3rd Conference on Sustainability in Civil Engineering (CSCE'21)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

A REVIEW ON FRP REPAIRING OF FIRE DAMAGED RC MEMBERS

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Abstract- The mechanical properties of concrete are highly affected by the fire event. Load bearing-capacity of reinforced concrete (RC) structural members reduced due to reduction in concrete strength caused by the elevated temperature. This study presents a review on repairing techniques of fire damaged RC structural members. The investigations covered physical dimensions, loading-effect method and bonding behavior and residual-strength assessment. The advantages of fiber reinforced polymers (FRP) recall of RC members' performance/strength over the steel coating, enlargement of the section, steel-plate bolting (SPB) and fiber reinforced polymers (FRP) are discussed. The fiber reinforced polymers (FRP) post-fire repairing technique reviewed to achieve the design or more strength, as compared to pre-heated, of damaged RC member. It was observed that FRP coating, around the RC members, enhanced the strength up to or more than the pre-heated design strength of concrete.

Keywords- Fire damaged RC members, fire exposure, post-fire assessment, post-fire repairing methods.

1 Introduction

In the construction industry, concrete is the most widely used building material since it is easily available, very cheap material. More importantly, it can be molded into any shape with less skilled labor as compared with the steel structures. As concrete is quasi-brittle material, it has very high strength in compression but weak in tension. Reinforced concrete (RC) structure consists of several structural members, such as slab, beams, columns and footing. The collapse of the building occurs due to the failure of these structural members. Failure of the structural members can occur due to degradation, which can be caused by earthquakes, overloading, blast, high temperature exposure, deformation caused by seismic loading, variation in structural design and lack of maintenance. The ultimate strength of RC structural members decreases due to the fire exposure causing the reduction in strength and stiffness of the material. In the case of fire, the mechanical decay of concrete and even significant effects at the structural level may occur due to spalling and reinforcement exposure [1].

The elevated temperature and cooling affect the load bearing capacity by reducing the strength of concrete [6]. After fire, it becomes necessary to assess the mechanical properties of the RC members and adopt some repairing methods if required. There are a lot of methods for the treatment of RC structural members. The main methods which are being used are the bolt plating method, section enlargement method, fiber reinforced polymers (FRP) coating/jacketing method [2]. Steel coating for the retrofitting can be used for improving the seismic shear strength but the rectangular column's coating can be buckled at the hinged area when subjected to lateral loading [7]. Steel-plate-bolting (SPB) method is usually adopted for the RC flexural members by fixing steel plates, both opposite sides, with the help of bolts [8]. The replacement method is, only used when the cost factor is not important, mostly adopted for the slab repairing [3]. FRP unidirectional repair of the RC column can enhance the load bearing capacity of the post-heated column up to or greater than the original level of

pre-heated column [4]. FRP coated RC structural members can be capable of achieve satisfactory resistance during fire [5].

After the fire event, proper repairing and retrofitting are required for further use of the structure. This is because the high-temperature leaves adverse effects on concrete. This can be in form of spalling of concrete debonding between steel and concrete. There are many studies on the repairing techniques of concrete but this study focuses on the significance of the FRP repairing of the RC members after the fire. Steel jacketing and increasing the dimensions of the structural members are costly methods of repairing techniques. The use of the FRP repairing technique is economical compared with other techniques and no extra load is applied over the member as it is light in weight. Also, this technique doesn't reduce the workspace and free area between the repaired members. Post-fire repairing of RC members with FRP can even help in enhancing, more than pre-fire, the strength of the member.

2 Properties of Fire Subjected RC Members

Reinforced concrete gets a permanent decrease in strength due to high temperatures. Elevated temperature leaves adverse effects on reinforced concrete (RC) members. Initial morphology varied after the event which results in a decrease in mechanical properties of concrete after fire [9]. Microstructural properties of concrete are exposed at elevated temperatures [10]. Spalling of concrete depends upon two factors, pour-vapor pressure and thermal stress caused by the elevated temperature as described in Figure 1. Pore-vapor pressure cannot form spalling but only contribute to micro-cracks along with heat surface. Under thermal stress, these micro-cracks likely to buckle and spall near the heating surface [15]. Different RC members behave differently which are described below.

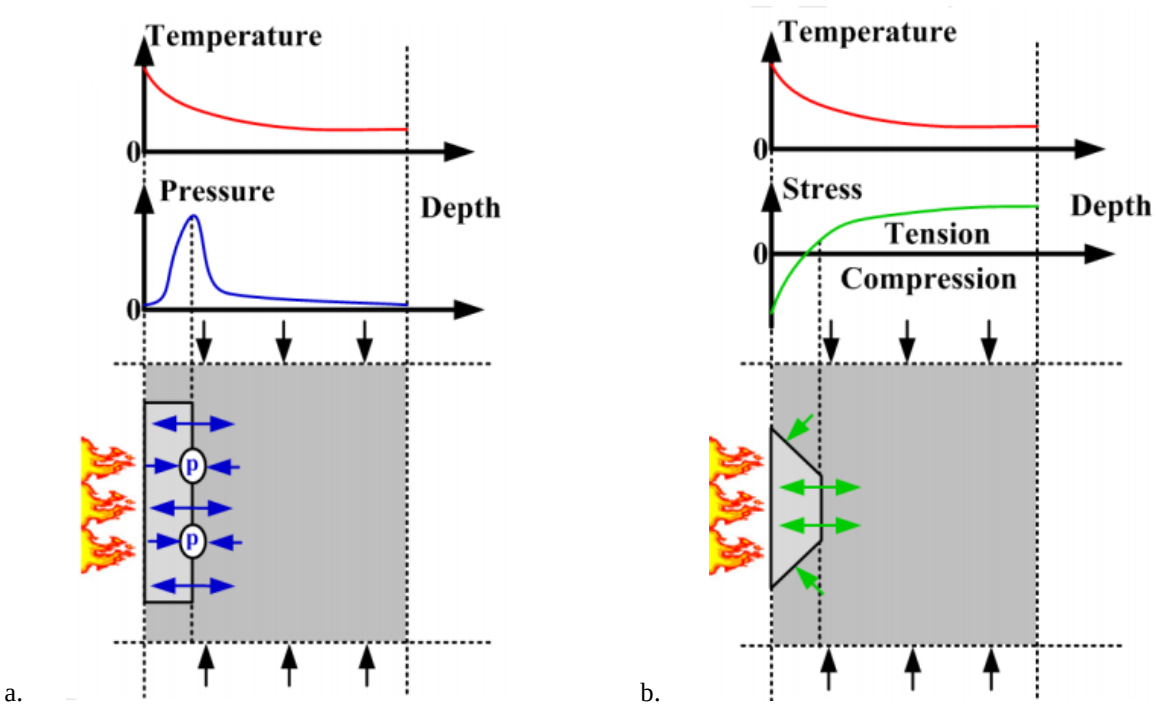

Figure 1: Spalling Factors of concrete due to Fire, a. pore-vapor pressure, b. thermal stress [15]

2.1 Compression Members (Columns)

The column can suffer fire up to four dimensions. Bending type depends upon the number of faces exposed to fire. One- and three-sided exposed column may be considered subject to uniaxial bending and if two or four faces exposed to fire will be considered subject to biaxial bending. Tan et al. [11, 12] developed a method, for one-, two-, three- and four-sided

exposed column, to examine the fire resistance of column while spalling of concrete was not considered. The decrease was observed in residual strength of corner column two-sided exposed to asymmetric fire and subjected to uniaxial and biaxial bending [13]. Enlargement of dimensions of columns enhances the fire resistance [14].

2.2 Flexural Members

2.2.1 Beams

Many research studies have been conducted on the performance of flexural members exposed to elevated temperatures. In an analysis of experimental study considering beam type, beam load ration and concrete cover thickness, it was concluded that primary beams are shown better fire resistance in comparison with secondary beams because the tensile strength wasn't degraded [16]. Variations in shear failure modes were observed mandatory in frame-restrained beams and cantilever beams after exposure to elevated temperature. So, for evaluation of after-fire shear capacity, the design of RC beams is not acceptable under room temperature [17].

2.2.2 Slabs

Several studies have been conducted to evaluate the performance of slabs under fire. Three main factors that influence the fire resistance are load level, the thickness of concrete cover and temperature. Spalling in concrete produced by fire seriously reduces the structural and thermal response of the slab which makes it less resistant to fire [18]. It is obvious, in high temperatures, that the degradation of stiffness and strength of the material is the main factor affecting the behavior of structure [19]. During the fire, the complications in the behavior of structure are cracking, degradation and thermal expansion. The stress-strain graph at different elevated temperatures has been presented in Figure 2.

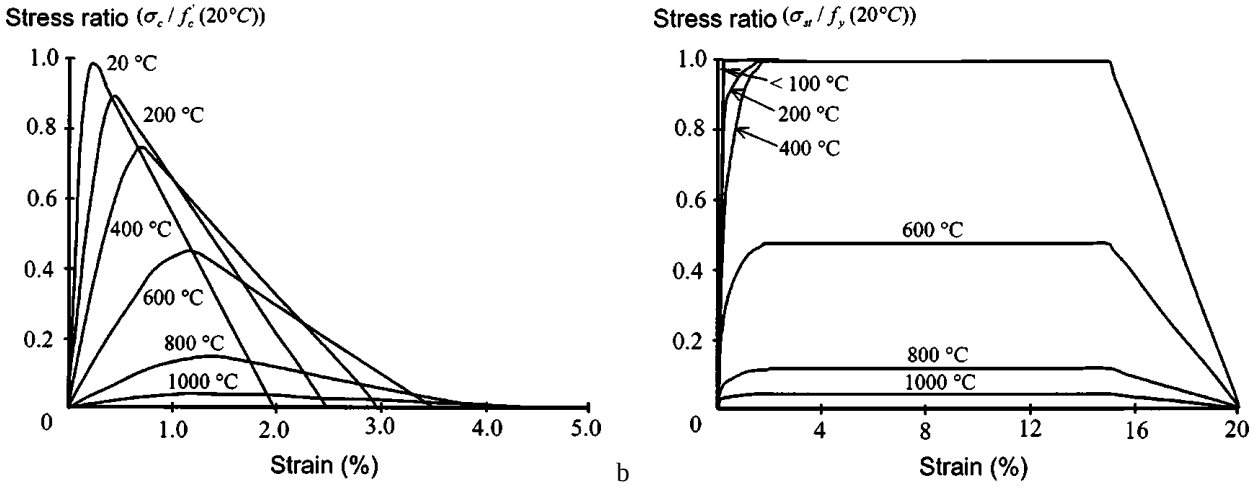

Figure 2: Stress-strain relationship for concrete at elevated temperature, b. Stress-strain relationship for steel at elevated temperature [19]

3 Types of Repairing Techniques of RC Members

Several techniques are being used for repairing fire damaged RC members. The most commonly adopted techniques are steel jacketing/coating, section enlargement and FRP repairing technique. The technique is adopted based on the damaged condition of the member. Table 1 provides the detailed damaged condition so that the repairing method is adopted accordingly. It is proposed that the level two damaged segment can be fixed by the section enlargement technique, and the third level damaged is appropriate for the steel jacketing or with FRP repairing technique. Level four is more severe damage case it should be replaced. The member falling in the damage category of dangerous cannot be repaired. There is only way

to use it is to reconstruct it instead of repairing. The serious level can be repaired by the section enlargement technique after removing the most damaged [20]. FRP and steel plate bolting (steel jacketing) techniques can be used for the moderate and mild level of damaged RC members.

Table 1- Description of Damages and Repairing Technique Proposed According to Damaged Type [20]

Degree of damage	Dangerous	Serious	Moderate	Mild
Level of damage	Level four	Level three	Level two	Level one
Temperature of concrete	≥700	600-700	400-500	<400
Temperature of reinforcement	400-500	350-400	100-300	<100
Damaged condition	Out of plane deformation	Deflection exceeding one to three times	Deflection meeting the limit	No changes

The advantage of the techniques used for repairing fire-damaged RC members improve the structure bearing capacity, stiffness, stability, and give economical solutions to exceed the life of the structures. The techniques are used also to improve the ultimate load capacity of the structure members and provide anti-corrosion to the member as well. The disadvantage of the techniques using is that they will never achieve the original strength of the structural members.

3.1 Steel Jacketing Technique.

In this technique, the steel is wrapped around the fire damaged RC structural member. The steel plates and sheets are attached to the surface of the RC member with the epoxy resins or cement paste. Install the angle on the corners of RC members (beam and column) and connect them with a splicing plate. The size of the angle and plate is determined by the designated bearing capacity. The ends are interconnected with another transverse member. The upper end of the column's steel jacketing extended up to the upper floor while the lower end anchored to the foundation. The steel has more density which adds additional weight to the structure as well. The bolting and cutting of steel plates according to section, needed to be repaired, size and shape make it uneconomical. This technique is suggested for severe fire damaged RC members.

3.2 Section enlargement Technique

The section enlargement technique is the strengthening technique used to achieve the ultimate load bearing capacity of stability and stiffness. In this technique, the residual strength is investigated first and the section is enlarged so that the ultimate bearing capacity and strength should be achieved to support the desired loading. The section enlargement technique was adopted for repairing the bridge columns, after two hours of fire exposure, after determining the residual strengths [21]. The section enlargement reduces the free area between the RC columns and the headroom between the beam and the floor. This technique can be used for recall of strength of moderate and mild type of fire damaged members.

3.3 FRP Repairing Technique

Fire badly affects the RC members and due to which it cannot be used for the desired purpose because of a reduction in its mechanical properties. Without any retrofitting of the structural members, it is very risky to utilize the building after the fire event. For this one of the repairing methods is FRP. In this technique, the sheet of FRP attached with the structural members to rehabilitate the ultimate strength of RC members reduced due to fire.

3.3.1 Superiority of FRP repairing over other techniques

FRP repairing technique is more economical than any other repairing technique. Fibers present inside the polymers enhance the strength of the RC members. As the FRP is lightweight than steel jacketing and section

enlargement, there is no need to tackle additional loading of repairing materials. Easy to handle, place and cut as it is lightweight than the steel. Compared with section enlargement repairing technique, reduction in free area and headroom is very little that it is negligible. Above discussed advantages make FRP repairing better than others.

4 FRP Repairing Method Adopted Fire Damaged RC Members

Fire event leaves adverse effects on reinforced concrete members. The degradation and spalling of concrete are the major defects caused by the fire event. The increase in corrosion damage reduction is a factor reducing the flexural strength of damaged RC beams. Reinforced concrete coating and steel coating are traditionally used for the rehabilitation of the reinforced concrete members. Past few years, the use of fiber reinforced polymers has been increased as a strengthening method as it is lightweight and less complex of anchorage. The characteristics of FRP like lightweight, high strength, high impact resistance, durability, and corrosion resistance have made it a better material for the rehabilitation of RC [22, 23]. FRP coating is more effective in rehabilitating the flexural member with damage location on top of the member than the bottom. FRP with the provision of the epoxy coating and coarse aggregates inside the coating surface shown in better distribution of stress and cracks propagation [24]. There are two ways of applying the FRP repairing on RC members, one is externally bonded FRP strengthening and the second is near surface mounted FRP strengthening.

4.1 Externally bonded FRP strengthening

For externally bonded FRP strengthening, the FRP sheets are attached to the surface to restore the ultimate capacity of RC members [25]. The test was conducted on fire damaged beams strengthened by FRP sheets with novel coating. From the test, it was concluded that the novel coating improved the fire resistance of FRP sheets [26]. Figure 3 illustrates the externally bonded FRP strengthening technique to restore and rehabilitate the ultimate strength of a T-beam. The bonding behavior of the RC T-beam and the carbon fiber reinforced polymer was observed. The FPR restores the ultimate strength and there is no need to enlarge the dimensions of the reinforced concrete structural member.

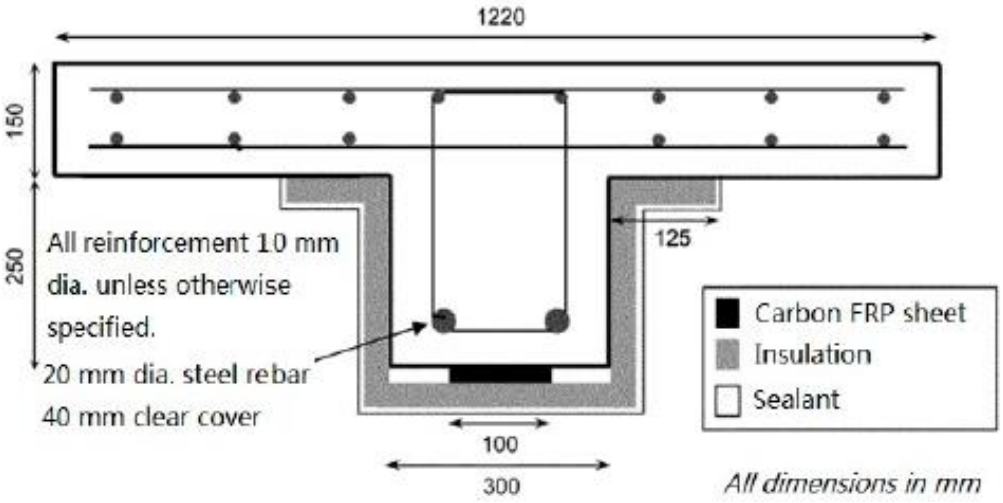

Figure 3: Externally bonded FRP strengthening [26]

4.2 Near surface mounted FRP strengthening

Near surface mounted (NSM) FRP strengthening is an advanced technique that was developed last decade. Mahmoud et al. conducted research on NSM's enhanced performance [27]. In comparison with the externally bonded method, NSM

gives better safety from external damage. Figure 4 elaborates the arrangements for the NSM of the RC beam. The epoxy resin is used for inter-surface bonding. The adhesive property of epoxy resin improved the bonding between FRP sheets and concrete at elevated temperatures. The RC members repaired with NSM technique give fire endurance of two hours.

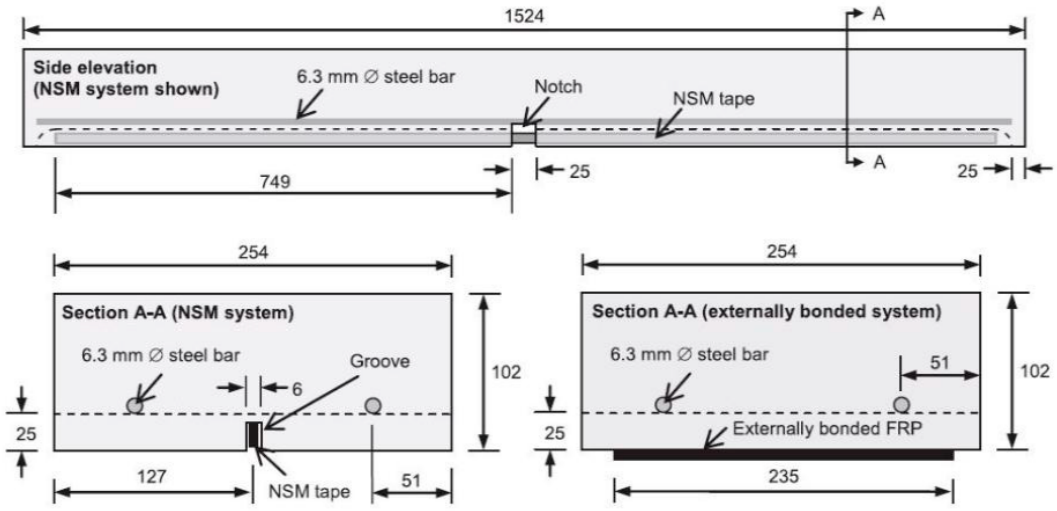

Figure 4: Near surface mounted and Externally bonded FRP strengthening [28]

5 Conclusions

This paper provides a review of the FRP repairing technique of RC structural members damaged by a fire event. Other repairing techniques like section enlargement and steel coating were also discussed. The techniques using for repairing fire-damaged review are done to achieve the desired or required properties of the structure to make it usable instead of reconstructing the whole structure. The techniques using are very effective for improving the structural members' properties as well as to increase the lifespan of the structure.

The outputs of the study summarized as follows:

- The FRP, steel coating and section enlargement method were used for the repairing of RC members damaged by fire. The FRP, concrete reinforcement and section enlargement repairing techniques are applicable for the RC slabs after exposure to elevated temperature. Since the section enlargement is an effective and economic solution for the slab repairing.
- FRP rehabilitation method is the most widely used in the world. Externally bonded FRP and near surface mounted FRP strengthening techniques were compared. NSM has shown better results such as more ductile performance and the anchoring of FRP is better in NSM than the externally bonded FRP technique.
- FRP repairing is far good for the rehabilitation of the RC beams
- The section enlargement technique can more effectively enhance the stiffness and ultimate load of compression members. Also, the construction is simple but the building clearance decreases.
- The properties of FRP are deeply studied. FRP coating, compared with steel coating and section enlargement, is easy to handle, lightweight, high strength to weight ratio and corrosion resisting.

It is concluded in this study that the FRP repairing technique is an easy method of repairing and does not apply any additional load on members caused by the weights of other repairing materials.

Acknowledgment

The author would like to thank all the organizations and persons who helped throughout this study, especially Engr. Prof. Dr. Majid Ali for his kind support and guidance in framing and improving the manuscript. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

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