

Review

# Repair of Fire-Damaged Reinforced Concrete Flexural Members: A Review

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Received: 15 July 2019; Accepted: 18 September 2019; Published: 23 September 2019



**Abstract:** The mechanical properties of both concrete and steel reinforcement, and the load-bearing capacity of reinforced concrete (RC) structures are well known to be temperature-sensitive, as demonstrated by the severe damage that major fires cause in buildings, followed—in extreme cases—by their collapse. Since in most cases RC structures survive a fire, retrofitting fire-damaged RC members is a hot subject today. In this paper, after a recall on the performance of RC beams and slabs in fire, different repair techniques are considered, among them externally bonded reinforcement, near surface-mounted fiber-reinforced polymers (FRP), bolted side plating, jacketing with high- and ultra-high performance concretes or mortars, and damaged-concrete replacement. Last but not least, the design equations aimed at evaluating the residual load-bearing capacity after repairing are also presented and discussed.

**Keywords:** fire exposure; RC beams; RC slabs; residual load-bearing capacity; repair techniques

## 1. Introduction

The mechanical properties of reinforced concrete (RC) members are greatly affected by the high temperatures developed during a fire. Hence, the fire-damaged components cannot satisfy the design requirements. Up to now, the main repair methods of RC flexural members include section enlargement method, fiber-reinforced polymers (FRP) reinforcement method, and bolt-plating reinforcement method [1–5]. All the repair methods can be used directly or indirectly by adding jackets to recover the designed ultimate strength of the fire-damaged flexural members.

The section enlargement method is simple, sophisticated, and widely used. This method can be applied to general concrete structures, such as beam, column, slab, foundation, and other structural members [6]. Although it is recognized as one of the most cost-effective and convenient methods, the interior space is reduced because of the enlargement of the cross-sectional areas of components.

The FRP repair method, involving externally bonded reinforcement (EBR) strengthening and near-surface mounted (NSM) FRP strengthening [6], has been widely used in civil engineering because of its advantages of being light weight, high strength, and corrosion resistant. For the EBR strengthening method, the FRP wraps are bonded on the surface of RC components to increase the compressive strength of the fire-damaged concrete, though the strengthening effectiveness of FRP jacketing is dependent on the interfacial bonding. For the NSM strengthening method, FRP bars or sheets are embedded into the structural surface, thus the bonding strength can be enhanced. The effectiveness of the NSM strengthening method has been proved by several experimental results [7–14].

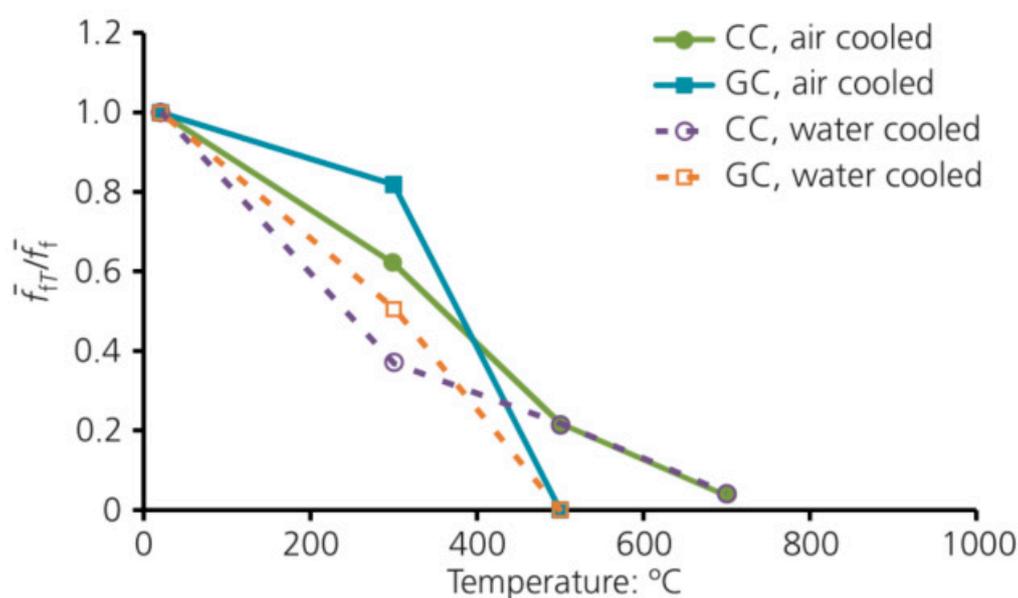
The bolted side-plating (BSP) technique is used to fix steel plates on the two opposite side faces of RC beams with anchor bolts [15]. Compared with the FRP repair method, the BSP technique can enhance both the tensile and compressive reinforcements of an RC beam. In the meantime, the premature

debonding and peeling failure of the bonded FRP sheets will also be inhibited. Therefore, it has obvious advantages for strengthening fire-damaged RC beams.

## 2. Behavior of RC Flexural Members Subjected to Fire

### 2.1. Beams

The performance of flexural members subjected to fire has been studied by many researchers [16–22]. Experimental and numerical investigations of the fire resistance of RC beams were conducted by Ding et al. [23]. Three main factors, namely beam type, cover thickness, and beam load ratio, were considered. The analysis results showed that the critical reason why the fire resistances of the primary beams were better than that of the secondary beam was that the tensile strength of longitudinal reinforcements in the primary beams did not degrade. Hou et al. [24] studied the behavior of fiber reinforced active powder concrete (RPC) beams with fire insulation. During the tests, the temperature distribution, structural response, fire resistance, failure mode, and fracture morphology were measured. The test results showed that three longitudinal reinforcements fractured suddenly and a single crack occurred across the central cross section. In addition, the fire responses of nonadiabatic and adiabatic RPC beams were compared. The fire resistance performance of hybrid-fiber reinforced RPC beams can be greatly improved by means of fire insulation. The residual strength of concretes after exposure to fire has been studied [25]. The test results indicated that the residual flexural strength of beams was affected by high temperature and sudden cooling. Figure 1 shows the trend of residual flexural strength.  $\bar{f}_f$  and  $\bar{f}_{fT}$  are the values of flexural strength of the concrete at ambient temperature and after being exposed to evaluated temperature  $T$  then cooled down, respectively. CC means concrete with calcareous aggregates, and GC means concrete with granite aggregates.



**Figure 1.** Residual flexural strength of concrete with calcareous aggregates (CC) and granitic aggregates (GC) (adapted from [25]).

Li et al. [26] studied the residual behavior of fire-damaged RC frames and the effect of fire exposure and beam-to-column bending strength ratio on the failure mode; hysteretic loops, load carrying capacity, stiffness degradation, and ductility were also studied. Jiang et al. [27] found obvious changes in the shear failure modes of cantilever beams and restrained frame beams after they were exposed to fire, and thus drew a conclusion that the design formulae for RC beams under room temperature are no longer suitable for evaluating post-fire shear carrying capacity.

## 2.2. Slabs

Huang et al. [28] developed a model that focused particularly on the effect of spalling on structural performance under fire exposure. A total of sixteen specimens were analyzed by using slabs with different degrees of bonding. It is obvious that the adjacent cold structure provided considerable thermal constraint for the floor slab in the fire prevention room, and the pressure film force inside the floor slab was the main factor to reduce the concrete spalling.

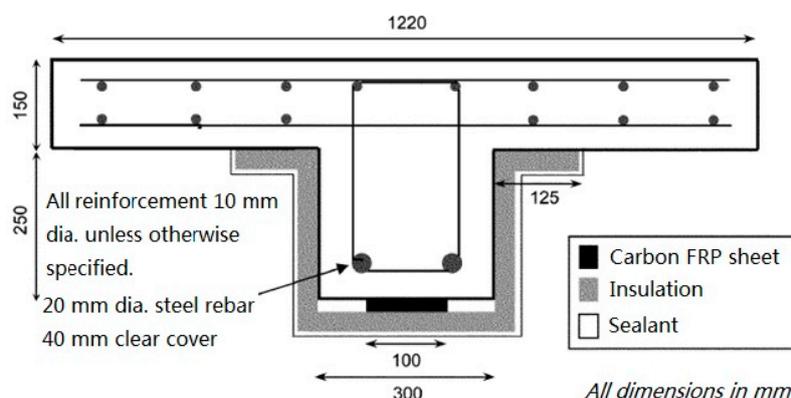
## 3. Repair Methods for Flexural Members

### 3.1. Repair Method of Fire Damaged Beam

#### 3.1.1. Externally Bonded Reinforcement (EBR) Strengthening

FRP bars and sheets have been widely used in civil engineering due to their advantages of being light weight, having high strength, and being corrosion resistant [29–36]. For externally bonded reinforcement (EBR) technology, FRP sheets were bonded on the surface of concrete to restore the flexural capacity due to the confinement effect [37,38].

Ji et al. [39] developed a novel fire-resistant technique with nano-clay intumescent coating, which is externally bonded reinforcement strengthening. The fire-damaged beams strengthened by FRP sheets with the novel coating were tested. The test results demonstrated that this new coating can improve the fire resistance of the FRP sheets. Compared to the control beams, the bending strength of the damaged RC beams repaired with this new method increased by 34%. A similar experimental program was conducted by Williams et al. [40]. The bending behavior of fire-damaged T-shaped beams strengthened by carbon fiber reinforced polymer (CFRP) sheets was studied. The CFRP sheets were bonded on either the side or bottom faces of specimens. Figure 2 shows the cross section of repaired T-beams. Meanwhile, an analytical model to predict temperature distribution across the section was also developed.

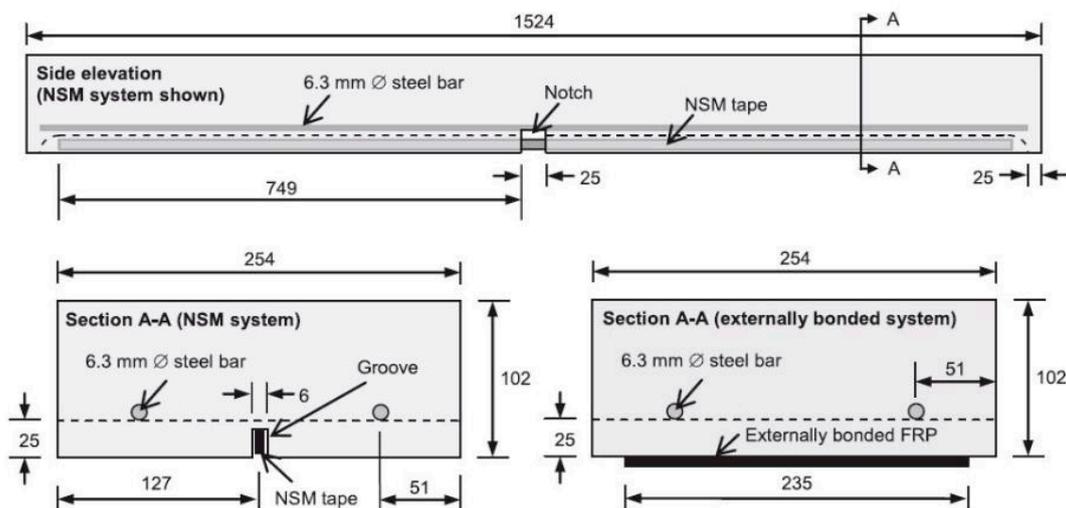


**Figure 2.** Cross section of strengthened, insulated T-beam (adapted from [40]). FRP: fiber-reinforced polymers.

#### 3.1.2. Near-Surface Mounted (NSM) FRP Strengthening

NSM FRP is a new enhancement technology that was developed in the past ten years. Al-Mahmoud et al. [13] and Lorenzis et al. [14] conducted extensive research studies on the enhanced performance of NSM. Compared with the EBR method, the advantages of NSM method include that FRP unlikely to debond from the concrete surface and provided better protection from external damaged. Burke et al. [7] evaluated the effects of elevated temperature on NSM FRP and EBR FRP strengthened RC beams. Figure 3 exhibits the specific arrangement of the concrete beams. A total of 16 RC beams were tested. The epoxy resin was adopted as the adhesive. The test results showed that the epoxy adhesive can enhance interfacial bonding between concrete and FRP sheets at ambient temperature. Palmieri et al. [8] tested 12 RC beams repaired with NSM FRP bars. The specimens

were exposed to a standard fire. The results demonstrated that the specimens strengthened with NSM FRP could provide a fire endurance of two hours. In addition, the tests of residual strength on beams demonstrated that interfacial bonding between concrete and FRP sheets was maintained. The beams were still able to maintain up to 80% of their flexural capacity under ambient temperature when the adhesive temperature was below 200 °C. Moreover, Palmieri et al. [9] also investigated the performance of FRP repairing systems subject to fire exposure. The specimens included six full-scale NSM FRP-RC beams. Each of them was preloaded to the service loading of the strengthened members. The parameters of the specimens are listed in Table 1. The test results indicated that the strengthened beam provided one-hour fire endurance under the service loading. With regard to the tested specimen (B1-F3-2), increasing the loading after one-hour fire exposure and retaining a constant temperature, its residual strength capacity reduced to 77% of the designed strength. Figure 4 shows the relationship between fire exposure time and deflection curves during and after fire for specimen B1-F3-2. Furthermore, Thi et al. [10] carried out a study on the bending performance of fire-damaged concrete slabs repaired with NSM CFRP rods. The effect of location of CFRP rods, as shown in Figure 5, on the ultimate strength was studied. The test results demonstrated that the best way to repair the structural elements was to install CFRP rods inside grooves cut in the structure.



**Figure 3.** Near-surface mounted (NSM) and externally bonded reinforcement (EBR) FRP strengthened reinforced concrete (RC) beams (adapted from [7]).

**Table 1.** Details of specimens (adapted from [9]).

Beam	FRP	Adhesive	Tg °C	Insulation	Thick Bottom (mm)	Thick Side (mm)	Density (kg/m <sup>3</sup> )	Conductivity (W/mK)
B1-F3-1	GFRP	Epoxy Sikadur 30	62	Promat L-500	50 + 50	20	500	0.09
B1-F3-2	GFRP	Epoxy Sikadur 30	62	HPC + Omega	25 + 20	10 + 10	527	0.07
B1-F3-3	GFRP	Epoxy Sikadur 30	62	HPC + Omega	35 + 20	10 + 10	527	0.07
B1-F3-4	GFRP	Epoxy Sikadur 30	65	HPC + Omega	20 + 15	10 + 10	527	0.07
B2-F3-1	CFRP	Epoxy Fortresin	65	Promat L - 500	30 + 30	20	500	0.09
B4-F3-1	CFRP	Mortar Sikagrout 212	65	HPC + Omega	10 + 10	10 + 10	527	0.07

Note: GFRP means glass fiber reinforced polymer.

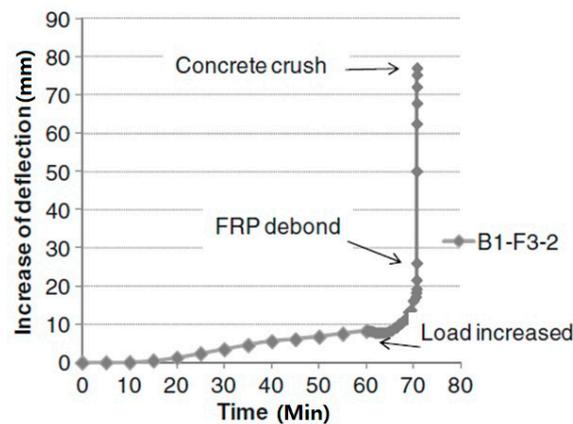


Figure 4. Time versus deflection curves during and after a fire exposure (adapted from [9]).

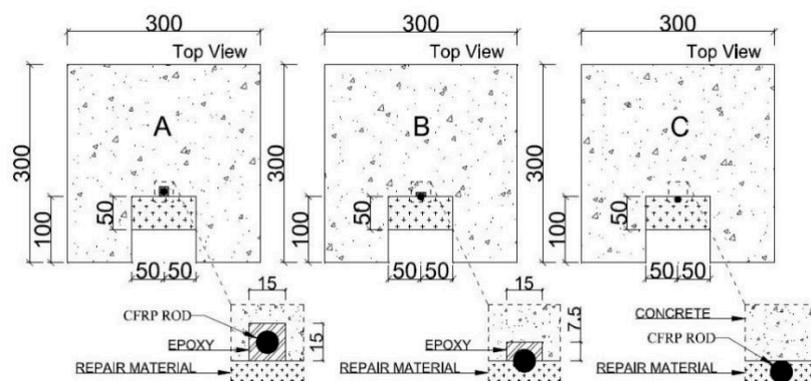


Figure 5. Locations of carbon fiber reinforced polymer (CFRP) rods in beams (A) embedded in epoxy; (B) embedded in interface; and (C) embedded in repair material (adapted from [10]).

### 3.1.3. Bolted Side Plating (BSP) Technique

BSP is a technique in which the plates are installed to the side faces of the RC beams by means of anchor bolts [41–46]. The behavior of this type of beams is determined by the degree of partial interaction at the interface between concrete and steel plates. The peak load and stiffness of the fire-damaged beam repaired by BSP technique were significantly increased, but the change in ductility was different as the strengthening configuration varied. The bending reinforcement effect is enhanced with increasing steel plate thickness and decreasing anchor bolt spacing, while the stiffening rib of steel angle can effectively limit the steel plate buckling. When the steel–concrete interfacial slippage and the plate buckling are properly restrained, the degree of cooperation between the steel plate and the concrete beam can be significantly improved.

Li et al. [15] conducted a test on seven BSP strengthened beams with different plate heights and bolt spacings. Figures 6 and 7 show the configurations of strengthening measures from the section view and the front view. The repaired RC beams reinforced with deeper steel plates were much more effective in improving the bending strength and the ductility than those reinforced with a larger number of anchor bolts. A simplified elastic–plastic system was employed to compare the strength, stiffness, and ductility of light and moderately reinforced BSP strengthened beams (Figure 8). Unlike RC beams strengthened by steel plates anchored on the beams' bottom surface, BSP strengthened beams require anchor bolts to be evenly distributed throughout the span. Otherwise, the huge transverse slip will occur in the span, resulting in unsatisfactory brittle failure. Moreover, longitudinal slip begins at the end of the plate and gradually decreases toward the mid-span. In a BSP beam with deep steel plates, the longitudinal slips at the centroid level of the steel plates alternately reverse their directions, as the bolt spacing and the steel plate stiffness ratio vary. In addition, the enhancement of bending capacity in

BSP beams was provided by both the bending stiffness of steel plates, and the coupling action between the tension of steel plates and the compression of concrete.

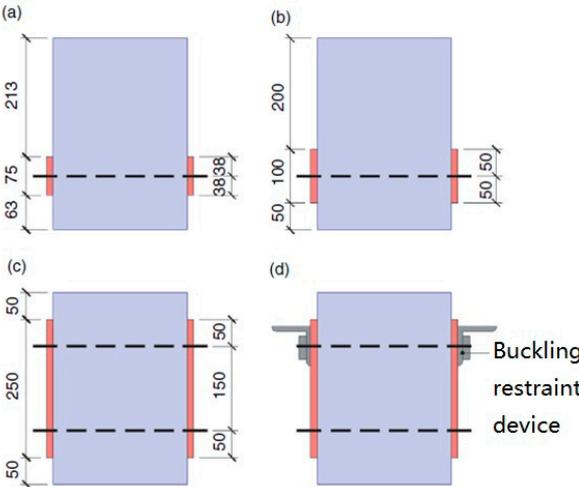


Figure 6. Section view of strengthened specimens (a) P75B300; (b) P100B300 and P100B450; (c) P250B300; and (d) P250B300R and P250B450R (dimensions in millimeters) (adapted from [15]).

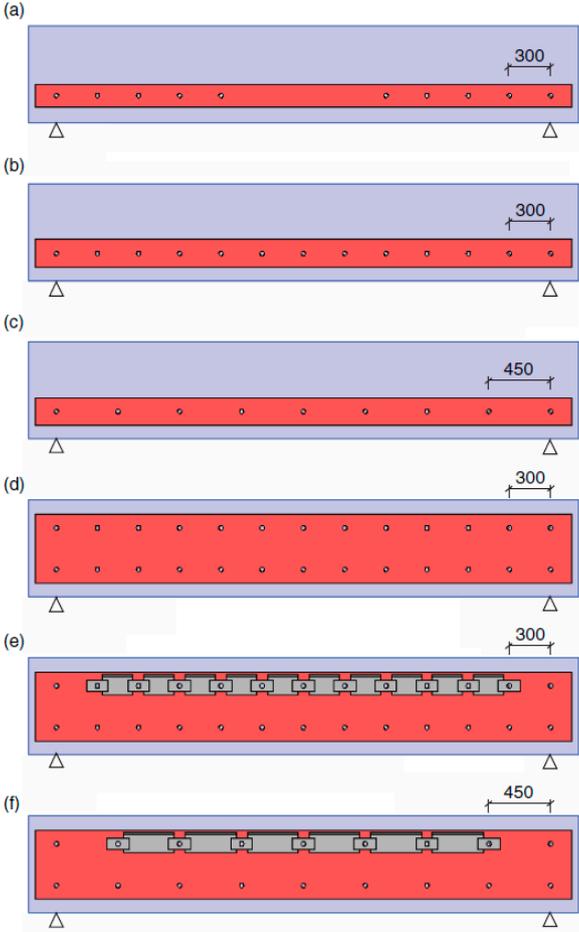
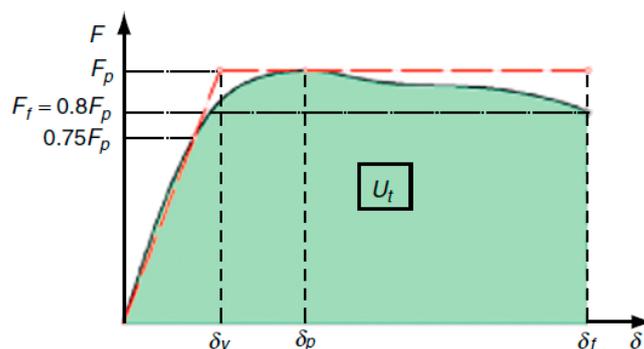


Figure 7. Elevation view of strengthened specimens (a) P75B300; (b) P100B300; (c) P100B450; (d) P250B300; (e) P250B300R; and (f) P250B450R (dimensions in millimeters) (adapted from [15]).



**Figure 8.** Equivalent elastic–plastic system of the load–deflection curve (adapted from [15]).

The shear performance of fire-damaged RC beams strengthened by BSP technique was investigated by Jiang et al. [1]. Six beams were tested and five of them were exposed to fire according to the standard ISO 834 temperature curve. The fire-damaged beams were then repaired by BSP and subjected to four-point bending tests. The researchers studied the development of the temperature and deflection of specimens considering the fire exposure, the failure mode, and the interfacial slip. Table 2 shows the parameters of BSP specimens and the change of shear capacity, stiffness, and ductility of the specimens. We can clearly conclude from Table 3 that the loading capacity of the beams recovered significantly after repair.

**Table 2.** Shear capacity, stiffness, and ductility of specimens (adapted from [1]).

Specimen	Plate Thickness (mm)	Plate Depth (mm)	Bolt Spacing (mm)	Number of Rows of Bolts	Shear Capacity		Stiffness		Ductility	
					$P_u$ (kN)	Change (%)	$K_e$ (kN/mm)	Change (%)	$U_t$ (kN/mm)	Change (%)
CTRL	—	—	—	—	690	19%	88.5	11%	3796	47%
CTRL-AF	—	—	—	—	580	—	79.4	—	2580	—
P2B2-AF	4	200	200	2	800	38%	90.2	14%	5812	125%
P2B1-AF	4	200	100	3	930	60%	88.6	12%	18,927	634%
P3B2-AF	4	300	200	2	840	45%	82.1	3%	15,359	495%
P3B1-AF	4	300	100	3	1030	78%	113.5	43%	20,458	693

### 3.2. Repair Method of Post-Fire Slab

#### 3.2.1. Section Enlargement Strengthening

Section enlargement strengthening is a repair method based on increasing the sectional area to enhance the ultimate load carrying capacity and stiffness of members. Yao et al. [47] pointed out that section enlargement strengthening was an economical and effective method to repair fire-damaged RC slabs. As early as the beginning of this century, Waleed et al. [48] conducted a study on the repair of cracked concrete slabs. A total of six full-size one-way RC slabs with 2.5 m length, 1.0 m width, and 0.15 m thickness were tested. The bottom of the cracked slab was repaired by a 50-mm-thick concrete cover and additional steel bars. The results indicated that the bending strength of the cracked slabs can be restored by using the section enlargement strengthening method, while the ductility of the repaired slabs increased slightly.

#### 3.2.2. Replacement of Concrete Reinforcement Method

The replacement concrete reinforcement method is mainly used for damaged members with concrete deterioration, strength reduction, and local damage. This method consists of replacing the locally damaged concrete with newly cast concrete to restore the ultimate loading capacity, meanwhile, this method can effectively keep the appearance of the original structures. Yang et al. [49] discovered that the load-bearing capacity could be restored well when only the damaged concrete was removed and damaged parts were filled with fine stone concrete.

### 3.2.3. Fiber Reinforced Polymer (FRP) Strengthening

Maluk et al. [50] conducted fire resistance tests on thin CFRP pre-stressed RC slabs. Their test results showed that explosive spalling led to sudden collapse in a fire. In addition, the anchorage was damaged due to instability, which was controlled by the temperature of tendons, while the presence of CFRP grids within the anchorage zones appeared to increase the time-to-failure for slabs that failed due to loss of anchorage. Haddad et al. [51] studied the performance of fire-damaged RC slabs repaired with FRP sheets. Sixteen one-way slabs were cast, heated at 40 °C for two hours and strengthened by the FRP sheets, which consisted of recurring water and strengthening with FRP. Their results indicated that the bending strength increased by 58%. Waleed et al. [48] also mentioned the use of CFRP to restore the ultimate bending strength of one-way slabs. According to the test results, the load carrying capacity of slabs repaired with CFRP can be increased by 140%. Experimental results in the literature [40] showed that CFRP can significantly improve the bending strength and bending stiffness of beam-column joints. The increases in bending strengths are listed in Table 3.

**Table 3.** The increase in flexural resistance strength.

Reference	Slab Size (mm)	Technique	FRP Material	Strength Increase (%)
Haddad et al. [51]	1500 × 700 × 75	EBR	CFRP/GFRP	25% to 58%
Gherdaoui et al. [52]	965 × 680 × 60	EBR	CFRP	23% to 65%
Harajli et al. [53]	670 × 670 × 55	EBR	CFRP	26% to 73%

## 4. Analytical Model of Flexural Members

### 4.1. Residual Bearing Capacity of Flexural Elements

Kodur et al. [54] proposed an analytical model to estimate the residual strength of RC beams after fire exposure. A simplified empirical equation was developed to analyze the maximum rebar temperature, and then a modification factor  $\lambda$  was proposed. The value of  $\lambda$  depended on the axis distance (distance from the center of the rebar to the nearest exposed surface), the depth-to-width ratio of the concrete section, and the fire duration. Based on the relationship between  $\lambda$  and these parameters, an equation was developed that provides predictions with minimal variations from the temperature values predicted by detailed thermal analysis. The flexural capacity of an RC beam after fire exposure can be given by:

$$M_n = A_s f_{yT} \left( d^* - \frac{A_s f_{yT}}{1.7 b^* f'_c} \right) \quad (1)$$

where

$M_n$  is the flexural capacity of the fire-exposed RC beam, kNm;

$A_s$  is the area of tension steel, mm<sup>2</sup>;

$f_{yT}$  is the residual strength of reinforcing steel, MPa;

$d^*$  is the effective depth of the damaged concrete section, mm;

$b^*$  is the width of the damaged concrete section, mm.

### 4.2. FRP Strengthening

According to the existing test results, a number of analytical models were established to analyze the fire resistance of flexural members [55–60]. The fire resistance of CFRP repaired beams mainly depended on the mechanical characteristics of the interface under high temperatures [61,62]. Dai et al. [63] established a three-dimensional numerical model to study the bending behavior of EBR-CFRP repaired beams. The results showed that the fire resistance of specimens was overestimated because the change of temperature was not considered. A nonlinear bond stress–slip relationship at the CFRP-concrete

interface was developed to take into consideration the bonding characteristics between CFRP and concrete at elevated temperatures.

Because the material property of FRP bars and sheets were primarily dependent on the glassy transition temperature  $T_g$ , the value of  $T_g$  becomes a critical parameter in each model. Bisby et al. [64] adopted the sigmoid function to describe the degradation of the tensile strength of FRP bars and sheets. The calculated results agreed well with the available results [40,65]. The relationship is as follows:

$$\frac{f_T}{f_0} = \left(\frac{1 - \alpha_1}{2}\right) \times \tanh\left[-\alpha_2 \times \left(\frac{T}{T_g} - \alpha_3\right)\right] + \left(\frac{1 + \alpha_1}{2}\right) \quad (2)$$

where  $f_0$  is the tensile strengths at ambient temperature, MPa;

$f_T$  is the tensile strengths at an elevated temperature  $T$ , °C;

$\alpha_1 = 0.556$ ,  $\alpha_2 = 5.624$ , and  $\alpha_3 = 0.630$ .

Kodur and Yu [11] presented a model to evaluate the fire response of concrete beams repaired with NSM technology. The high-temperature characteristic of the materials, the boundary conditions, and the bond degradation caused by the temperature of the FRP–concrete interface were considered in this method. Dai et al. [63] investigated the spalling failure criterion by comparing the analytical and numerical results. In addition, the overall performance of the cantilever concrete beam strengthened by NSM technology was studied. In order to calculate the slip between FRP bars (or bands) and surrounding adhesives, the bond slip relationship developed by Cruz and Barros [66] was introduced into the analytical model. The following results were obtained:

$$\tau(s) = \tau_m \cdot \left(\frac{s}{s_m}\right)^\alpha, s < s_m \quad (3)$$

$$\tau(s) = \tau_m \cdot \left(\frac{s}{s_m}\right)^{-\alpha}, s > s_m \quad (4)$$

where  $\tau(s)$  is the bonding stress acting on the contact surface between the FRP and adhesive in the length;

$\tau_m$  is the bond strength, MPa;

$s_m$  is slip at peak bond stress, mm;

$\alpha$  and  $\alpha'$  are parameters defining the local bonding stress–slip relationship.

Yu et al. [67] proposed an analytical model that could conveniently predict the fire resistance of NSM FRP strengthened RC beams with satisfactory accuracy, where two possible failure modes (i.e., “steel yielding after FRP slipping” and “FRP fracture after steel yielding”) were presumed for the NSM FRP strengthening system under fire.

#### 4.3. BSP Technique

BSP technology can be tracked from the 1980s. According to a series of experimental and theoretical studies, Oehlers et al. [41] established the relationship between the degree of the plate–RC partial interaction and the shear stiffness of the bolt connection. A computer program was developed by Su and Siu [42,43] to calculate the non-linear behavior of bolt groups under in-plane loading. To verify the accuracy and effectiveness of this program, a numerical investigation was carried out to study the response of individual bolts subjected to in-plane loads and a bolt group. The conclusion can be drawn that the elastic limit of a bolt group could be about 30% lower than its load-bearing capacity. Figure 9 shows the assembly and meshing of a BSP beam [44]. Li et al. [68] established the following formula to evaluate the shear strength of the BSP beams.

$$P_u = \frac{P_{st}(d_0 - \frac{x}{2}) + V_d(\frac{d_0 - x}{\tan \theta}) + T_v(\frac{d_0 - x}{2 \tan \theta})}{\frac{a}{2} - (\frac{x}{2} \sin \theta + z_1) K_a} \quad (5)$$

$$K_a = \frac{L^3}{(EI)_c [0.03224L^4\beta_m(1 + \beta_p^{-1}) + 281.369]} \cdot \frac{aK_b}{4S_b \cos \theta} \quad (6)$$

$$P_{st} = A_{st}f_{yt} \quad (7)$$

$$V_d = \alpha_E f_{ct} A_{st} \quad (8)$$

$$T_v = \frac{f_{yv} A_{sv}}{s_v} \left( \frac{d_0 - x}{\tan \theta} \right) \quad (9)$$

$$\beta_p = \frac{(EI)_p}{(EI)_c} \quad (10)$$

$$\beta_m = \frac{K_b/S_b}{(EI)_c} \quad (11)$$

where  $P_u$  is the shear capacity of the BSP beam, kN;

$P_{st}$  is the tensile force of longitudinal tensile reinforcement, kN;

$V_d$  is the dowel force of tensile reinforcement, kN;

$T_v$  is the tensile force of stirrups, kN;

$f_{ct}$  is the tensile strength of concrete material, MPa;

$A_{st}$  is the sectional area of longitudinal tensile reinforcements, mm<sup>2</sup>;

$\alpha_E$  is the ratio between the elastic moduli of rebar and concrete;

$A_{sv}$ ,  $s_v$ , and  $f_{yv}$  are the cross-sectional area (mm<sup>2</sup>), spacing (mm), and yield strength of stirrups (MPa);

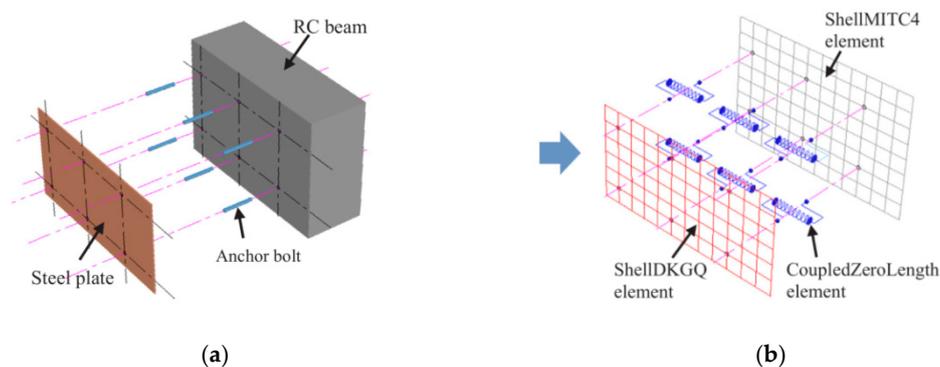
$x$  is the depth of the shear-compression zone, mm;

$d_0$  is the effective depth of RC beam, mm;

$L$  is the beam length, mm;

$K_b$  is the shear stiffness of an anchor bolt, kN/mm;

$S_b$  is the horizontal bolt spacing, mm.



**Figure 9.** Assembly and meshing of a bolted side-plating (BSP) beam (a) assembly of components; and (b) meshing and connection (adapted from [44]).

In addition, in order to limit the load-bearing capacity in shear, the shear and compressive stresses should satisfy the criterion of Equation 15 [69].

$$\frac{\tau_c}{f_c} \leq \left[ \frac{\tau_c}{f_c} \right] = \sqrt{0.0089 + 0.095 \frac{\sigma_c}{f_c} - 0.104 \left( \frac{\sigma_c}{f_c} \right)^2} \quad (12)$$

where

$\tau_c$  is the shear stress of concrete in the shear-compression zone, MPa;

$\sigma_c$  is the compressive stress of concrete in the shear-compression zone, MPa;  
 $f_c$  is the compressive strength of concrete material, MPa.

## 5. Conclusions

This paper presented a review of the repair methods for fire-damaged RC flexural members. The main findings of this study are summarized as follows:

- (1) The externally bonded reinforcement (EBR), near-surface mounted fiber reinforced polymer (NSM FRP) strengthening, and bolted side-plating (BSP) technique were adopted to repair fire-damaged RC beams. Moreover, the section enlargement strengthening, replacement of concrete reinforcement method, and fiber reinforced polymer (FRP) strengthening were applied to repair slabs after exposure to elevated temperatures. Since section enlargement is an economic and effective method, it is widely used in civil engineering.
- (2) The FRP has been widely used for the repairing of post-fire beams and slabs all around the world. The mechanical properties and bonding properties of EBR and NSM FRP systems of bending members represented by beams have been extensively studied, and it has been found that compared with EBR, NSM FRP has more obvious advantages, such as better anchoring ability, better bonding characteristics, and higher ductility. However, when using epoxy resin as an adhesive, it is necessary to ensure fire protection of the repaired members because the epoxy resin is sensitive to fire. The test results conducted by a large number of researchers showed that the fire-damaged RC beams repaired by BSP technology exhibited obvious enhancement in shear capacity, stiffness, and ductility. However, at present, the method of section enlargement is the most economical and applicable method, and the construction is convenient.
- (3) One major question is the level of fire resistance of the components after the repair. Whether considering externally-bonded reinforcement, near surface-mounted FRP, bolted side plating, or jacketing with high- and ultra-high-performance concretes or mortars, all are considered a permanent repair. Hence, it is necessary to provide fire protection of the repaired components.

**Author Contributions:** W.M., C.Y., and J.Z. reviewed references; L.W. conceived the idea and wrote the paper.

**Funding:** This research was funded by the National Key Research and Development Program of China (Grant No. 2017YFC0703001) and the National Natural Science Foundation of China (Grant No. 51678297).

**Conflicts of Interest:** The authors declare no conflict of interest.

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