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Experiment Study on Flexural Behavior of Fire Damaged Prefabricated Hollow Slab Strengthened by CFRP and TRM

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Abstract. Six prefabricated concrete hollow slabs strengthened with different methods were tested under static loads to investigate the flexural performance and reinforcement effects. First, four slabs were exposed to ISO-834 standard fire for 1 hour, and then respectively strengthened with carbon fiber reinforced polymer (CFRP) sheets or textile reinforced mortar (TRM). Through static loading tests, the cracking load, ultimate load, failure mode of these slabs were recorded and compared. The experimental results indicated that the ultimate bearing capacity and stiffness of strengthened hollow slabs have improved greatly. The slabs strengthened by CFRP have better performance in improving the bearing capacity, while TRM reinforcement method is more effective to improve the stiffness and deformation capacity of the prefabricated hollow slabs.

1. Introduction

Due to the material property degradation of reinforced concrete structures, the bearing and deformation capacity will lost a lot after fire exposure. When fire damage was not severe, these capacities could often be restored to normal level by proper reinforcement methods. At present, carbon fiber reinforced polymer (CFRP) reinforcement method is widely used in reinforcement of reinforced concrete structures. However, CFRP reinforcement method will lost most reinforcement effects at fire or high temperatures due to the softening of the adhesive. Nowadays, the reinforcement method of spraying textile reinforced mortar (TRM) on concrete surface became one of the new reinforcement methods. TRM, a new type of composite material, is composed by fiber fabric mesh and high strength polymer mortar. TRM can improve the bearing capacity and deformation capacity of structural members by spraying polymer mortar and laminating fiber fabric mesh. Comparing with CFRP method, TRM reinforcement method has better fire resistance and durability. What's more, polymer mortar has better compatibility with concrete matrix.

At present, most researches on CFRP-strengthened concrete structure focus on the performance of ordinary concrete structures without fire exposure. The research about the reinforcement of prefabricated hollow slabs after fire is rare. Many researchers have done lots of studies about the mechanical behavior of CFRP-strengthened un-damaged prefabricated hollow slabs at room temperature [1-3]. The tests were conducted by literature [4] to study the post-fire performance of precast hollow slab. In addition, a new generation of composites combining high strength textile fibers with inorganic matrices have been recently proposed as a structural retrofitting material for the



deficient RC members namely the textile reinforced mortar (TRM) [5], identified in the literature also as TRC [6] or FRCM [7]. As a new reinforcement method, most researches were conducted on TRM-strengthened ordinary concrete members, while little was on TRM-strengthened fire-damaged concrete members. Hu K. [8, 9] tested four TRM-strengthened fire-damaged reinforced concrete slabs, and indicated that TRM reinforcement method can strengthen the fire-damaged slabs effectively, and the bearing capacity was better than the un-damaged slab.

In order to study the effects of different methods, different reinforcement ratio, a series of static tests on fire damaged prefabricated hollow slabs, strengthened with CFRP or TRM, are conducted. The experimental results can provide much effective design and construction guide for practical engineering.

2. Test design

2.1 Test specimen

Six full-scale prefabricated hollow RC slabs (dimensions of 500 mm width and 120 mm depth) were fire-exposed, strengthened and tested under two-point bending load. These hollow slabs came from an actual multistory brick building, and a total length of them is 3900 mm. Test scheme lists in Table 1.

Table 1. Reinforcement scheme of prefabricated hollow slabs

Specimens Numbers	fire exposure	Reinforcement Method	Width of cloth	CFRP thickness	TRM thickness
S0	NO	—	—	—	—
SF0	1 hour	—	—	—	—
SFC1	1 hour	One-layer CFRP	100×2	0.167	—
SFC2	1 hour	Two-layer CFRP	100×2	0.334	—
SFT2	1 hour	Two-layer TRM	500×1	—	24
ST2	NO	Two-layer TRM	500×1	—	24

Specimen S0 is the un-strengthened slab without fire exposure, and SF0 is the un-strengthened specimen with 1 hour of fire exposure. SFC1 and SFC2 were exposed to fire for 1 hour, and then strengthened respectively with one layer and two layers of CFRP sheets. SFT2 is the fire-damaged specimen strengthened with 2 layers of TRM. ST2 is the reference un-damaged specimen strengthened by 2 layers of TRM. The reinforcement method of CFRP and TRM is shown in figure 1 and 2.

2.2 Test Method and Layout of Measuring Points

Four un-strengthened prefabricated hollow RC slabs were exposed to ISO-834 standard fire for 1 hour, and then were cooled naturally to room temperature. During fire test, the mid-span deflection of the slabs and internal temperature of the slab cross-section were measured. The temperature measure points were arranged as in Figure 1 and Figure 2, R1-R4.

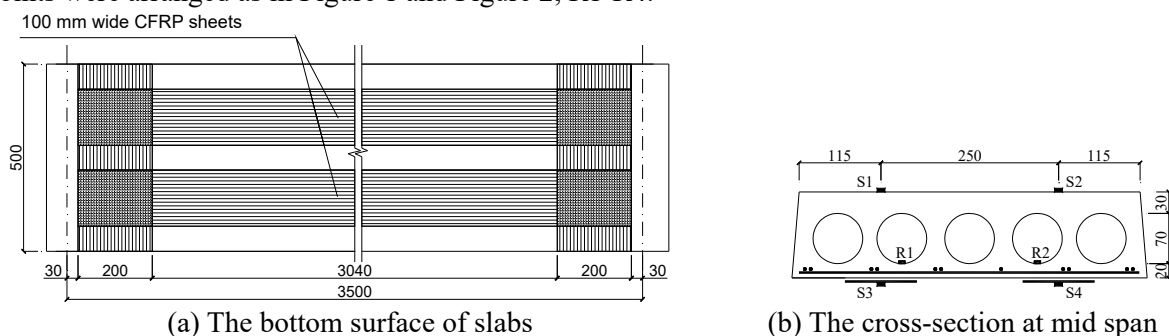


Fig 1. Schematic diagram of CFRP reinforcement SFC1 and SFC2 (Unit: mm)

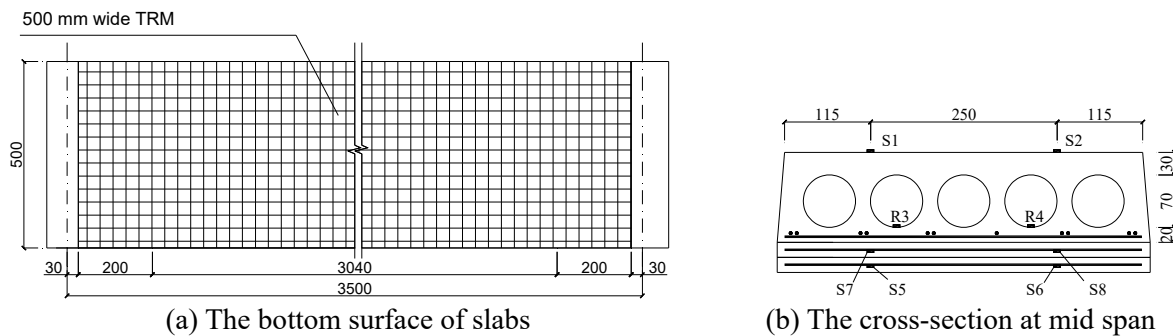


Fig 2. Strengthening sketch map of SFT2(ST2) (Unit: mm)

After fire test, the CFRP and TRM strengthening layers were applied on the fire-damaged slabs, as shown in Figure 3. Afterwards, static loading tests were conducted after natural curing for 28 days. Five displacement sensors, D1-D5, were used to measure and record the deflection of the specimens, as shown in figure 4.

Strain measurement of the concrete, CFRP and TRM fabrics at mid-span was made by eight strain gauges, S1-S8, as shown in figure 1 and figure 2. Two-point loading and multistage loading system was adapted in the test. As shown in figure 4, the distance between the loading points was 1167mm, and the clear span of the specimens was 3500mm. Before cracking, 10 percent of predicted failure load was applied on the specimen at each step. After cracking, the step load changed to 5 percent. The crack load, ultimate load, crack development of the specimen were investigated.



Fig 3. Reinforcement of specimens

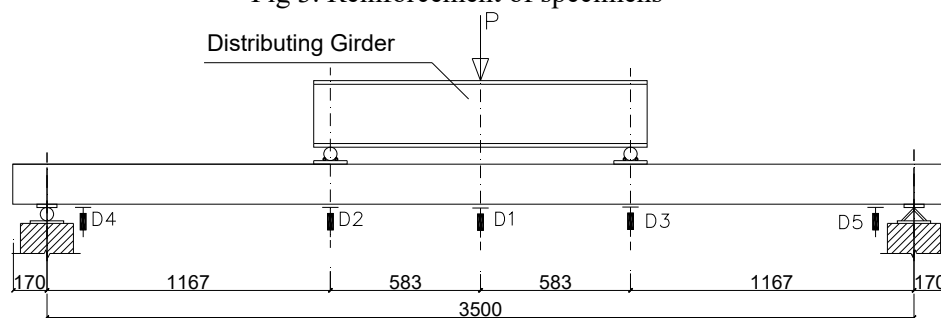


Fig 4. Loading Device and Displacement Meter Arrangement (Unit: mm)

3. Test results and analysis

3.1 Description of failure mode

When exposed to fire for 1 hour, the mid-span deflection of four prefabricated hollow RC slabs reached 50 mm, and the deflection reduced to 5mm after cooled to room temperature. During the fire test, the measured maximum temperature in the circular holes was 290 °C. After fire, the maximum temperature increased to 320 °C. The observation of static tests is described as follows.

For specimen S0, the main crack appeared in the middle zone of the span, and finally the reinforced

layers broke into two parts along the mid-span crack (figure 5a). The original concrete in the upper part cracked in a “Y” shape. For specimen SF0, an arched crack appeared around the left support in the early stage. Finally, the mid-span crack developed from the bottom to the top of the slab section, and the pre-stressed steel bars were tensile ruptured (figure 5b). The failure mode of both S0 and SF0 was pure bending failure.

Specimen SFC1 was strengthened with one layer CFRP after exposed to fire for 1 hour. The main damage happened at a distance of 800 mm from the support. The crack appeared and developed with an about 30 degrees inclination. The failure mode of SFC1 was shear failure. Due to the original quality problem of SFC1, local concrete on the side of middle zone fell off in the test (figure 5c). Specimen SFC2 was strengthened with two layers of CFRP after fire exposure of 1 hour. In the test, the diagonal cracks in the shear zone were rapidly developed and penetrated through the entire section, the CFRP sheets peeled off, and the pre-stressed steel bars were tensile ruptured (figure 5d). The failure mode of SFC2 was shear failure.

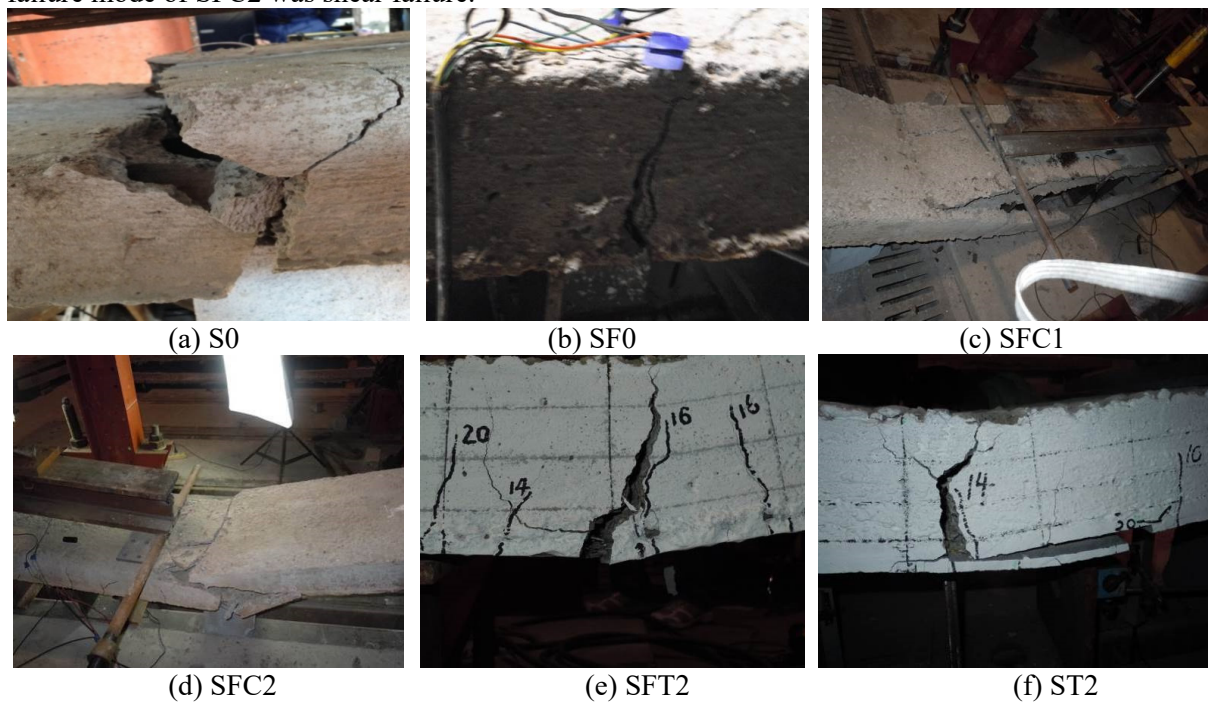


Fig. 5. Failure mode of specimens
Table 2. Cracking loads and failure loads

Specimen	Cracking load/kN	Ultimate load/kN	Max deflection/mm	Failure mode
S0	11.0	11.6	17.4	BFS
SF0	7.6	11.4	55	BFS
SFC1	9.0	26.4	135	SFC
SFC2	9.1	33.0	105	SFC
SFT2	12.0	22.0	130	BFF
ST2	10.0	20.0	60	BFF

BFS: Bending Failure of Steel Bar Tensile Broken. SF: Shear Failure of Concrete Section. BFF: Bending Failure of Fabrics Tensile Broken

Specimen SFT2 was strengthened with two layers of TRM after 1 hour of fire. When the specimen is damaged, the fabric around the location of one loading point and the pre-stressed steel bar are ruptured, and the mortar layer peeled off from the original concrete slab at the main crack zone (figure 5e). The failure mode of SFT2 was bending failure. Specimen ST2 is a specimens strengthened directly with two-layer TRM without fire. Due to improper on-site lifting, ST2 had a transverse fracture crack on the roof before reinforced treatment. When the specimen was under static loading, it

broke from the initial crack (figure 5f). The failure mode of ST2 was also bending failure with the rupture of fabric and pre-stressed steel bar. The summary of failure mode for these specimens is recorded in Table 2.

3.2 Load-deformation curve

The load-deflection curves and the history of concrete and fiber strain of the tested specimens are shown in figure 6. The concrete strain is negative, and the fiber strain of CFRP and TRM is positive.

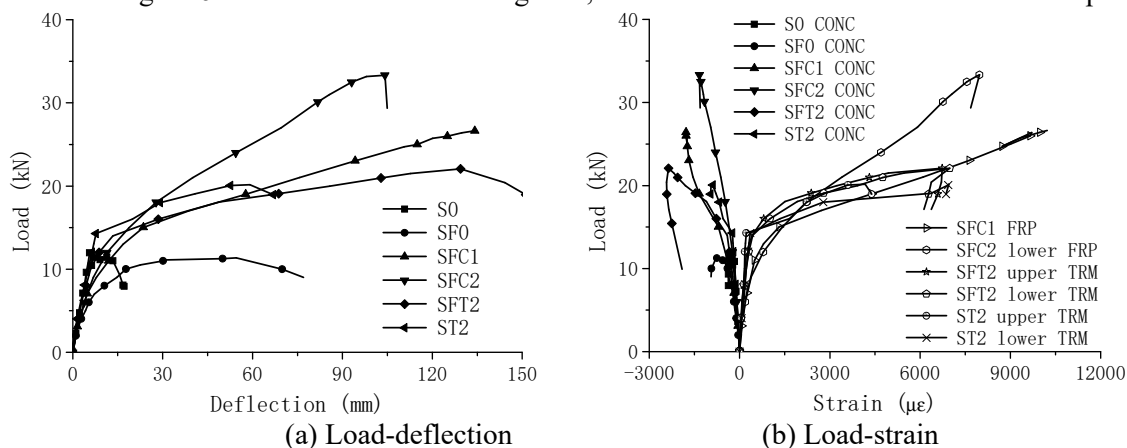


Fig. 6. Load-deformation curve

The following conclusions can be drawn from Figure 6 and Table 2.

(1) After fire exposure, the elastic modulus of concrete decreased due to the effect of high temperature. Although having the same ultimate load, the stiffness of specimen SF0 after cracking is always less than that of the un-fire specimen S0. After the reinforcement with TRM or CFRP, the stiffness, bearing capacity and ductility of the fire-damaged specimens all improved obviously.

(2) CFRP and TRM reinforcement methods significantly increased the crack resistance, bearing capacity and deformation property of the prefabricated hollow slabs after fire. In contrast, the specimens strengthened with CFRP, SFC1 and SFC2, had a higher bearing capacity than TRM strengthened slab SFT2. However, for specimen SFT2, the ductility is better, and the cracking load is higher than that of CFRP strengthened slabs SFC1 and SFC2. It is indicated that TRM reinforcement can effectively improve the stiffness and ductility of components. The test results also show that the crack resistance and bearing capacity improved little for TRM strengthened fire-damaged hollow slab SFT2, compared to that of TRM strengthened un-damaged specimen ST2. But the deformation capacity of SFT2 are twice than that of the specimen ST2.

(3) Under the test conditions in this paper, the cracking load of specimens SFC1, SFC2 and SFT2 increased respectively by 19%, 20% 58%, and the ultimate load of specimens SFC1, SFC2 and SFT2 increased by 132%, 189% and 93%, respectively. In addition, the cracking load of SFC1 and SFC2 were not different, but the ultimate load of SFC2 increased up to 57% than that of SFC1. The ultimate load of SFC1 is 40% higher than that of TRM strengthened slab SFT2.

(4) For specimen SFC1 and SFC2, the CFRP strain growth is almost the same in the early. After concrete cracking, the strain growth of SFC2 lagged behind that of specimen SFC1, and the growth rate is relatively slower. It shows that with the CFRP layers increase, the stiffness and bearing capacity increased. Compared SFC2 with SFT2, it can be seen that the TRM fiber strain of SFT2 has an obvious delayed increase in the early stage of loading, while increased much rapid than the strain of SFC2. It indicates that the initial stiffness of TRM strengthened slab SFT2 was larger and the later stiffness weakened.

(5) As can be seen from the load-strain curve of TRM strengthened specimen SFT2 and ST2, the deformation of upper and lower TRM layer is synchronous. The strain of TRM fiber at the lower layer is slightly larger than that at the upper layer, which indicated that TRM at the upper and lower layers can work well together.

4. Conclusion

In this paper, the static tests were conducted on the fire damaged prefabricated concrete hollow slabs, strengthened with CFRP or TRM material. The experimental data, including crack load, ultimate load, failure deflection and strain, were recorded and analyzed. The following conclusions can be drawn.

(1) CFRP and TRM reinforcement method can significantly increase the ultimate bearing capacity of the prefabricated hollow slab whether fire damaged or not, and also increase the stiffness and deformation capacity obviously. For one-layer CFRP, two-layer CFRP and two-layer TRM reinforcement, the cracking load increased respectively by 19%, 20% 58%, and the ultimate load increased by 132%, 189% and 93%, respectively.

(2) The ultimate bearing capacity of two-layer CFRP reinforcement specimen is 57% higher than that of one-layer CFRP reinforcement specimen. Respectively for one-layer CFRP and two-layer CFRP reinforcement specimen, the ultimate bearing capacity is 40% and 96% higher than that of TRM reinforcement slab.

(3) CFRP reinforcement method is simpler to construct and more effective than TRM reinforcement method in improving the bearing capacity, but TRM reinforcement method has greater deformation capacity.

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