International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume –04, Issue – 12, December 2019, PP – 25-37

Behavior of Reinforced Concrete Bubbled Slabs Exposed to Fire Flame under Static Load

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Abstract: This work devoted to study the behavior of reinforced concrete bubble slabs exposed to fire flame. The experimental work concluded casting and burning nine specimens under static load. 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 (200, 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 test results show that, RC bubble slab exposed to 200℃ at 30 and 60 minutes with 20 mm cover spalling not happened but in specimen with 10 mm concrete cover spalling occurred. All RC bubble slab exposed to 300℃ and 400℃ spalling occurred, damage of spalling for bubble slabs exposed to 300℃ in 30-minute fire duration more than 400℃ by (32 %) otherwise at 60-minute fire duration damage of spalling in 400℃ more than 300℃ by (49 %). Deflection during burning was observed due to static load and elevated of temperature, deflection increase with increase fire flame temperature and duration, increase of fire duration to 60 minute from 30-minute leadto increase in deflection with fire flame rate (200, 300 and 400) ℃ by (57, 79 and 68) % respectively in compassion with slabs exposed same fire rate at 30 minute.

Keywords: reinforced concrete, bubble slabs, Fire flame rate, spalling effect

1. Introduction

Fire is one of the major hazards for structures and buildings. Generally, concrete have good resistance to fire when compared to the other construction materials like steel or wool. In the case of exposing RC slab to high temperatures for long time, mechanical losses regarding its properties will occur and expulsive spalling occur [1].

1.1 Behaviour of RC Slabs Exposed to High Temperature

Karim in 2005 [2] investigated the behavior of solid slab subjected to fire flame. The experimental work was casted and tested twenty-four RC slab with dimension (60x60x4 cm) with compression strength (30 and 38 MPa) and two steel ratio (0.00492 and 0.00875). Sixteen RC slab were subjected to fire flame at temperature around of (400,500 and 600 ℃) for one hour, the cooling method was gradually after that the slabs tested in flexural under uniformly load. The result showed that, it may be concluded that ultimate load capacity of reinforced slab specimens decreased with increasing fire temperatures. The higher decrease occurred in the slab specimens having higher steel ratio and subjected to 600 °C. The residual load capacity of reinforced slab specimens at 600 °C ranges between (84.2-86%) for slab specimens of series(A) which were reinforced with steel ratios of (0.00875,0.00492) respectively and (83.7-85%) for slab specimens of series (B) with the same steel ratios. The fired slab specimens were found to be capable of resisting the service load but with a decreasing factor of safety. The non-destructive test results showed more reduction in the test results after exposure the slab specimens to fire compared with the control specimens.

Prasad in 2016 [3] examined the thermal behavior related to the reinforced concrete slabs which have been exposed to fire. The paper mainly focuses on the percentage deflection of RC slab when exposed to elevated temperature. The RCC slabs (3300x1200x200 mm) were modeled using ANSYS14.5, to show the behavior of slab at elevated temperature with M25, M70 and M100 grade of concrete and with cover of 30mm,40mm and 50mm. Analysis has been conducted for studying load-deflection pattern and percentage of deflection with and without heat with a pressure of 0.1N/mm^2. In stage one, nine specimens were modeled to show the effect of different grade of concrete with different cover. The heat is applied on the basis of ISO 834 curve. The result indicated that deflection related to slabs decreases as the cover provided increases. It was also found that the slab's deflection decreases as the grade of concrete increases. From the result incurred it can be seen that the analysis has shown minimum deflection for M100 with cover 50mm.

Ghanem et al in 2016 [4] studied the behavior related to the reinforced concrete slabs which have been exposed to fire. There are 2 phases of analysis have been conducted, in the first step (group A), the fire duration was variable and ranged between one to three hours while, the concrete cover was fixed and equal to 25mm. In the next step (group B), the concrete cover was variable from 30 mm to 35mm and 40mm while the fire duration was constant at 4 hours. The structure's responses are based on fire duration as well as concrete cover's thickness. The RC (3100x3100 mm) slabs were modeled to show the effect ofslab thickness, and different fire duration. Deflection, lower strain and upper strain of RC slab at temperature of 600 ℃ were also evaluated for the two stages. The result showed that, In the first stage (group A) the failure load decreases from 15.3% to 36.6% compared to control slab. In the second stage (group B) the failure load decreases from 10.22% to 21.9% compared to control slab. And the failure load increases due to increases the concrete cover from 25 mm to 35 mm by 22.22% which burned for constant duration (4 hours) at the same temperature.

1.2 Spalling

The spalling can be defined as breaking away or delaminating the concrete's surface layer because of the exposure to high temperatures. Spalling have a lot of variations. Corner spalling and explosive spalling are the major 2 types of concrete spalling in structural performance. The explosive spalling that tend to happen violently and unexpectedly early in the process of fire exposure, is detected generally in the laboratory tests related to small material specimens and structural elements in addition to the real structures in accidental fires, while the corner spalling is regularly detected along corners of square or rectangular concrete beams or columns, is less violent and more gradual process [5].The approach that lead to spalling is typically include high thermal stress occur due to rapid heating and/or large build-up related to pressure in porous concrete, that the concrete's structure doesn't have the ability to dissipate, because of moisture evaporation. Such action result in creating fractures and expulsion related to the material's chunks from surface layers. Particularly, the major requirements for spalling were determined as: the moisture content has been of minimum two percent, and steep temperature gradients in materials. For the latter, 5 K/mm value is rough minimum and at 7K/mm-8 K/mm spalling is possible [6].Whereas spalling could happen in all the types of concrete, the high strength concrete has more susceptibility to fire induced spalling in comparison to the normal strength concrete because of its low ratio of water-cement and low permeability, as compared to NSC [7].

2. Expiremental 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 nine specimens. Table (1) show the tested RC bubbled slabs.

Table (1) Tested RC Bubbled Slabs

Group No.	Labeling	Fire flame rate ^{o}C	Fire flame duration min.	Cooling method	Cover mm
A	BNA2-30-2	200	30	gradually	20
	BNA3-30-2	300	30	gradually	20
	BNA4-30-2	400	30	gradually	20
B	BNA2-60-2	200	60	gradually	20
	BNA3-60-2	300	60	gradually	20
	BNA4-60-2	400	60	gradually	20
C	BNA2-30-1	200	30	gradually	10
	BNA3-30-1	300	30	gradually	10
	BNA4-30-1	400	30	gradually	10

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.

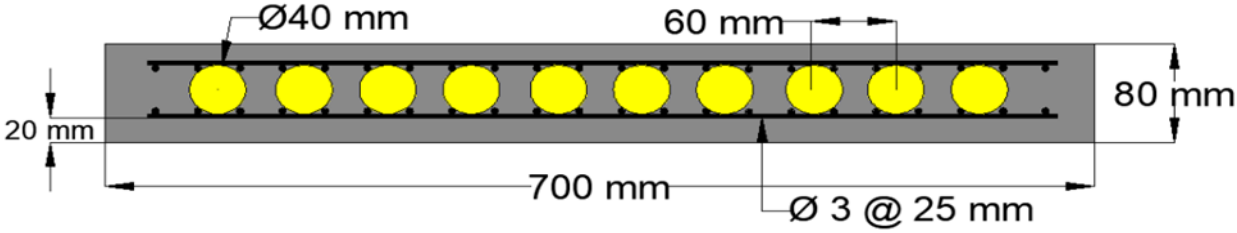


Fig. (1) Details of RC Bubbled Slab

The main investigated variables are:
1. fire flame temperature (200, 300 and 400) ℃.
2. fire flame duration (30 and 60) minutes.
3. concrete bottom cover (20 and 10) mm.

2.2 Material and Mixture Properties

In this investigation, the cement used was Ordinary Portland Cement (O.P.C) (type1)produced in Iraq of (ALMAS). This cement complied with the Iraqi SpecificationNo.5 (1984).Very fine sand with maximum size 600µm was used. This sand wasseparated by sieving (zone 4) sand (specific gravity of 2.7).For normal concrete slabs,rounded gravel with a maximum size of 10mmwas used.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. 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 1minute 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 [8].

2.4 Burning Process

The RC slab specimens were subjected to fire flame by burners shown in plate (1). 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.

Plate (1) Burners

The deflection in mid span was measured through the burning by using dial gage (0.01 sensitivity) plate (2) show the dial gage setup. Also The temperature was measured in two point. Thermocouple type K with capacity (-50 to 1300) ℃ was used to measure the temperature in depth of slab (at neutral axis) and the infrared

thermometer with ability (-32 to 550) ℃ was used to measure the fire rate on bottom face of slab plate (3) show the temperature device measurement.

Plate (2) Dial Gage Setup

Plate (3) Temperature device measurement

The burning test carried under equivalent uniform load, equivalent load consists of steel plate (50 kg) and four sack with weight (200 kg) the total equivalent was (8 kpa). Plate (4) show burning test. Figure (2) show the burning test details.

a) Setup the Specimen, Layer of Fine Sand (2 cm) Laid Between the Specimen and Steel Plate to Ensure the Distribution of Load.

C) Setup the Burners.
Plate (4) Burning Test

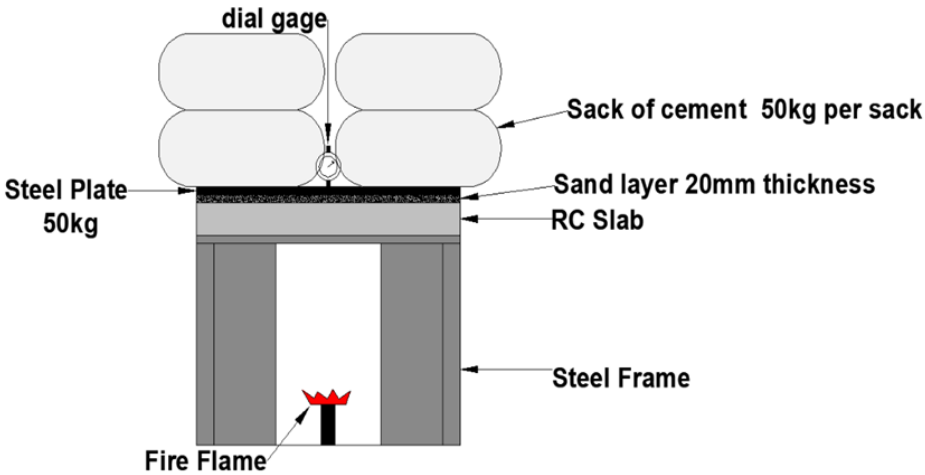


Figure (2) Burning Test Details.

3. Results and Discussion

The effect of elevated temperatures on RC bubbled slabs was significantlyobserved. Spalling occur in some specimens and deflection was measured during specimens exposed to fire flame. Burning RC bubbled slabs divided into three groups.

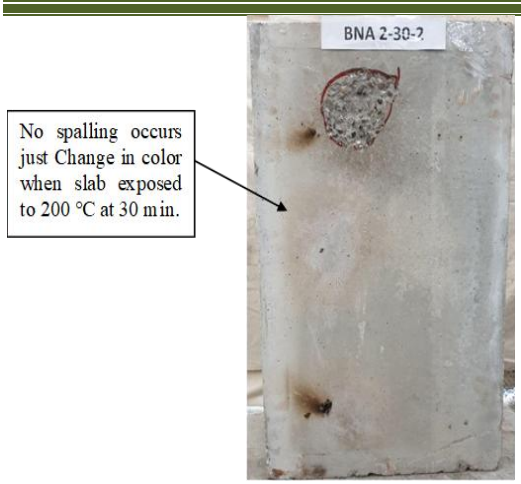
3.1 Group A

3.1.1 First Spalling Time and Spalling Damage in Group A

Spalling was observed in test at fire flame rate 300 ℃ and 400 ℃ but the spalling not occur at 200 ℃ at fire flame duration 30 minute (BNA2-30-2). First spalling occurs in slab exposed to 300 ℃ at 15 minute and temperature on face of exposed slab was 220 ℃ and temperature was 97 ℃ at mid depth of slab (BNA3-30-2). The damage of spalling on exposed face of slab at 300 ℃ was 66 % (damage percentage measured respect to origin area of slab face). At 400 ℃ the first spalling occurs in 25 minute at temperature 370 ℃ on face of slab and 99 ℃ in mid depth of slab. The damage of spalling on face of slab exposed to 400 ℃ was 50 %.

These result show the RC slabs exposed to fire flame (200, 300 and 400) ℃ at 30-minute spalling influence by “fire flow rate”, slow fire flow rate (300 ℃) more spalling damage than fast fire flow rate (400 ℃).

Plates (5) to (7) show spalling mode in Group A. figures (3) to (5) show the temperature-time history at face and mid depth of tested slabs in Group A. Table (2) show the results of tested specimens.



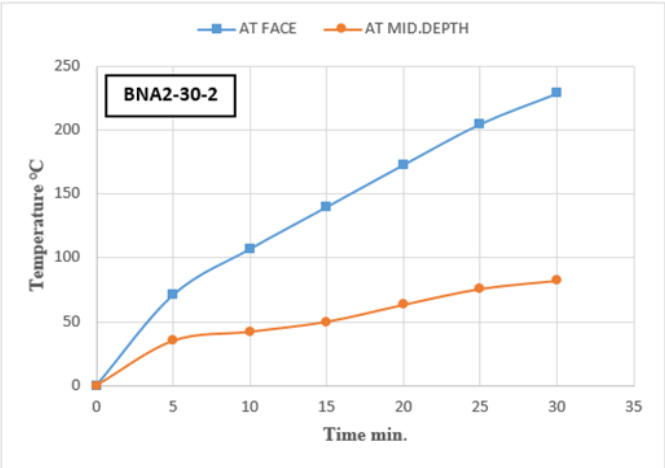
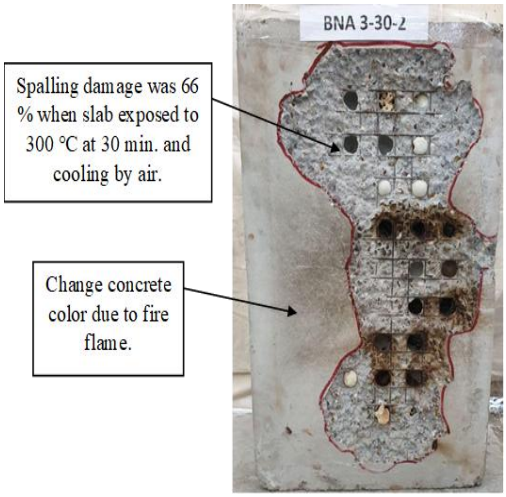


Plate (5) Spalling Mode in BNA2-30-2Figure (3) Temperature-time History at Face and mid depth of BNA2-30-2



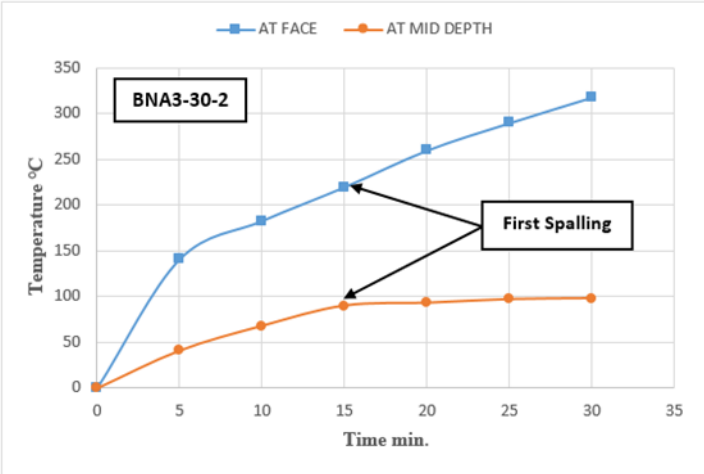
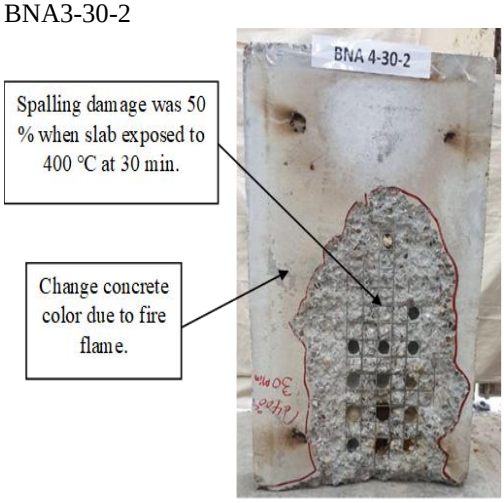


Plate (6) Spalling Mode in BNA3-30-2 Figure (4) Temperature-time history at face and mid depth of BNA3-30-2



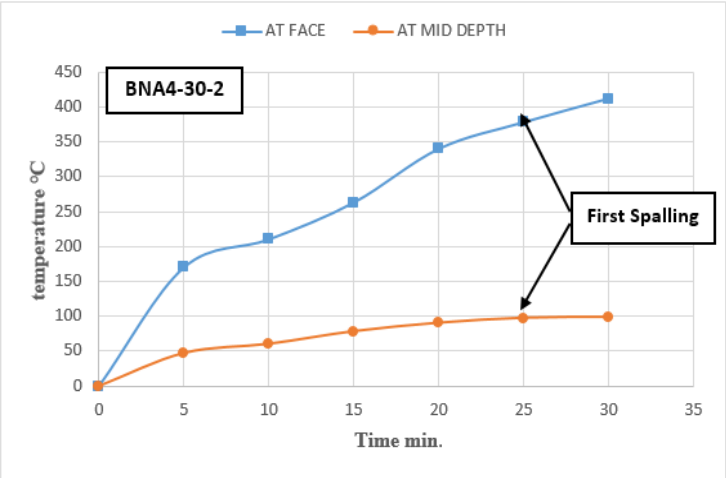
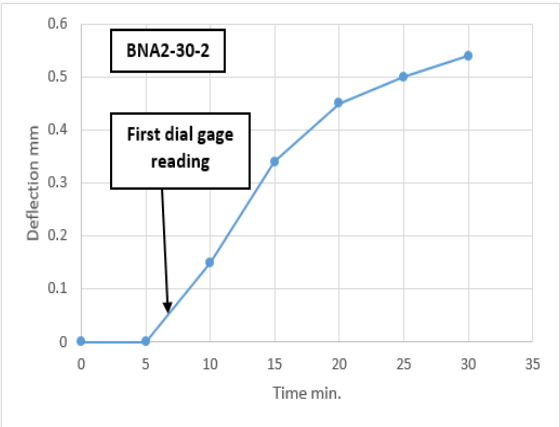


Plate (7) Spalling Mode in BNA3-30-2 Figure (5) Temperature-time history at face and mid depth of BNA3-30-2

3.1.2 Central Deflection Under Fire Flame of Tested Slabs in Group A

Deflection was measured during exposed the slabs to fire flame under equivalent load at fire duration 30 minute. The effect of elevated temperature on deflection was observed, the deflection was 0.54 mm at end of time when exposed to 200 ℃ (BNA2-30-3), the dial gage began reading at 8 minute from start the test. At 300 ℃ the deflection was 0.64 mm (BNA3-30-2), at 4-minute dial gage start reading and when first spalling occur deflection was 0.48 mm. Raise the temperature to 400 ℃ at same fire duration cause increase in deflection, the deflection was 0.8 mm (BNA4-30-2), first reading of dial gage was at 3 minute and at first spalling deflection was 0.72 mm.

The results show increase in deflection when exposed to 300 ℃ by (18.5 %) in compression with slab exposed to 200 ℃ and increase by (48 %) at 400 ℃ respect to slab exposed to 200 ℃. From these results can be concluded the deflection increase with increase the fire flame rate at same fire duration, this increase due to loss in capacity of slab. Figures (6) to (9) shows the deflection-time history of tested slabs in group A.Table (2) show the results of tested specimens.



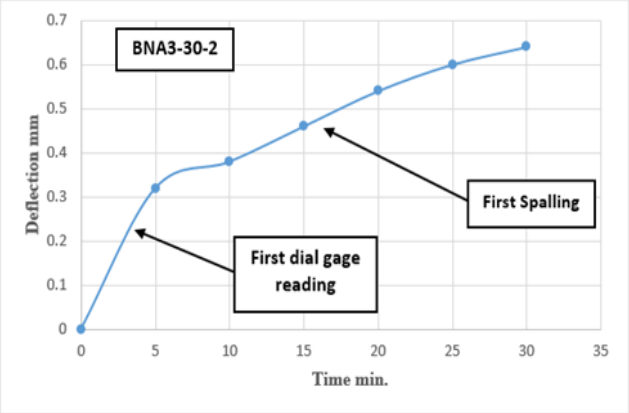
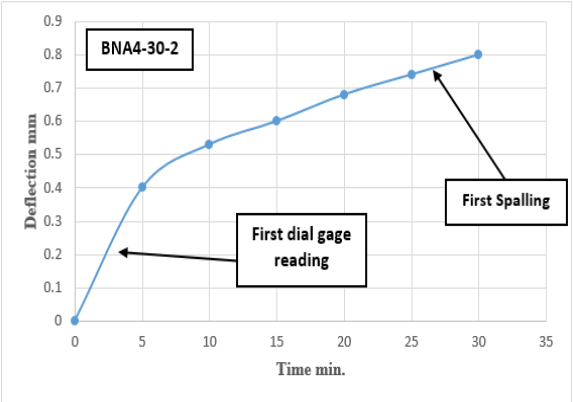


Figure (6) Deflection-time History at Center of BNA2-30-2Figure (7) Deflection-time History at Center of BNA3-30-2



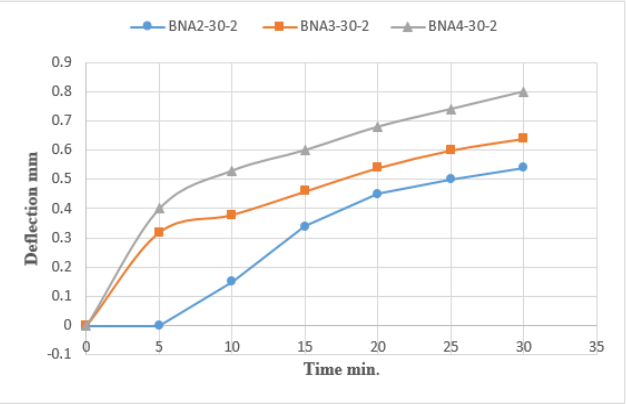


Figure (8) Deflection-time History at Center of BNA4-30-2 Figure (9) Deflection-time History of Group A

3.2 Group B

3.2.1 First Spalling Time and Spalling Damage in Group B

In this group the effect of increase fire duration to 60 minute was investigated. Spalling was observed in test at fire flame rate 300 ℃ and 400 ℃ but the spalling not occur at 200 ℃ at fire flame duration 60 minute (BNA2-60-2). First spalling occurs in slab exposed to 300 ℃ at 48 minute and temperature on face of exposed slab was 240 ℃ and temperature was 98 ℃ at mid depth of slab (BNA3-60-2). The damage of spalling on exposed face of slab at 300 ℃ at 60 minute was 28.7 % (damage percentage measured respect to origin area of slab face). At 400 ℃ the first spalling occurs in 55 minute at temperature 362 ℃ on face of slab and 97 ℃ in mid depth of slab. The damage of spalling on face of slab exposed to 400 ℃ was 43.83 %.

The results show, fire duration 60-minute effect on RC slabs and lead spalling at 300 ℃ and 400 ℃. To reach fire flame rate (200,300 and 400) ℃ at 60 minute "fire flow rate" slower than 30 minute. At 400 ℃ in 60-minute

spalling damage on face of tested slab more than in 300 ℃ at 60 minute, otherwise at 30-minute fire duration spalling damage in 300 ℃ more than 400 ℃. From these results can conclude at same fire flame rate significant spalling damage occur at higher temperature (400 ℃) with increase fire duration. Plates (8) to (10) show spalling mode in Group A. figures (10) to (12) show the temperature-time history at face and mid depth of tested slabs in Group B. Table (2) show the results of tested specimens.

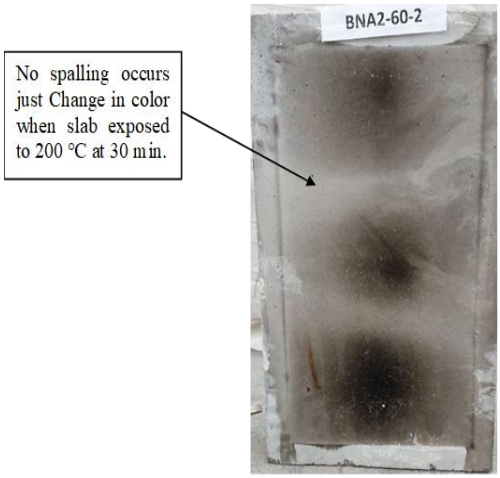


Plate (8) Spalling Mode in BNA2-60-2

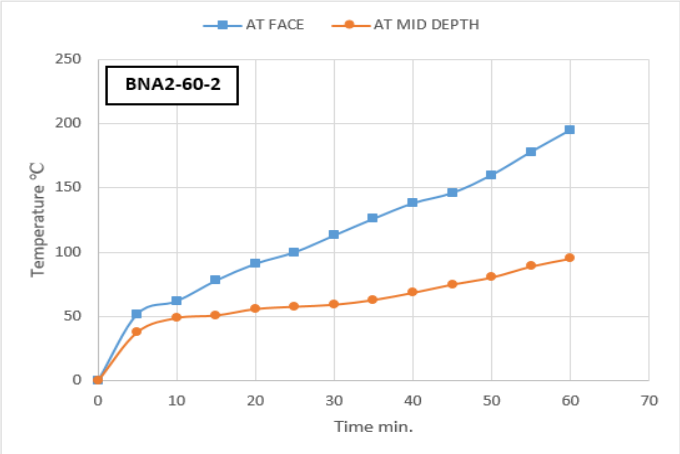


Figure (10) Temperature-time history at face and mid depth of BNA2-60-2

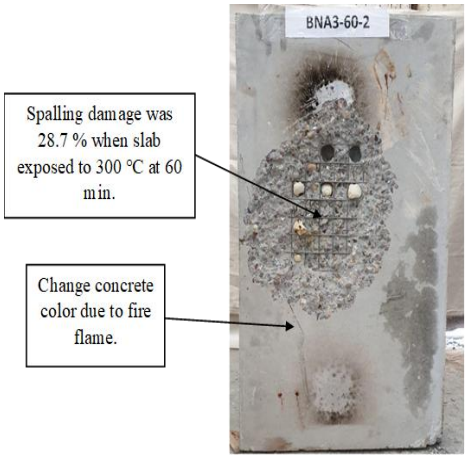


Plate (9) Spalling Mode in BNA3-60-2

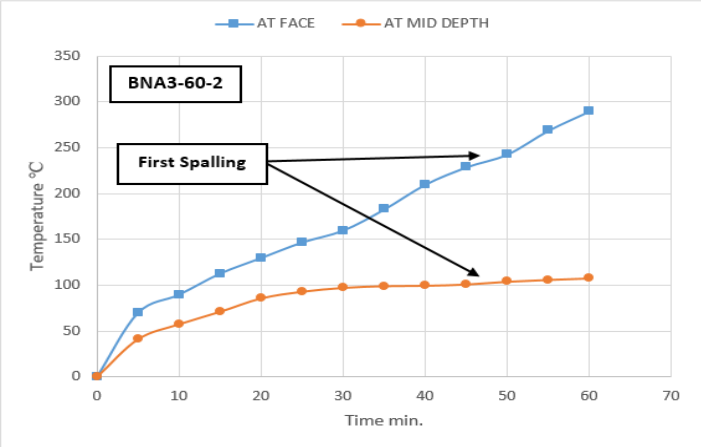


Figure (10) Temperature-time history at face and mid depth of BNA3-60-2

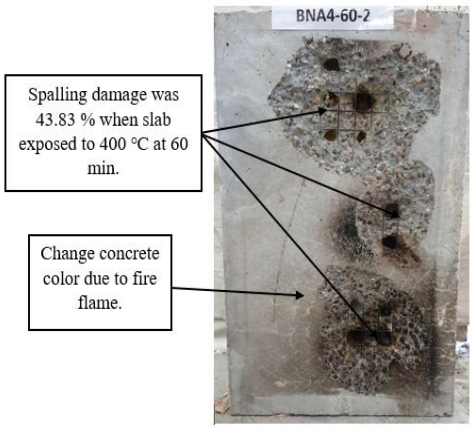


Plate (9) Spalling Mode in BNA4-60-2

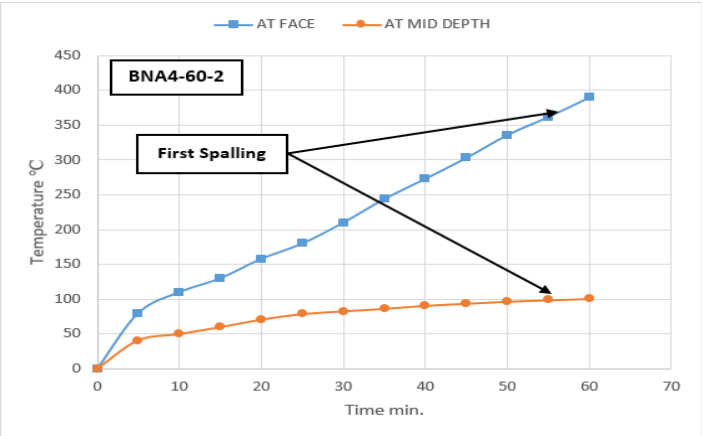


Figure (10) Temperature-time history at face and mid depth of BNA4-60-2

3.2.2 Central Deflection Under Fire Flame of Tested Slabs in Group B

Deflection was measured during exposed the slabs to fire flame under static load at fire duration 60 minute. The effect of elevated temperature on deflection was observed, the deflection was 0.85 mm at end of time when exposed to 200 ℃ (BNA2-60-2), the dial gage began reading at 22 minute from start the test. At 300 ℃ the deflection was 1.15 mm (BNA3-60-2), at 3-minute dial gage start reading and when first spalling occur deflection was 0.9 mm. Raise the temperature to 400 ℃ at same fire duration cause increase in deflection, the deflection was 1.35 mm (BNA4-60-2), first reading of dial gage was at 2 minute and at first spalling deflection was 1.2 mm.

The results show increase in deflection when exposed to 300 ℃ at 60 minute by (35 %) in compassion with slab exposed to 200 ℃ and increase by (58 %) at 400 ℃ respect to slab exposed to 200 ℃. Increase of fire duration to 60 minute from 30-minute lead to increase in deflection with fire flame rate (200, 300 and 400) ℃ by (57, 79 and 68) % respectively in compassion with slabs exposed same fire rate at 30 minute (Group A). Also at 200 ℃ in 60 minute first dial gage reading delay by 14 minute.

From these results can be concluded the deflection increase with increase the fire flame rate at same fire duration, at 60-minute fire duration the fire flow rate was slower than in 30 minute, at this fire flow rate and duration the effect of equivalent load was observed significantly. Figures (10) to (13) shows the deflection-time history of tested slabs in group B. Table (2) show the results of tested specimens.

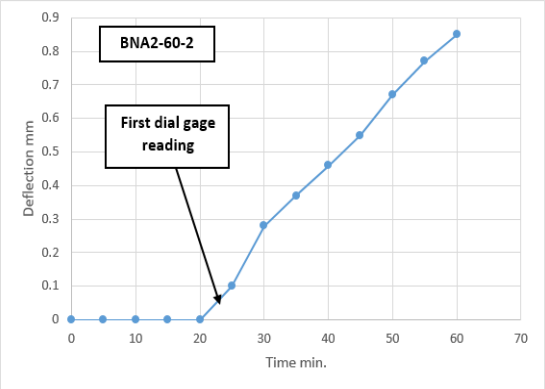


Figure (6) Deflection-time History at Center of BNA2-60-2

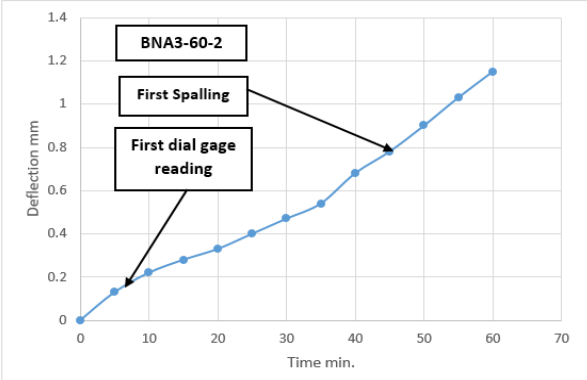


Figure (7) Deflection-time History at Center of BNA3-60-2

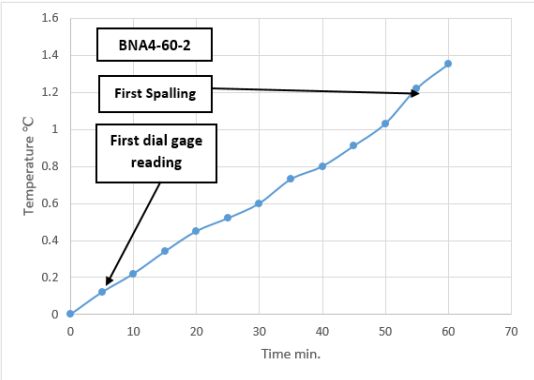


Figure (6) Deflection-time History at Center of BNA4-60-2

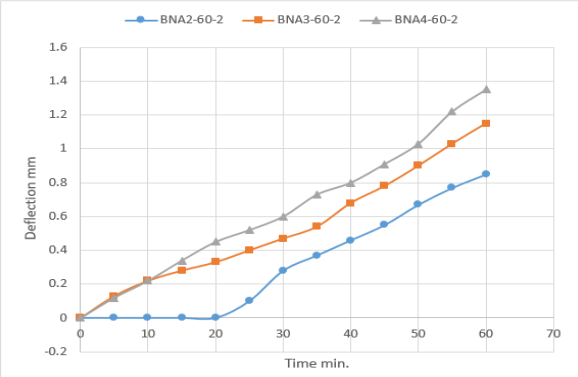


Figure (7) Deflection-time History of Group B

3.3 Group C

3.3.1 First Spalling Time and Spalling Damage in Group C

In this group the effect of concrete cover on spalling was investigated. In this group Spalling was happen in all fire flame rate (200, 300 and 400) ℃ with fire duration 30 minute and 10 mm concrete cover, the first spalling occurs at 200 ℃ in 15-minute when temperature at face of slab 140 ℃ and 77 ℃ at mid depth of slab (BNA2-30-1). Damage of spalling in slab exposed to 200 ℃ was 13.82 %. First spalling occurs in slab exposed to 300 ℃ at 12 minute when temperature on face of exposed slab was 165 ℃ and temperature was 75 ℃ at mid depth of slab (BNA3-30-1). The damage of spalling on exposed face of slab at 300 ℃ was 34.83 %. At 400 ℃ the first spalling occurs in 18 minute at temperature 285 ℃ on face of slab and 98 ℃ in mid depth of slab. The damage of spalling on face of slab exposed to 400 ℃ was 64 % (BNA4-30-1).

The results show when decrease concrete cover to 10 mm (50 % from 20 mm) the spalling occur in 200 ℃. Also the first spalling time became earlier when exposed to 300 ℃ and 400 ℃ in compression with slabs in group A (with concrete cover 20 mm). the main reason of these results is near the bubble to exposed face of slab so the temperature transfers to bubble faster than slabs with 20 mm in group A. Plates (10) to (12) show spalling mode in Group C. figures (8) to (10) show the temperature-time history at face and mid depth of tested slabs in Group C. Table (2) show the results of tested specimens.

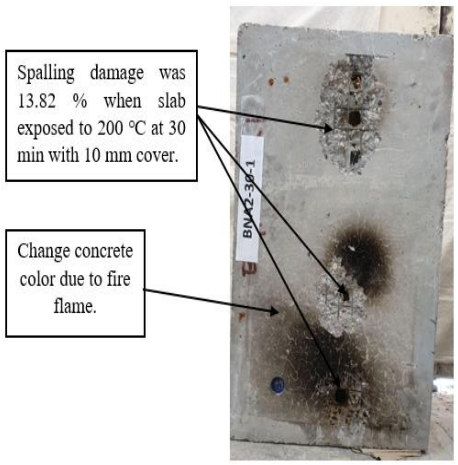


Plate (10) Spalling Mode in BNA2-30-1

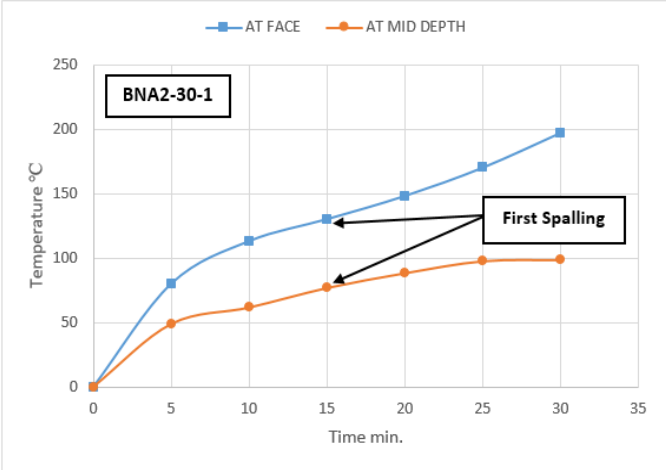


Figure (8) Temperature-time history at face and mid depth of BNA2-30-1

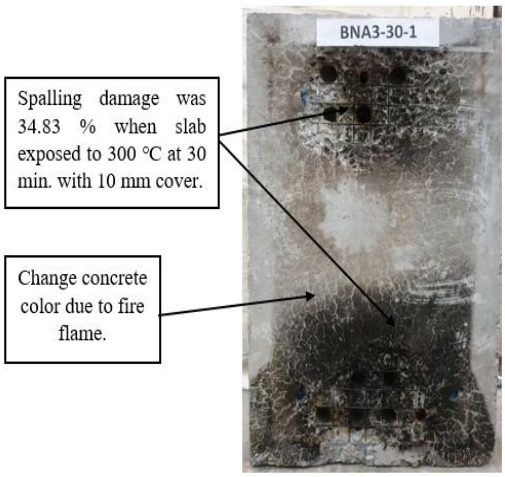


Plate (11) Spalling Mode in BNA3-30-1

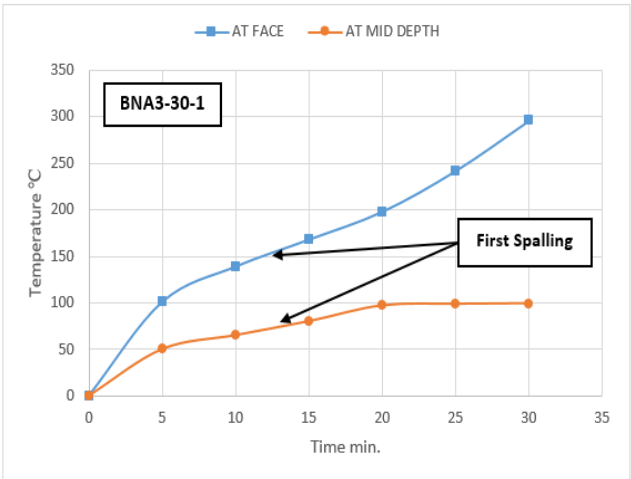


Figure (9) Temperature-time history at face and mid depth of BNA3-30-1

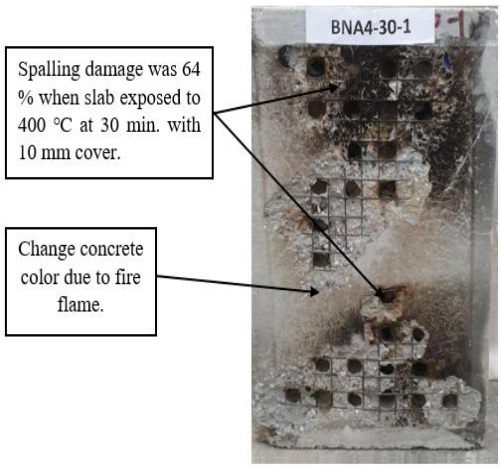


Plate (11) Spalling Mode in BNA4-30-1

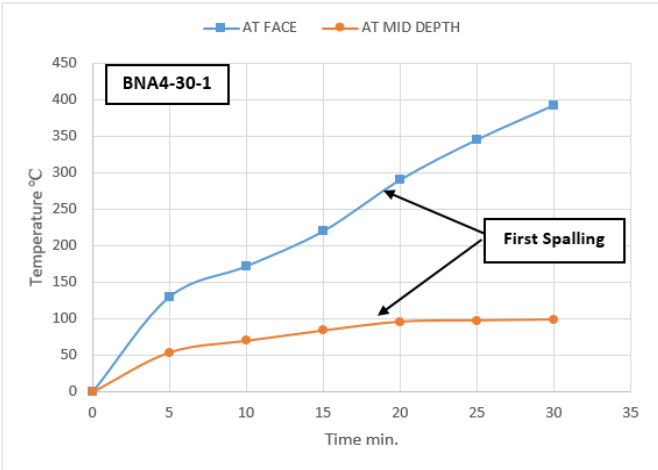


Figure (10) Temperature-time history at face and mid depth of BNA4-30-1

3.3.2 Central Deflection Under Fire Flame of Tested Slabs in Group C

When RC slabs exposed to fire flame under equivalent load Deflection was recorded. The deflection was 0.53 mm at end of time when exposed to 200 ℃ (BNA2-30-1), the dial gage began reading at 8 minute from start the test and deflection was 0.29 mm when first spalling occurs. At 300 ℃ the deflection was 0.71 mm (BNA3-30-1), at 5-minute dial gage start reading and when first spalling occur deflection was 0.48 mm. Raise the temperature to 400 ℃ at same fire duration lead to increase in deflection, the deflection was 0.8 mm (BNA4-30-1), first reading of dial gage was at 4 minute and at first spalling deflection was 0.67 mm.

The results show decrease concrete cover to 10 mm (50 % from 20 mm) the deflection not influence significantly in compression with slabs in group A with concrete cover 20 mm because deflection depend upon depth of slab, concrete type and other parameters. From these results can be concluded when exposed RC bubbled slabs to fire flame at same duration the effect of concrete cover insignificant on deflection. Figures (4-11) to (4-14) shows the deflection-time history of tested slabs in group C. Table (2) show the results of tested specimens.

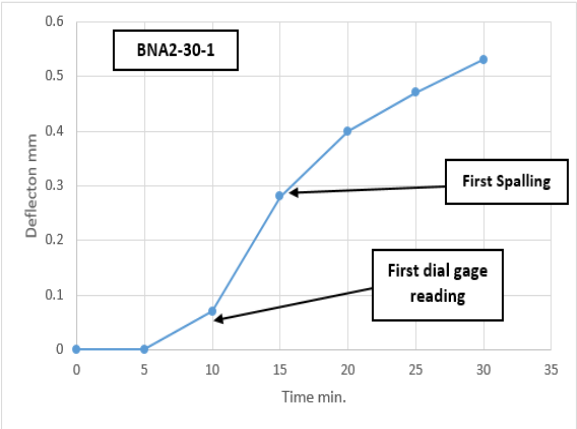


Figure (11) Deflection-time History at Center of BNA2-30-1

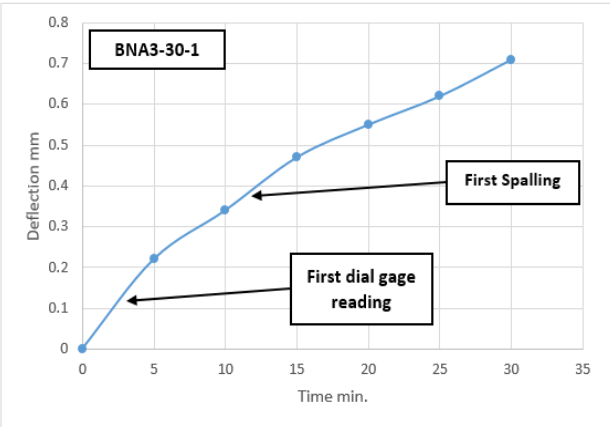


Figure (12) Deflection-time History at Center of BNA3-30-1

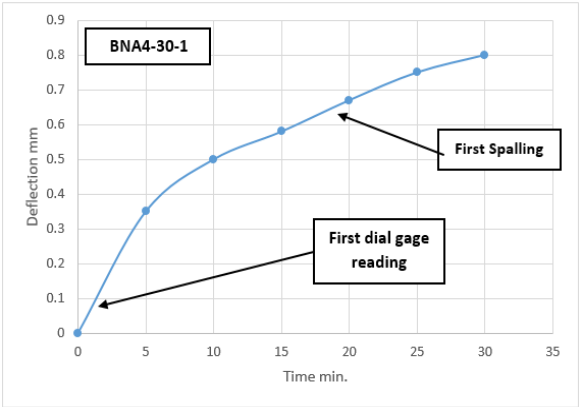


Figure (13) Deflection-time History at Center of BNA4-30-1

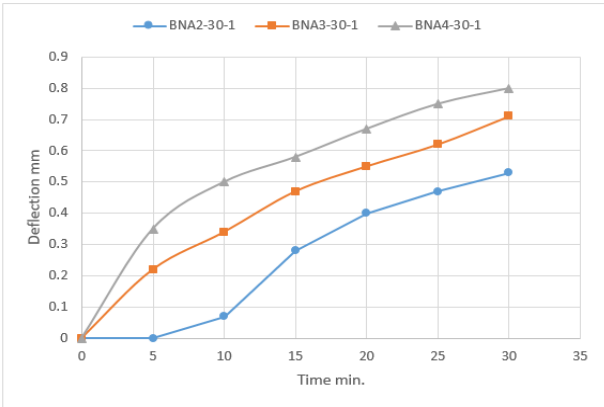


Figure (14) Deflection-time History of Group C

Table (2) Results of Tested Specimens

Group No.	Labeling	Fire flame rate °C	Fire flame duration min.	First spalling time min.	Spalling damage %	Central deflection at end of time mm.
A	BNA2-30-2	200	30	-----	-----	0.54
	BNA3-30-2	300	30	15	66	0.64
	BNA4-30-2	400	30	25	50	0.8
B	BNA2-60-2	200	60	-----	-----	0.85
	BNA3-60-2	300	60	48	28.7	1.15
	BNA4-60-2	400	60	55	43.83	1.35
C	BNA2-30-1	200	30	15	13.82	0.53
	BNA3-30-1	300	30	12	34.83	0.71
	BNA4-30-1	400	30	18	64	0.8

4. Conclusions

- RC bubble slabs with concrete cover 20 mm exposed to fire flame 200 at 30 and 60-minute spalling not occur, just change in color of exposed face of tested slab.
- In 300 ℃ and 400 ℃ fire flame rate at fire duration 30-minute spalling occur. Damage of spalling in 300 ℃ more than 400 ℃ by (32 %) at same fire duration, concrete cover 20 mm.
- Decrease concrete cover by 50 % from 20 mm spalling occur in 200 ℃ and first spalling time became earlier in comparison with bubble slabs with 20 mm concrete cover.
- First spalling effect by fire duration, first spalling occurs in bubble slab exposed to 300 ℃ and 400 ℃ fire flame at 30 minute earlier than 60 minute.
- Effect of equivalent load under fire flame observe in the test, deflection increase with increase fire flame rate and duration. Increase in deflection when exposed to 300 ℃ at 60 minute by (35 %) in compassion with slab exposed to 200 ℃ and increase by (58 %) at 400 ℃ respect to slab exposed to 200 ℃, increase of fire duration to 60 minute from 30-minute lead to increase in deflection with fire flamerate (200, 300 and 400) ℃ by (57, 79 and 68) % respectively in compassion with slabs exposed same fire rate at 30 minute.

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