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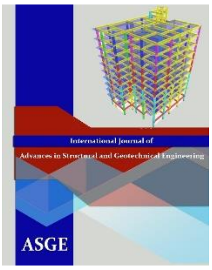

International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 *Online ISSN 2812-5142*

Special Issue for ICASGE'19

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ASGE Vol. 03 (04), pp. 214-226, 2019

International Conference on Advances in Structural and Geotechnical Engineering

ICASGE'19

25-28 March 2019, Hurghada, Egypt

Rehabilitation of Beams Made of Aluminum Powder and Pumice Stone after fire using Different Techniques

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ABSTRACT

In this paper, the structural behavior of reinforced concrete beams made of pumice stone (PS) with aluminum powder (AP) after exposure to fire and rehabilitation by three different techniques (concrete jacket, steel plates and carbon fiber reinforced polymer (CFRP)) was studied. The beams were subjected to fire at 800°C, with a period of 2 h. As a result, the rehabilitation of beams after fire by using the different techniques has a positive effect on loading capacity in bending and deflection for all concrete mixes, but the rehabilitation by concrete jacket is the best technique on the flexural behavior in this study and then comes rehabilitation by steel plates. In addition, the rehabilitation of beams using CFRP strips after fire has a positive effect on flexural behavior regardless concrete type, but need to improvement of glued method.

Keywords: beams, fire, aluminum powder, pumice, rehabilitation, concrete jacket, steel plates, carbon fiber.

1. INTRODUCTION

Fire affects buildings negatively, where elevated temperatures cause significant damage to structural elements. Thus, the strain is increasing when the stress reaches the maximum value because of fire [1-3]. Hence, buildings must be protected from fire damage. Production of lightweight concrete (LWC) has contributed to higher fire resistance, where LWC exposed to high temperature (700°C) has greater compressive strength compared to normal concrete [4-5]. Moreover, LWC has many advantages that make it one of the most important types of concrete [6-10]. However, there is still a need to develop lightweight concrete to be more resistant to fire. Lightweight concrete can be produced by using lightweight aggregates or a foaming agent, where pumice stone is used as lightweight aggregate and aluminum powder as agent producing blanks [11-14]. Most studies use aluminum powder and pumice in the production of non-structural lightweight concrete [15-17]. It is possible to repair and re-use structures again after being subjected to fire, but this depends on the level of deterioration that occurred to the structural elements [18]. The properties of beams which are made of LWC after the fire have not been widely studied despite the use of LWC in structural elements in important projects on a large scale [19]. This study is conducted to study the structural behavior of reinforced concrete beams which are made of aluminum powder with pumice after fire and their rehabilitation by different techniques.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

The used cement was (CEM I 42.5 N) produced according to (ESS 4756-1, 2009) [20]. The silica fume (SF) was used as an addition. Table 1 presents the different properties of both cement and silica fume. The dolomite was used as coarse aggregate and the pumice stone (PS) was used with a different replacement of coarse aggregate with the maximum size 12 mm. The natural sand was used as fine aggregate and the different aggregates properties are displayed in Table 2. The aluminum powder (AP) was used to increase the concrete resistance to fire by creating voids in the concrete. Tap water was used in concrete mixing with superplasticizer (SP) to achieve slump in the range (85-95 mm). Table 3 shows the different properties of both superplasticizer and aluminum powder. The carbon fiber reinforced polymer (CFRP) was used for rehabilitation of beams after the fire. The CFRP strips of 50 mm width and 1.2 mm thickness. Table 4 presents properties of the used CFRP. Steel plates have been used in this study. The yield stress of steel plates was 473.4 N/mm^2. The ultimate tensile strength was 581.3 N/mm^2. The percentage of elongation was 16.8%.

Table 1: Characteristics of cement and silica fume

Basic properties		Cement	SF
Specific gravity		3.15	2.15
Fineness (cm^2/g)		3555	264498
Setting time (min.)	Initial	139	—
	Final	197	—
Soundness (mm)		1	—
Compressive strength (MPa)	2-days	25.9	—
	28-days	49.3	—

Table 2: Characteristics of aggregates

Basic properties	Dolomite	Pumice	Sand
Specific gravity (SSD)	2.65	0.96	2.5
Unit weight (kg/m^3)	1680	678	1620
Absorption (%)	1.59	37.23	1.87
Fineness modulus	—	—	2.67
Clay and other fine materials (%)	0.17	0.94	1.3

Table 3: Properties of aluminum powder and superplasticizer

Property	AP	SP
Color	Silver-gray	Brown
Specific gravity (g/cm^3)	2.7	—
Atomic weight	26.98	—
Volumetric mass at 20°C (kg/l)	—	1.16
Shelf life (month)	—	18

Table 4: Properties of CFRP

Property	Value
Density (g/cm^3)	1.6
Tensile strength (N/mm^2)	3100
Elastic modulus in tension (N/mm^2)	165000
Strain at break	1.8%

2.2 Specimens Production

The structural lightweight concrete was produced by using 75% pumice stone as a replacement of dolomite with 0.5% aluminum powder as an addition to the cement weight. The sand/total aggregate ratio was 44%. Moreover, 420 kg/m^3 cement was used with 12% silica fume in the production of mixtures, and W/C ratio varied from 0.45 to 0.49 with superplasticizer (0.8%-1.8%) to achieve slump in the range 85-95 mm. The curing period in the water tank was 28-days after 24 h from casting. The details of concrete mixtures are displayed in Table 5.

Table 5: The manufactured mixtures

Mix	**Materials (kg/m^3)**							
	C	**SF**	**AP**	**W**	**SP**	**Sand**	**Dolomite**	**PS**
M1- control mix	420	50.4	-	189	7.56	736.4	937.3	-
M4-AP0.5%-PS0%	420	50.4	2.1	193.2	6.72	731.6	931.1	-
M7-AP0%-PS75%	420	50.4	-	205.8	3.36	721.4	229.5	249.5
M11-AP0.5%-PS75%	420	50.4	2.1	189	7.56	735.6	234.0	254.3

2.3 Fire Procedure

Concrete beams were exposed to direct fire after the finishing of curing and drying at room temperature. The beams were directly exposed to fire flame in the gas oven with temperature 800°C for a period of 2 h. The beams were put in the gas oven for 2 h with measuring fire temperatures constantly during the fire by using thermal sensor (type K) connected with thermocouples (type K) and thermometer. The measured temperature variations did not exceed ±3°C in all beams. The rehabilitation of beams and testing were done after firing and self-cooling to 22°C in the oven.

2.4 Rehabilitation of beams and Testing

The rehabilitation of the reinforced concrete beams made of lightweight concrete after the fire was by using three different methods; the first method was using CFRP strips with width 50 mm and thickness 1.2 mm, where preparation of concrete surfaces was before putting a layer of the epoxy matrix on the bottom of beams. After that, the strips of carbon fiber were put on epoxy matrix, then the second layer of epoxy matrix was put on fiber strips. The second method was using steel plates with width of 100 mm, thickness of 4 mm and the steel plates were installed for covering 100% of effective span of beam. The steel plates have been affixed using expansion bolts which were inserted into the holes with depth 80 mm. The last method was using concrete jacket, where the holes were created with diameter of 10 mm and depth of 70 mm on each side of the beams to insert the stirrups with diameter of 8 mm inside beams, two bars with diameter of 10 mm were added as main steel of reinforced concrete jacket. The stirrups were glued into the holes by using Kimapoxy 165 after cleaning the holes with an air blower, then sprinkling the addibond 65 on the top surface of beams to improve the bond between old and new concrete. Finally, the new concrete layer was cast. Figs. 1 to 3 show steps of rehabilitation of the reinforced concrete beams. The flexural behavior of produced beams after the fire and rehabilitation by different techniques was studied at 800°C for a period 2 h, where the beams were with a cross-section of 150×150 mm and 1000 mm length. The main reinforcement was high-strength reinforcing steel with diameter 10 mm. The details of reinforcement and loading of beams are displayed in Fig. 4.

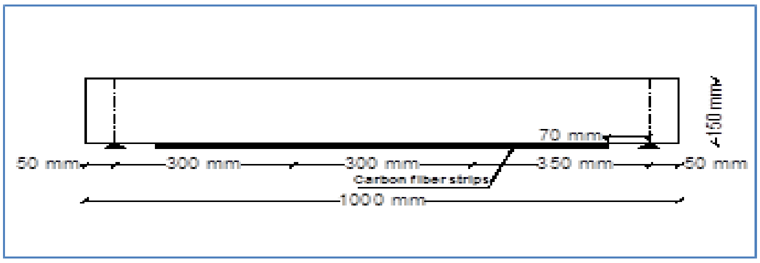


Fig. 1: Steps of rehabilitation of beams using CFRP

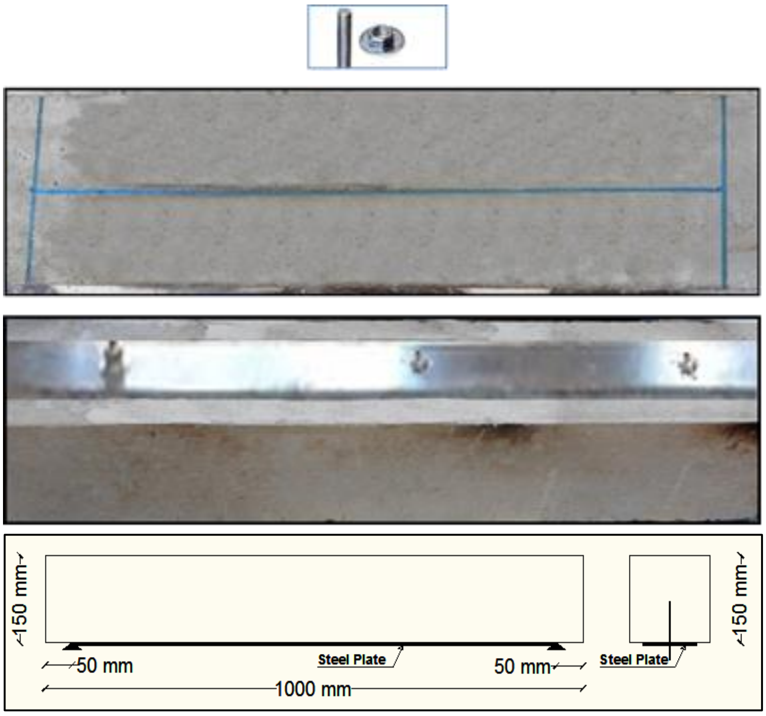


Fig. 2: Rehabilitation of beams using steel plates

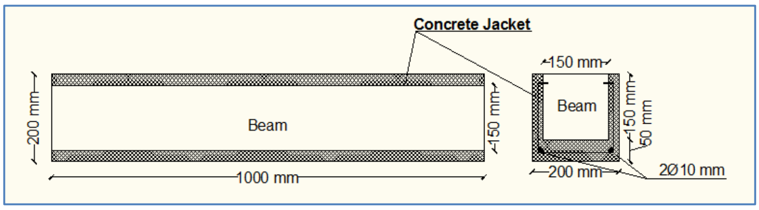


Fig. 3: Rehabilitation of beams using concrete jacket

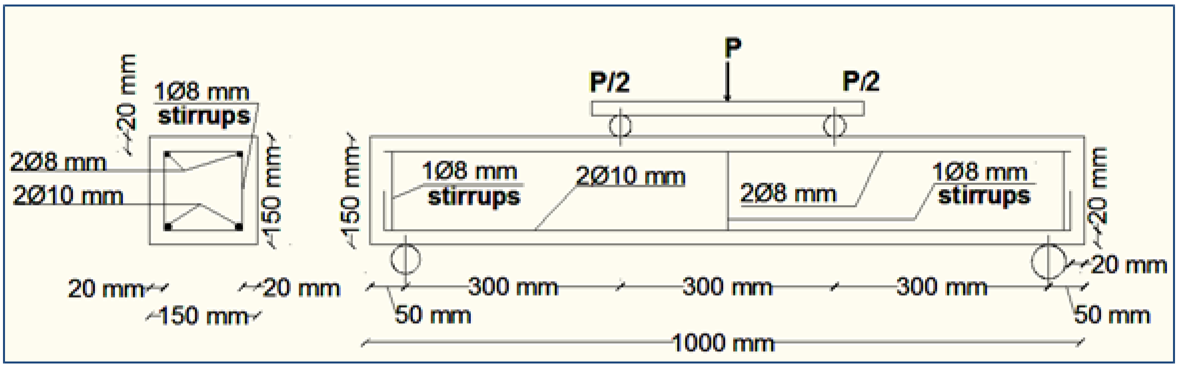


Fig. 4: Details of reinforcement and loading of beams

3. RESULTS AND DISCUSSION

The structural behavior of the control beams made of mixture (M1) was studied after exposure to fire at 800°C for a period 2h and rehabilitation of the beams by three techniques (CFRP strips, steel plates and concrete jacket). The load-deflection behavior of beams is shown in Fig. 5, and crack pattern is shown in Fig. 6. Based on the results it can be noticed that:

1. The load capacity in flexure decreased by about 43.8% when the beams were exposed to fire of 800°C for a period 2h, while the deflection values at mid-span increased by about 6.4%.
2. The loss of load capacity in flexure decreased by about 18.8%, while the deflection values at mid-span decreased by about 8.9%, when the beams were repaired using CFRP strips after fire exposure with the same previous conditions, this is attributed to the mechanical properties of CFRP.
3. The loss of load capacity in flexure decreased by about 31.25%, while the deflection values at mid-span decreased by about 11.03%, when the beams were repaired using steel plates after fire exposure with the same previous conditions, as a result of resistance of steel plates to flexural behavior.
4. The loss of load capacity in flexure decreased by about 35.94%, while the deflection values at mid-span decreased by about 12.81%, when the beams were repaired using concrete jacket after fire exposure with the same previous conditions, this may be due to the increase in the cross-section of beam and steel reinforcement.

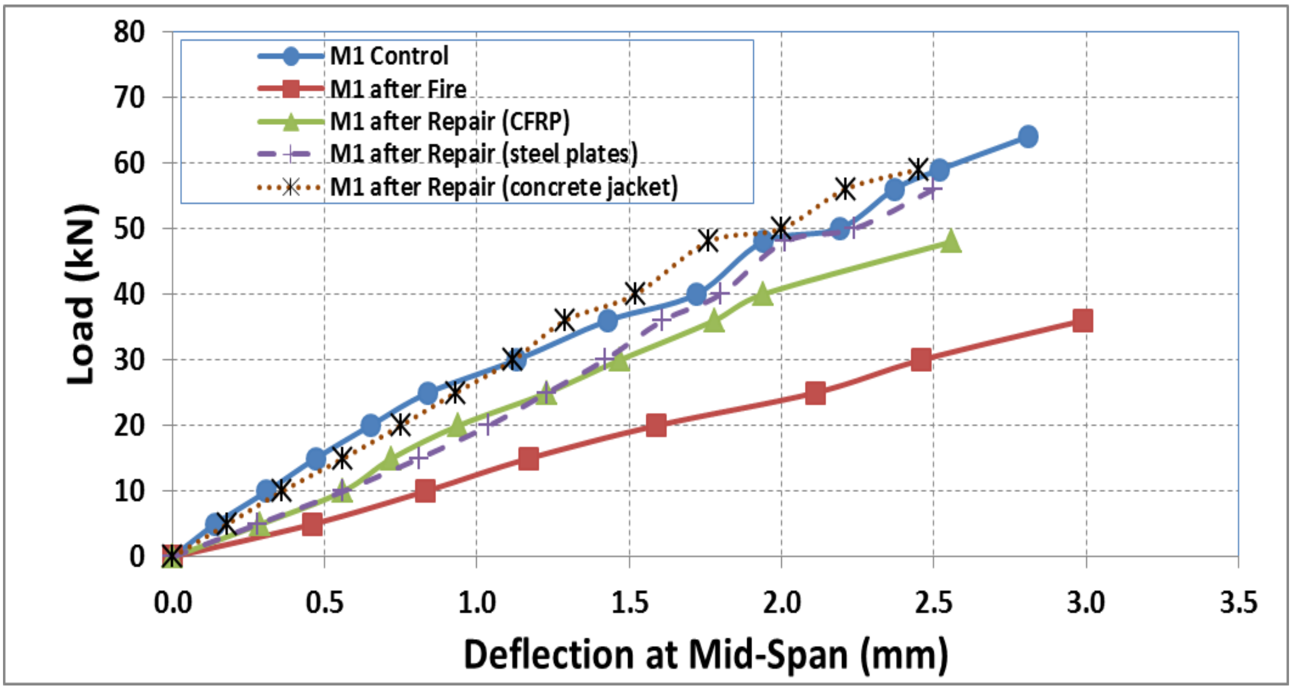


Fig. 5: Load-deflection curve of beams mixture (M1) after fire and repair

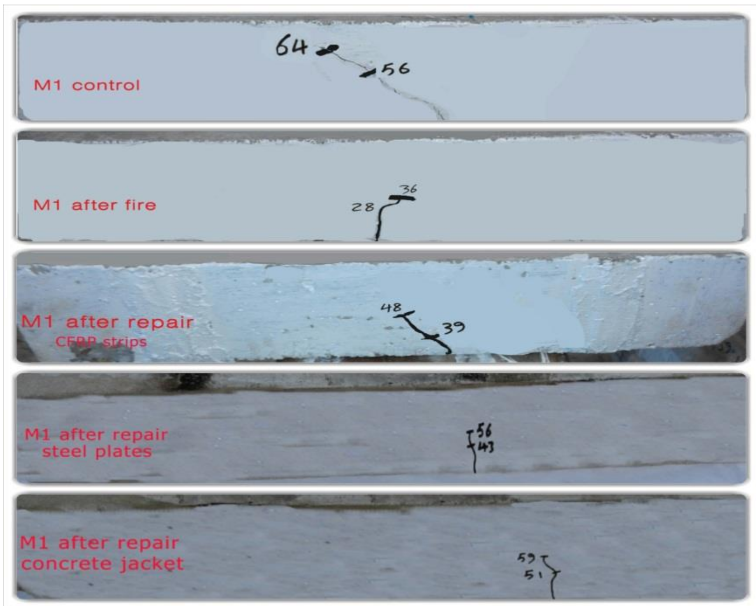


Fig. 6: Crack pattern of beams mixture M1

The structural behavior of beams made of mixture (M4) was studied after exposure to fire of 800°C for a period 2h and rehabilitation of the beams by three techniques (CFRP strips, steel plates and concrete jacket). The load-deflection behavior of beams is shown in Fig. 7, and crack pattern is shown in Fig. 8. Based on the results it can be noticed that:

1. The load capacity in flexure decreased by about 36.9% when the beams were exposed to fire of 800°C for a period 2h, while the deflection values at mid-span increased by about 5.3%.

2. The loss of load capacity in flexure decreased by about 21.7%, while the deflection values at mid-span decreased by about 10.2%, when the beams were repaired using CFRP strips after fire exposure with the same previous conditions, this because of the mechanical properties of CFRP.
3. The loss of load capacity in flexure decreased by about 34.7%, while the deflection values at mid-span decreased by about 3.4% when the beams were repaired using steel plates after fire exposure with the same previous conditions, as a result of resistance of steel plates to flexural behavior.
4. The load capacity in flexure increased by about 39.13%, while the deflection values at mid-span decreased by about 1.9% when the beams were repaired using concrete jacket after fire exposure with the same previous conditions, this is attributed to the increase of both a cross-section of beam and steel reinforcement.

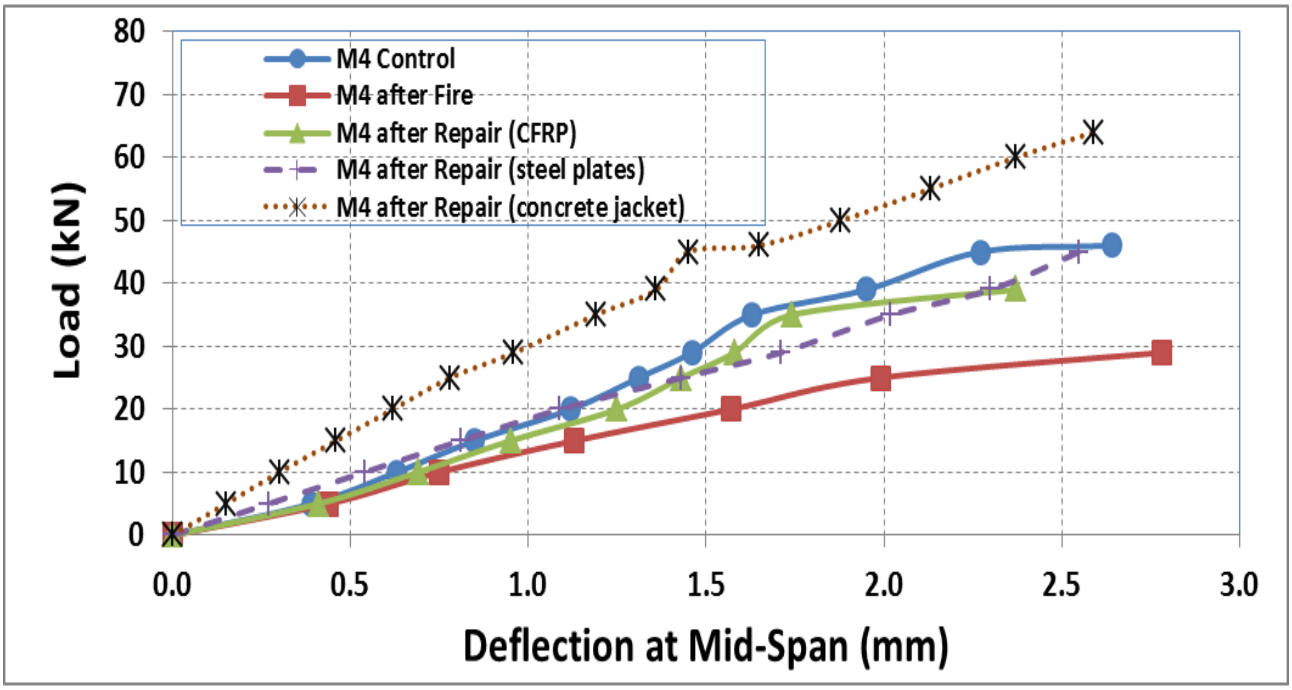
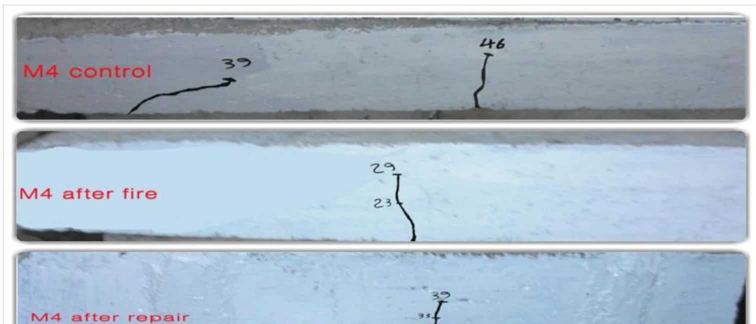
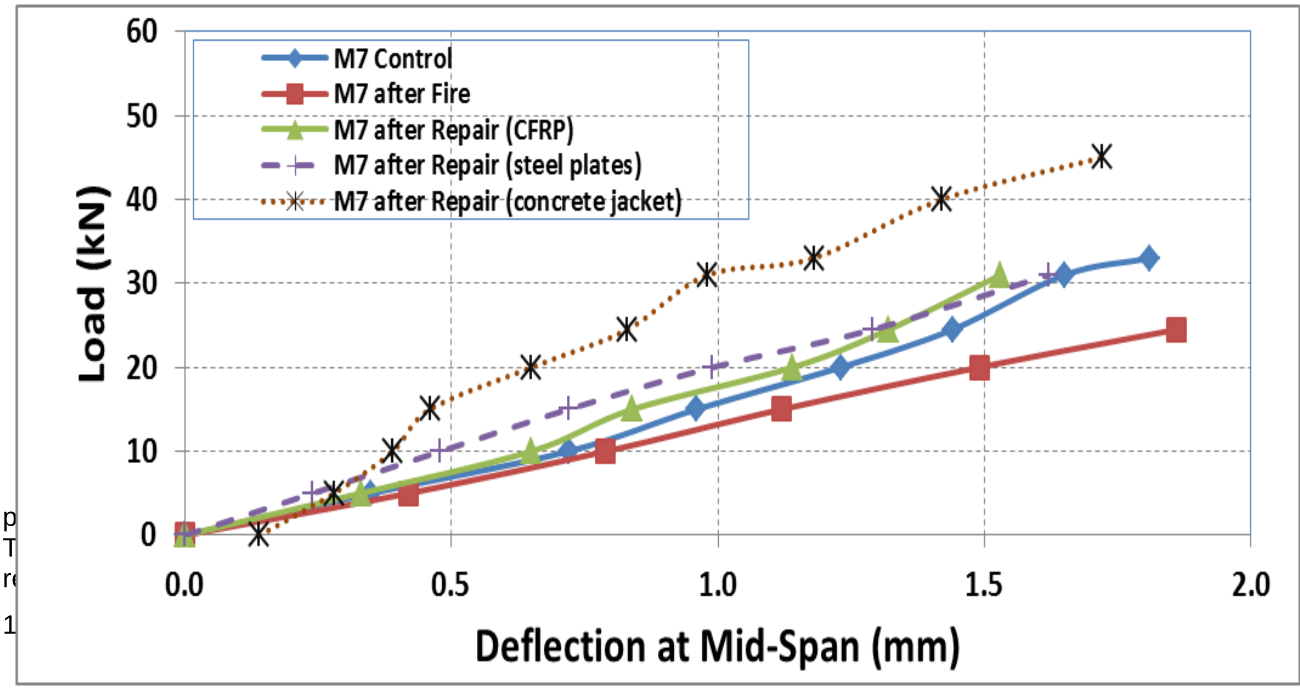


Fig. 7: Load-deflection curve of beams (M4) after fire and repair





2. The loss of load capacity in flexure decreased by about 19.6%, while the deflection values at mid-span decreased by about 15.4%, when the beams were repaired using CFRP strips after fire exposure with the same previous conditions, this because of the mechanical properties of CFRP.

3. The loss of load capacity in flexure decreased by about 21.21%, while the deflection values at mid-span decreased by about 10.49% when the beams were repaired using steel plates after fire exposure with the same previous conditions, as a result of resistance of steel plates to flexural behavior.

4. The load capacity in flexure increased by about 54.5%, while the deflection values at mid-span decreased by about 4.97% when the beams were repaired using concrete jacket after fire exposure with the same previous conditions, this may be due to the increase in the cross-section of beam and steel reinforcement.

Fig. 9: Load-deflection curve of beams (M7) after fire and repair

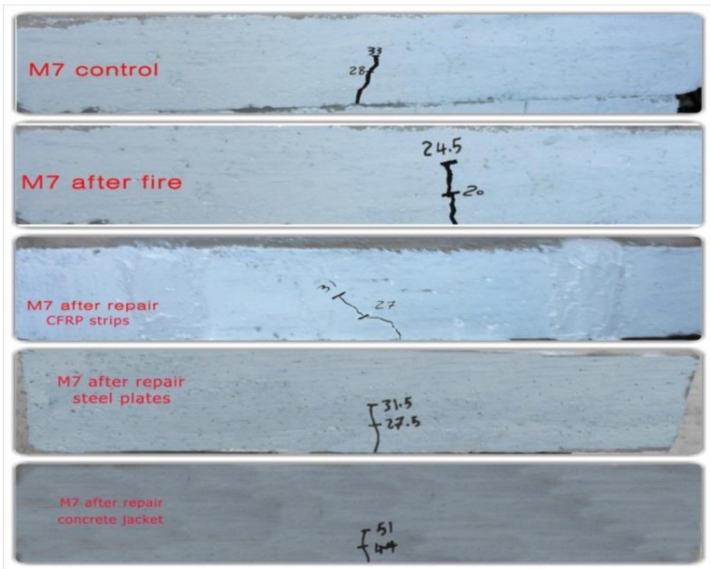


Fig. 10: Crack pattern of beams (M7)

The structural behavior of beams made of mixture (M11) was studied after exposure to fire of 800°C for a period 2h and rehabilitation of the beams by three techniques (CFRP strips, steel plates and concrete jacket). The load-deflection behavior of beams is shown in Fig. 11. and crack pattern is shown in Fig. 12. Based on the results it can be noticed that:

1. The load capacity in flexure decreased by about 31% when the beams were exposed to fire of 800°C for a period 2h, while the deflection values at mid-span increased by about 4.1%.

2. The loss rate of load capacity in flexure decreased by about 20.3%, while the deflection values at mid-span decreased by about 12.9%, when the beams were repaired using CFRP strips after fire exposure with the same previous conditions, this is attributed to the mechanical properties of CFRP.
3. The loss of load capacity in flexure decreased by about 34.7%, while the deflection values at mid-span decreased by about 10.13% when the beams were repaired using steel plates after fire exposure with the same previous conditions, as a result of resistance of steel plates to flexural behavior.
4. The load capacity in flexure increased by about 48.6%, while the deflection values at mid-span decreased by about 5.53% when the beams were repaired using concrete jacket after fire exposure with the same previous conditions, this is attributed to the increase of both a cross-section of beam and steel reinforcement.

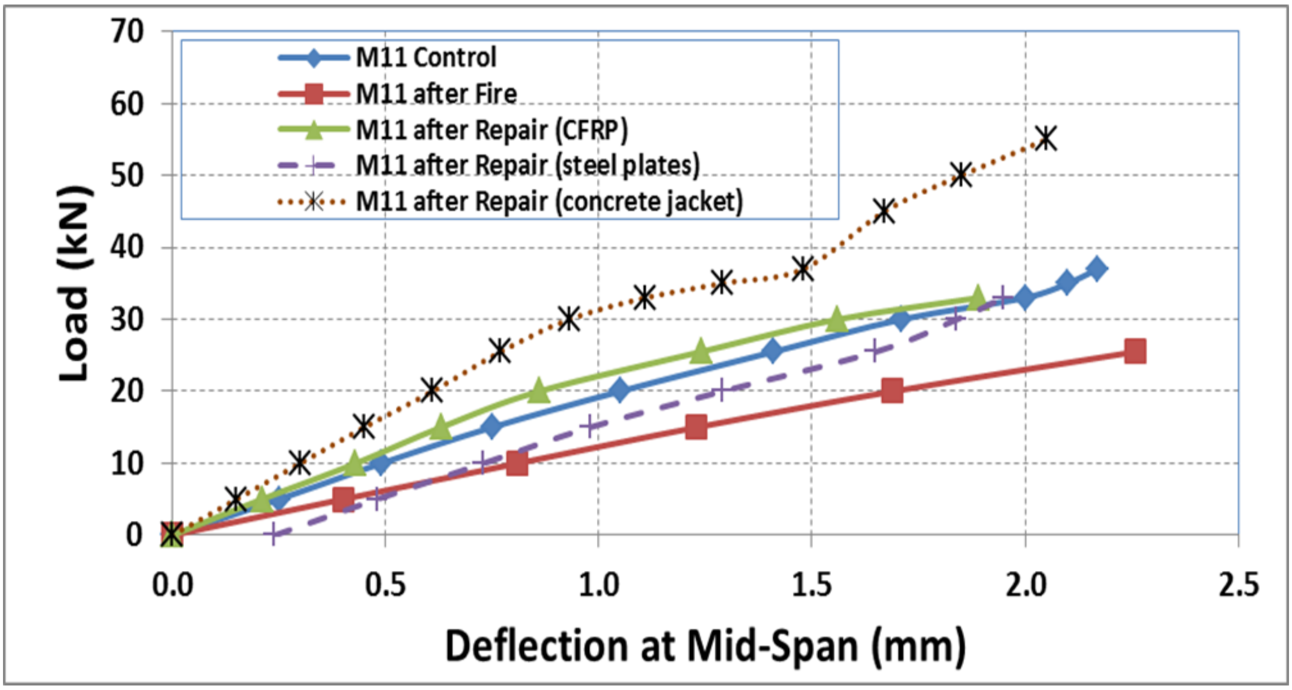


Fig. 11: Load-deflection curve of beams (M11) after fire and repair

Fig. 12: Crack pattern of beams (M11)

From previous results it was found that the fire exposure has a negative effect on load capacity in flexure and deflection in mid-span for all mixtures, but the beams made of PS and AP (M7) have the best flexural behavior. In addition, the rehabilitation of beams using CFRP strips after the fire has a positive effect on flexural behavior regardless of concrete type. Moreover, the rehabilitation using concrete jacket is the best technique for flexural behavior.

4. CONCLUSIONS

- The load capacity of flexure decreases when beams are exposed to fire. On the other hand, the deflection of beams increases by fire exposure.
- The pumice stone and aluminum powder have a positive effect on load capacity in flexure and deflection.
- The rehabilitation of beams using CFRP strips and steel plates after the firing has a positive effect on flexural behavior regardless of concrete type, but need to improvement of glued method.
- The rehabilitation by concrete jacket is the best method for repair in this study.

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