising option for construction due to its exceptional strength, ductility, and durability properties [18][19].

UHPFRC demonstrates greater density and lower porosity, resulting in higher durability compared to conventional concrete. In general, concrete with compressive strength more than 150 MPa after 28 days curing and steel fibres with a high tensile strength of 850 to 2000 MPa. When fibre is added to the concrete mixture, the name of UHPFRC is used [20][21].

4. APPLICATION OF UHPFRC IN REPAIR WORKS

In a compilation, various rehabilitation projects have been documented, employing UHPFRC as a primary repair material. These projects predominantly encompass the restoration and enhancement of pre-existing structures, encompassing concrete and steel bridges, reinforced concrete beams, dams, bridge channels, and hydroelectric plants. The widespread utilization of UHPFRC in these rehabilitation endeavors underscores its versatility and effectiveness in bolstering the resilience and performance of diverse structural elements [20]. The addition of steel fiber content had a minimal impact on the compressive side specimens, with less than a 4% increase in ultimate moment when the tensile strength went from 8 MPa to 16 MPa. However, when UHPFRC was applied as a three-sided jacket, a substantial 53% improvement in the maximum flexural load was observed. The study concludes that a three-sided UHPFRC jacket, with a tensile strength of 16 MPa, can potentially triple the ultimate flexural load of an existing reinforced concrete beam [21].

The amount of load sustained by existing beams rises as the tensile strength of UHPFRC rises, as illustrated in Table 1, according to the numerical analysis the UHPFRC has a high potential in helping to restore the original capacity of fire damaged reinforced concrete members

Table 1 UHPFRC's tensile strength and its ability to improve the load bearing capacity of existing reinforced concrete beams [21]

Tensile Strength (MPa)	Increment (%)
8	119
12	200
16	244

When comparing the effectiveness of retrofit jackets in restoring the load-bearing capacity to its pre-fire levels, it was found that UHPFRC repair jackets exhibited improvements of 26.2%, in load-carrying capacity, respectively, in comparison to the NSC [15].

4. CONCLUSION

Concrete's vital role in construction, encompassing durability, ease of fabrication, strength, and fire resistance, is evident. While commonly perceived as fire-resistant, research highlights the potential damage to reinforced concrete structures under high temperatures. Understanding fire effects on RC structures is crucial for enhancing safety standards. Traditional repair methods are cost-effective, allowing rehabilitation of partially fire-damaged structures. However, material and repair method choices require thorough assessments.

The paper explores fire impact on RC structures, emphasizing color changes, cracking, and spalling. High temperatures significantly degrade concrete's mechanical properties. Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC) emerges as a promising solution, offering superior strength, ductility, and durability. Its application in various projects demonstrates versatility, with steel fibers enhancing strength. Numerical analyses conclude that, UHPFRC with higher tensile strengths, can notably improve load-bearing capacity in fire-damaged structures. This underscores UHPFRC's value in restoring original capacity, surpassing traditional repair jackets.

In summary, UHPFRC exploration as a repair material showcases its potential in preserving and enhancing resilience against fire and environmental factors. Adopting advanced materials like UHPFRC becomes imperative for ensuring structural longevity and safety.

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