Rehabilitation of Fire Damage Reinforced Concrete Bubbled Slabs

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Abstract

Rehabilitation of damage reinforced concrete structures instead of elimination it partially or totally is present important topic for civil engineer. Experimental investigation was carried out on seven reinforced concrete bubbled slabs, sex of them rehabilitated with CFRP strips after exposed to fire flame and loading until failure while one specimen keeps without burning as reference. The test parameters were; The dimension of specimens was (700x450x80) mm, all specimens have same compressive strength 30 MPa (normal concrete), ball diameter was 40 mm, ratio of reinforcement at top and bottom of slabs 0.00417, fire flame temperature was (300 and 400) ℃, fire flame duration (30 and 60) minutes and concrete cover (20 and 10) mm. the specimens were simply supported in two directions. The structural response of each slab specimen was investigated in terms of load-deflection behavior, ultimate load carrying capacity and mode of failure. The experimental results, generally, indicate that bubbled slabs rehabilitated using CFRP sheets restored flexural strength values nearly equal to or lower than those of the reference slab. Ultimate load of rehabilitated bubbled slabs reaches 79 % to 105 % from reference specimen. Most of the tested slabs have been failed by concrete crushing at supports.

Keywords: bubble slabs, rehabilitation, fire flame, spalling

1. Introduction

The reinforced concrete structure is performing efficiently throughout fire, also it can be repaired following the incident of fire due to the fact that their low heat conductivity avoids degradation or loss regarding mechanical strength of the concrete core as well as the internal reinforcing steel. Upon complete estimation, RC structure that is damaged via fire can be rehabilitated, rather than exposed to total or partial demolition succeeded by re-construction. Several materials could be used to repair the structure, like high-performance concrete, glass fiber-reinforced polymer, ferrocement, normal strength concrete, fiber-reinforced concrete, and epoxy resin mortar [1]. Haddad et. al in 2011 [2] investigated the behavior of reinforced concrete slabs repaired with advance composite materials and study the effect of repairing...
on increasing the flexural capacity of burn-damaged slabs. The results showed that most of the repaired slabs could approach their original stiffness and strength of unburnt slabs. Amer et al in 2016 [3], they were studied rehabilitation of twenty-one slab specimens (500x250x40) mm made of self-compacting concrete, eighteen of them are retrofitted with CFRP sheets after burning and loading until failure while three of them (which represent control specimens) are retrofitted with CFRP sheet after loading till failure without burning. The experimental results, in general, indicate that slabs retrofitted using CFRP sheets restored flexural strength values approximately equal to or lower compared to those of the reference slabs. Most of the tested slabs failed by concrete crushing at mid span and partial deboning of certain retrofitting systems were also observed for a few cases. A simulation based on ABAQUS program was carried out in 2017 by Luis Torres et al [4], in order to predict the flexural behavior of strengthen RC slabs with CFRP rods. RC slab (1000x900x159 mm) was fired during 90 minute in a furnace following ASTM E119, only bottom of slab exposed to fire. The test procedure was exposed fire to slab at duration 90 minute, due to the effect of fire, a detiorated concrete layer of 50 mm at the bottom of slab was removed. Then CFRP rods were installed, epoxy was used for the embedding of CFRP. Based on the results from experiment and simulation, it could be concluded that the proposed method was possible for strengthening RC structures after exposed to fire without changing size of members.

2. Experimental Work

2.1 Introduction

The experimental work was carried out at the structural engineering laboratory collage of engineering at the University of AL-Mustansiriya. The experimental work consists of seven specimens. Table (1) shows the tested RC bubbled slabs.

<table>
<thead>
<tr>
<th>No.</th>
<th>Labeling</th>
<th>Fire flame rate °C</th>
<th>Fire flame duration min.</th>
<th>Cooling method</th>
<th>Cover mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reference (R)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>BNA2-30-2</td>
<td>200</td>
<td>30</td>
<td>gradually</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>BNA3-30-2</td>
<td>300</td>
<td>30</td>
<td>gradually</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>BNA4-30-2</td>
<td>400</td>
<td>30</td>
<td>gradually</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>BNA2-60-2</td>
<td>200</td>
<td>60</td>
<td>gradually</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>BNA3-60-2</td>
<td>300</td>
<td>60</td>
<td>gradually</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>BNA4-60-2</td>
<td>400</td>
<td>60</td>
<td>gradually</td>
<td>20</td>
</tr>
</tbody>
</table>

All RC slab specimens have same dimension (700x450x80) mm; bubble diameter (40) mm with spacing between bubbles (60) mm center to center and the ratio of reinforcement in both bottom and top face is (0.00417). Figure (1) show the details of RC bubbled slab.
2.2 Material and Mixture Properties

In this investigation, the cement used was Ordinary Portland Cement (O.P.C) (type 1) produced in Iraq. This cement complied with the Iraqi Specification No.5 /1984 [5]. Very fine sand with maximum size 600μm was used. This sand was separated by sieving (zone 4) sand (specific gravity of 2.7). For normal concrete slabs, rounded gravel with a maximum size of 10mm was used. This aggregate complied with the Iraqi Specification No.45 /1984 [6]. The proportions by weight of cement: sand: aggregate were 1:1.5:3 with a water/cement ratio of about 0.45. The average 28-day cylinder compressive strength obtained was 30 MPa [7]. After casting, the specimens were covered with polythene sheets and after 14 hours they stripped of the molds and placed in water tank for 27-days and then burned.

2.3 Mixing Procedure

Firstly, a dry sand is loaded into the mixer and then added a 0.5L from water to moistening the sand. After that, gravel is mixed for 0.5 minutes with sand. After that, the cement has been added to mixer and all dry material are mixed for 1 minute to ensure the homogeneity of the mixture. Water was added after that in three stages and subjected to a process of mixing for three minutes. Then, mixer has been stopped, moved by hand and then resume the mixing process for another (3) minutes. This step is for homogeneity of the mix [7].

2.4 Burning Procedure

The RC slab specimens were subjected to fire flame by burners. The fire flame subjected to tension face of slab and placed on ground, the high of slab from the fire flame is 30 cm. steel frame was used for presented the real condition of burning, the frame was closed from all sides with opening. The burning test carried under static uniform load, static load was (8 kpa). Plate (1) show burning test.

Plate (1) Burning Test

2.5 Rehabilitation Procedure

After burning slabs at high temperature, the slabs were overturned (upside down) so that rehabilitating should be done on its bottom surface. For ensuring proper application regarding external strengthening materials, also for removing deformation (curved shape) due to the burning test, it has been essential for improving the characteristics related to concrete surface on contact areas that will be bonded. It included removing cement paste, the spalled areas at slabs were patched conventional concrete repair methodologies, grinding the surface by using an electrical hand grinder, and to remove dust created via surface grinding with the use of air blower. Adhesive has been utilized to tension face related to slab Sikadur-330 (2-part epoxy impregnation resin) has been applied in the presented study to bond CFRP strips in 2 directions, the spacing between
strips in long direction was 5 cm and in short direction 10 cm. The CFRP sheets placed in the bottom of slab after applying thin layer of epoxy. The time gap between the CFRP sheets bonding and the slab test was at least 7 days. The procedure of rehabilitation is shown in Plate (2).

![Plate (2) Rehabilitation Procedure]

2.6 Load Test

All RC slab specimens tested under uniform load by using hydraulic universal testing machine (MFL) with 3000 KN capacity which is available in structural engineering Lab, collage of engineering, Al-Mustansiriya University as can be seen in plate (3). A 0.01mm (ELE type) dial gauge was placed below the center of each slab to measure the central deflection. Figure (2) show the details of test.
3. Experimental Results and Discussions

After burning test completed it is notice four specimens need to rehabilitation based on spalling damage level. Specimens exposed to 200 °C at (30 and 60) minute spalling did not occur so no need for rehabilitation. After this step all specimens tested under uniform load until failure to study ultimate load capacity, load deflection relationship and failure mode to make comparison with reference slab that not exposed to fire flame. Plates (4) show the influence of fire flame on RC bubble slabs.
3.1 Ultimate Load Capacity

Ultimate load can be influence factor to investigate the behavior of rehabilitation RC bubble slab specimens after exposed to fire flame and efficiency of rehabilitation method in comparison with RC bubble slab not exposed to fire flame as references. The experimental results show the reference RC bubble slab has ultimate load (170 KN). The specimens burned in 200 °C fire flame rate and 30 min. fire flame duration no spalling occur then cooled gradually by air secondary loss in ultimate load in
compression with (R) bubbled slab not exposed to fire flame. The ultimate load of (BNA2-30-2) decrease to (7 %) from (R). The bubbled slab exposed to fire flame rate 200 °C fire flame rate at 60 min. fire flame duration show increase in ultimate load (BNA2-60-2) by (3 %) from (R). The increment of ultimate load in 60-minute fire flame duration because fire flow rate, to reach 200 °C at 60-minute fire flow rate slower than 30-minute. So increase ultimate load with increase of fire flame duration at same fire flame rate. For rehabilitated specimens, ultimate load of bubble slab exposed to 300 °C at 30 min. cooled gradually (BNA3-30-2) after rehabilitation decrease by (21 %) of reference bubble slab (R), at same fire duration but 400 °C (BNA4-30-2) the ultimate load decrease by (15 %) and the bubble slabs exposed to 300 °C and 400 °C at 60 min. (BNA3-60-2), (BNA4-60-2) the ultimate load decrease by (6 %), (12 %) from (R). From these results can be conclude ultimate load of rehabilitated fire damage RC bubbled slab influence by fire flame rate, at 30 minute when exposed to 300 °C and 400 °C fire flow rate faster in 400 °C than 300 °C so the fire damage (reduction in capacity) in 300 °C greater than 400 °C because slow fire flow rate lead to observe specimen more heat energy that cause spalling and loss in capacity. Otherwise when increase of fire flame duration to 60-minute fire damage in 400 °C greater than 300 °C. Table (2) show ultimate load capacity for tested slabs.

<table>
<thead>
<tr>
<th>No.</th>
<th>Labeling</th>
<th>Fire flame rate (°C)</th>
<th>Fire flame duration (min.)</th>
<th>Spalling damage level %</th>
<th>( P_{\text{Ultimate}} ) (KN)</th>
<th>( \frac{P_{\text{Ultimate}}}{P_{\text{Ultimate Ref.}}} ) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>170</td>
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<td>175</td>
<td>97</td>
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<tr>
<td>4</td>
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<td>300</td>
<td>30</td>
<td>66</td>
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<tr>
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<td>43.83</td>
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</tbody>
</table>

### 3.2 Load Deflection Relationship

Deflection was measured at center of slabs by (0.01mm) dial gage under load increment 5 KN and reading for this gages were recorded for each load increment. When a reinforced concrete slab is subjected to a gradual load increase, the deflection increases linearly with the load in an elastic manner. After the cracks start developing, deflection of the slab increases at a faster rate. After cracks have developed in the slab, the load-deflection curve is approximately linear up to the yielding of flexural reinforcement after which the deflection continues to increase without an appreciable increment in load.

The deflection increase of bubble slab at (0.6\( P_u \)) from reference bubble slab (R) influence by elevated of temperature, the bubble slab exposed to 200 °C fire flame rate at 30 min. fire flame duration with gradually cooling (BNA2-30-2) greater than (R) by (27 %). The bubbled slab subjected to 200 °C fire flame rate at 60 min. fire flame duration (BNA2-60-2) the deflection approximately equal (R) at same load. This identification because the 200 °C at 60 min. improve the tested slab as well as flexural capacity so the deflection slightly changed at same load. Figure (3) show the load deflection for reference and slabs exposed to 200 °C.

The result of rehabilitated RC bubble slabs show the deflection of slab exposed to 300 °C and 400 °C at 30 min. cooled gradually (BNA3-30-2), (BNA4-30-2) increase by (50 %), (30 %) at same load (0.6\( P_u \)) of reference bubble slab not exposed to fire flame (R). Also the fire flame duration influence in deflection,
when rehabilitated RC bubble slabs exposed to 300 °C and 400 °C at 60 min. cooled gradually (BNA3-60-2), (BNA4-60-2) the deflection increase by (33 %), (42 %) at same load of (R). from these results can conclude at fire flame rate 300 °C when increase the duration to 60-minute deflection decrease due to slow fire flow rate, heat energy transmits to specimen at 30 minute more than 60 minute that lead to spalling damage in 30 minute greater than 60 minute at 300 °C that cause deflection decrease when increase duration at 300 °C. The mechanism inverted when exposed specimen to 400 °C at same durations. Figure (4) show the load deflection for reference and rehabilitated slabs.

![Graph](image1)

Figure 3: Load-Deflection of Slabs Exposed to 200 °C at 30 and 60 min. and Reference

![Graph](image2)

Figure 4: Load-Deflection of Rehabilitation Slabs and Reference.
3.3 Mode Of Failure

3.3.1 Mode of Failure for Specimens Without Rehabilitation

When load is applied to these slab specimens, the first visible crack appeared at (0.3055, 0.282, 0.303) of ultimate load of slab specimens (R, BNA2-30-2, BNA2-60-2) respectively. The effect of fire flame rate and duration is noted in bubble slab exposed to 200 °C at 30 min. and cooled gradually (BNA2-30-2) the first cracking load decrease by (15 %) compare with (R). First crack loading not effect when bubble slab exposed to 200 °C at 60 minute. Plate (5) show the failure mode for reference and slabs exposed to 200 °C.

Plate (5) Failure Mode for Reference and Slabs exposed to 200 °C.

3.3.2 mode of failure for specimens with rehabilitation

All rehabilitated RC bubble slabs have approximately same failure mode under uniform load. When applied load increase it is noted the CFRP strips start partial debonding from the slab. The first visible crack observed on sides of tested slab then started micro cracks on tension face of tested slab, all slabs failure at crushing of concrete at supports. The reason of failure is the tension face worked as composite section included concrete, steel mesh and CFRP strips as one part in other word the tension face be more brittle before rehabilitation and at ultimate load either steel mesh or CFRB strips not reach to yield so the failure chose the weaker point as crush the concrete. Plate (6) show the failure mode of tested rehabilitated slabs.
4. Conclusions

From the experimental results obtained in this study the following conclusions can be summarized:

- Spalling failure did not occur when RC bubble slabs exposed to 200 °C.
- In 300 °C and 400 °C at fire 30-minute spalling occur. Damage of spalling in 300 °C more than 400 °C by (32 %) at same fire duration.
- First spalling effect by fire duration, first spalling occurs in bubble slab exposed to 300 °C and 400 °C but fire duration 30-minute spalling happened earlier than 60-minute.
- The test results specified that a significant improvement in flexural strength can be reached when used CFRP strips to rehabilitation RC bubble slabs.
- Ultimate load of bubble slab exposed to 200 °C at 30 and 60-minute reach to (88-103) % from reference bubble slab keep without exposed to fire flame.
- Ultimate load of rehabilitated bubble slabs reaches to (79-105) % from reference bubble slab keep without exposed to fire flame.
- rehabilitated tested slabs failed by concrete crushing at top fibers.

5. References


[7]. M. H. Mohammed, "Reinforced Concrete Strengthening by Using Geotextile Reinforcement for Foundations and Slabs", Master of Science in Civil Engineering, Civil Engineering Department, Faculty of Engineering, Al-Mustansiriyah University, 2017.