# Experimental Study on the Fire Resistance Performance of Bubble Beams under Standard Fire

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## ABSTRACT

**A bubble system has several benefits, including increased structure efficiency, reduced material consumption, lower overall cost of the structure, decreased construction time, and green technology. This research aims to evaluate the behavior of a reinforced concrete bubble beam exposed to elevated temperatures of 600 °C and 800 °C for 2 hours. It utilizes varying bubble diameters of 90 mm and 120 mm, with the bubbles having been placed in the core of the beams, where the stress in the neutral axis is zero. The experimental results revealed that, after being exposed to fire reaching 600°C for 2 hours, the beams with void diameters of 90 mm and 120 mm presented a reduction in flexural strength of 22.35% and 18.58%, respectively. However, after fire exposure at 800°C for the same time the reduction was 31.76% and 32.74%, respectively. The findings of the experimental study indicated that the beams' stiffness was decreased under the influence of fire, whereby elevated temperature exposure contributed to larger deformations and the formation of cracks.**

***Keywords-bubble system beam; elevated temperatures; hollow plastic spheres; burn duration; flexural failure***

## I. INTRODUCTION

Concrete is the most widely utilized manufactured material in the construction field. It contributes to approximately 60 % of the developed constructions in the built-up area. Generally, concrete is composed of fine and coarse aggregate, cement, and water and it stiffens progressively over time [1]. Nowadays, researchers are trying to reduce concrete's self-weight and improve its structural performance by modifying concrete mix proportions, utilizing various waste and constructional materials, including fibers, concrete demolition as aggregate, etc. [2]. Many approaches can be adopted to minimize structural concrete self-weight and reduce the demand for natural resources. These involve introducing voided, cellular, and hollow elements within the concrete structure or eliminating finer aggregate sizes [3, 4]. A bubble system could be utilized for the reduction of construction materials' consumption in addition to effectively minimizing their self-weight [5]. Also, these voids could decrease the beam's ultimate strength and increase mid-span deflection [6, 7]. A reinforced concrete bubble system can be designed by voiding the mid zone (neutral axis) of concrete between the compression and tension longitudinal reinforcing steel bars and replacing it with a plastic spherical bubble [8, 9]. This technique can reduce material self-weight up to a certain level without decreasing its strength, while also allowing for an increase in the construction spans. The practical application of bubble reinforced concrete beams hinges on their ability to provide adequate fire resistance while offering the benefits of reduced weight and improved thermal insulation. Previous research has examined bubble beams without considering the influence of fire exposure and has also explored the behavior of bubble deck slabs under elevated temperatures. However, there is a notable lack of research on the response of bubble reinforced concrete beams subjected to temperatures of 600 °C and 800 °C for 2 hours. The primary aim of this study is to investigate the behavior and performance of reinforced concrete beams incorporating bubbles placed in the core of the beams, with a specific focus on optimizing the maximum load bearing capacity following concrete weight reduction and exposure to fire.

## II. THEORETICAL BACKROUND

Authors in [10] investigated the flexural behavior of hollow reinforced concrete beams by incorporating a PVC pipe to reduce the weight of the structure. This technique is one of the proposed solutions for achieving lightweight beam structures. The findings demonstrated that the strength of the reinforced concrete beams increased by 6% due to the presence of a hollow PVC pipe in place of concrete in the low stressed zone. Authors in [11] conducted a test on five reinforced concrete beams of 150 mm × 200 mm × 1300 mm size. The purpose was to observe the behavior of reinforced concrete beams that contain air voids and are subjected to combined moments, namely the equal bending moment and torsional moment. The experimental results revealed that the beam containing voids may lose about 13%–23% of its solid ultimate strength under a combined load of equal fractions of bending and torsion moments. Authors in [12] carried out an investigation to determine the load carrying capacity, deflection, and crack patterns of the reinforced concrete beam that replaced the concrete above the neutral axis. They created air voids using recycled polythene balls with varying diameters of 35 mm, 65 mm, and 75 mm. The test results revealed that the flexural behavior of the conventional beam and the beam with polythene balls were marginally similar, and the deflection of the voided beams was considerably lower than that of the conventional beam. Authors in [13] explored the influence of cooling conditions on concrete slabs exposed to fire. Slabs, which were 125 mm thick, were exposed to varying temperatures of 300 °C, 400 °C, and 500 °C for 1 hour and 4 hours, with two methods, air cooling and quench cooling, being subsequently deployed, to cool them. The reduction in the flexural stiffness of the concrete slab exposed to 500 °C for a four-hour retention period was 28.67% and 37.89% for the air cooled and quench-cooled specimens, respectively. Authors in [14] examined the behavior of normal and high strength concrete exposed to elevated temperatures of 400 °C and 700 °C for 1 hour and 1.5 hours and having been cooled by the water and the ambient air. The results recorded a reduction in flexural and shear strength. At 400 °C, the residual flexural strength was 86%-91% and 84%-88% for NSC, and 84%-88% and 70%-72% for HPC for 1 hour and 1.5 hours, respectively. Whereas the residual flexural strength at 700 °C was noticed to be 53%-60% and 26%-41% for NSC, and 50%-58% and 37%-38% for HPC for 1 hour and 1.5 hours, respectively. The reduction in shear strength at 400 °C was 78%-93% and 75%-77% for NSC, and 90%-98% and 78%-93% for HSC for 1 hour and 1.5 hours, respectively. Whereas the residual flexural strength at 700 °C was noted to be 54%-57% and 38%-46% for NSC, and 50%-55% and 40%-45% for HPC for 1 hour and 1.5 hours, respectively. Authors in [15] discussed the influence of microstructural changes on concrete properties at elevated temperatures. Exposure to elevated temperatures caused noteworthy changes in the concrete's thermal, mechanical, and kinematic properties. These changes occurred above 400 °C and were more evident in the HSC rather than in the NSC. However, a large increase in the pore size and microcracking provided the maximum impact on strength reduction, which occurred in a temperature range between 400 °C and 800 °C, depending on the aggregate type and initial moisture content.

## III. EXPERIMENTAL WORK

The experimental work of the present study involved seven beams made of normal strength concrete with a target compressive strength of 30 MPa. The beams had 200 mm × 200 mm cross-section dimensions and 1200 mm length. The beams were simply supported with supports positioned 1000 mm apart. A two-point load was placed at a 100 mm distance from the beam's center, as illustrated in Figure 1. The longitudinal reinforcement consists of 2Φ10 mm bars in the compression zone (top location), in addition to 2Φ12 mm bars in the tension zone (bottom location). Shear reinforcement of Φ8@120 mm was used along the beam length. Six of these beams contained voids, three of them had 90 mm diameter voids and 30 mm spacing, and the other three had 120 mm diameter voids with the same spacing, as portrayed in Figure 2. The research methodology included the preparation of three beams without burning (control beams). The first one was without voids, the second beam had a 90 mm void diameter, and the third beam had a 120 mm bubble diameter. In addition, four voided beams (90 mm, and 120 mm) were subjected to elevated temperatures of 600 °C and 800 °C for 2 hours in the furnace. The computerized data acquisition was deployed in this research to capture the load and mid-span displacement. A load cell sensor of a capacity of 40 tons was utilized, in addition to an LVDT sensor, placed under the beam mid-span, with 100 mm capacity. The load was applied incrementally to record the crack pattern till the failure point. To facilitate the tracking of the specimens' behavior, Table I clarifies the designations and details of the specimens.

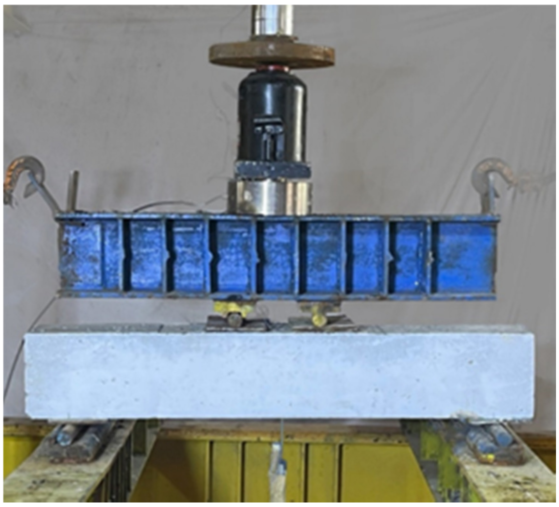

Fig. 1. Loading configurations of the tested beams.

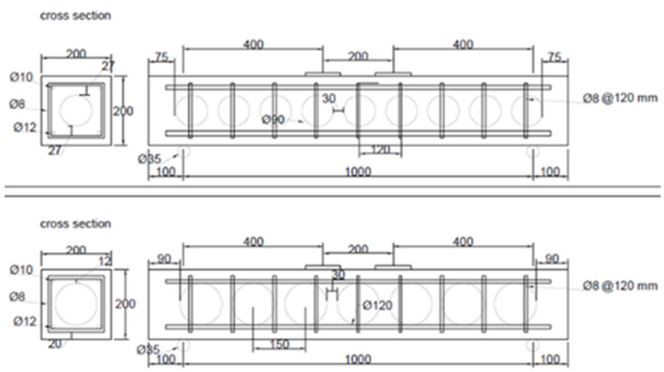


Fig. 2. Adopted beams' dimensions and reinforcement arrangement.

TABLE I. BEAM DESIGNATION

| beam | designation |
|---|---|
| Control | without voids and without burning |
| BB-D90-T25 | unburned beam with 90 mm bubble size |
| BB-D120-T25 | unburned beam with 120 mm bubble size |
| BB-D90-T600-2Hr | burned bubble (90 mm) beam at 600 °C |
| BB-D120-T600-2Hr | burned bubble (120 mm) beam at 600 °C |
| BB-D90-T800-2Hr | burned bubble (90 mm) beam at 800 °C |
| BB-D120-T800-2Hr | burned bubble (120 mm) beam at 800 °C |

## IV. MATERIALS USED AND ADOPTED METHODS

1. Cement: Ordinary Portland Cement (OPC) is mostly used for common structures. The properties of cement affect its performance in various applications, while different mixtures of cement utilized in construction are characterized by their physical properties. In the present study, certain parameters controlled the quality of the cement in the mixture.

2. Fine Aggregate (Sand): Fine aggregate is one of the components of concrete selected to meet the requirements of Iraqi Standard No. 45 [16]. The maximum grad size of 4.75 mm was used. Theoretical and laboratory studies were necessary to test all the physical and chemical properties of sand due to their effect on the compressive strength and durability of concrete.

3. Coarse Aggregate: Coarse aggregate provides structural support and helps reduce the amount of cement paste required in the mixture. The size of coarse aggregate depends on the specific application and strength characteristics of the concrete. According to the sieve analysis utilized, the samples are conformable within the limits of the Iraq specification No. 45. [16], that is, within the zone from 5 mm-20 mm.

4. Steel Reinforcement: Reinforcing steel is primarily responsible for the tensile strength of the structure. The steel bars deployed in this experiment, were the Φ8 for the shear zone and the Φ10 and Φ12 for the compression and tension zones, respectively. The steel bar's tensile strength was tested according to the ASTM A 370 and ISO 6935-2 [17, 18].

5. Hollow Plastic Spherical Bubbles: In this experiment, the voids were achieved using plastic balls with different diameters of 90 mm and 120 mm. The bubbles were arranged longitudinally with a spacing of 30 mm inside the concrete beams, specifically at the midsection between the longitudinal reinforcement, as clarified in Figure 3. It is worth mentioning that the bubbles have been attached to a small, long bar to be fixed during concrete pouring.

## V. MIX DESIGN

The mix design depended upon the proportions of raw materials. Several factors affected the properties of the mixture. Different mixing ratios produced different strength resistance. There are two types of concrete regarding the strength parameter. Concrete with a strength from 20 MPa to 50 MPa, namely Normal Strength Concrete (NSC), and concrete with a strength from 50 MPa to 120 MPa, namely High Strength Concrete (HSC). In this study, the mixture was designed to be composed of NSC. The mix design ratios of the prepared concrete are presented in Table II. Figure 4 illustrates the casting of concrete inside the molds. It is worth mentioning that the casted beams were cured in water for 28 days before testing.

Fig. 3. Wooden molds and bubbles.

TABLE II. ADOPTED MIX RATIOS TO PREPARE NORMAL CONCRETE STRENGTH

| Water content ratio % | Water, kg/m$^3$ | Cement, kg/m$^3$ | Fine aggregate, kg/m$^3$ | Coarse aggregate, kg/m$^3$ | Fcu (MPa) |
|---|---|---|---|---|---|
| 47 | 170 | 360 | 785 | 1089 | 36 |

Fig. 4. Concrete casting of the voided beams.

## VI. RESULTS AND DISCUSSION

### A. *Compressive Strength*

The compressive strength test of the cube and the observation of the fire's impact are summarized in Table III, where the temperature was set to 600 °C and 800 °C for 2 hours. The compressive strength of the unburned cube was 36 MPa. After burning the cube at temperatures of 600 °C and 800 °C for 2 hours the residual compressive strength was recorded to be 64% and 53 % respectively, as exhibited in Figure 5.

TABLE III. COMPRESSIVE STRENGTH BEFORE AND AFTER EXPOSURE TO TEMPERATURE OF 600 °C, 800 °C FOR 2 HOURS

| temperature (°C) | exposure period (hrs.) | compressive strength (MPa) | residual of compressive strength % |
|---|---|---|---|
| **25 C (without fire)** | --- | 36.0 | --- |
| **600 °C** | 2 | 23.0 | 64% |
| **800 °C** | | 19.0 | 53% |

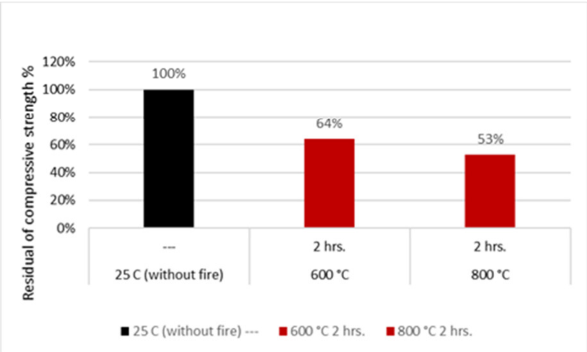


Fig. 5. Residual of compressive strength after exposure to 600 °C and 800°C.

## B. *Load-Deflection Curves*

The load mid-span behavior of the various tested specimens with two bubble diameters and two elevated temperatures for a 2 hour time period was recorded and drawn, as presented in Figures 6 and 7.

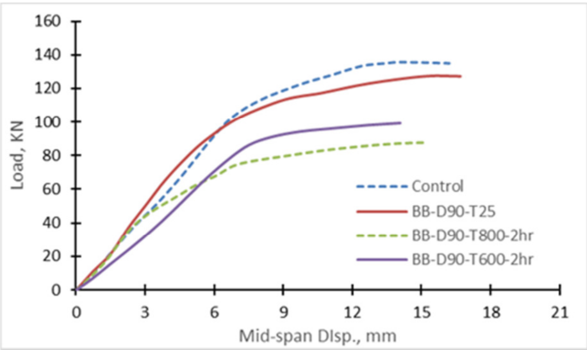


Fig. 6. Load-deflection curve for 90 mm voided beams.

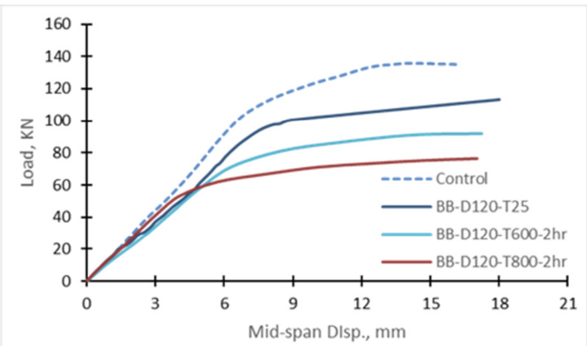


Fig. 7. Load-deflection curve for 120 mm voided beams.

Regarding, the unburned specimens with and without voids, it is evidenced that the inclusion of voids of a certain diameter within the reinforced concrete beam resulted in a slight reduction in the load bearing capacity of the beam, which is estimated to be 5.56% and 16.3% for the beams with a void diameter of 90 mm and 120 mm, respectively. This reflected the effect of voids' presence, which leads to reduced beam stiffness [19, 20]. After exposing the voided beams to the elevated temperatures of 600°C and 800°C for 2 hours, the beams with 90 mm void diameter reflected a noticeable reduction in load capacity of about 22.35% and 31.76%, respectively. In addition,considering 120 mm void diameter beams, subjecting the samples to such elevated temperatures rdemonstrated a significant reduction of the load capacity by 18.58% and 32.74%, respectively, as depicted in Figure 8. This can be explained by the fact that heating causes a reduction in the stiffness of the concrete beam, which is essential due to the decrease in the modulus of elasticity of concrete and the reduction in the/its effective section caused by cracking [21, 22]. It is notable that the reduction percentage of the load capacity after burning the voided specimens (90 mm and 120 mm) at 600°C was not the same, in contrast to the reduction value of the load capacity at 800°C burning, where the 120 mm voided beam reflected a higher reduction value than the 90 mm beam's load capacity.

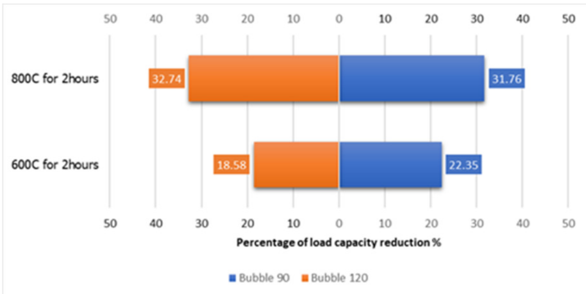


Fig. 8. Percentage of load capacity reduction of various tested reinforced concrete beams.

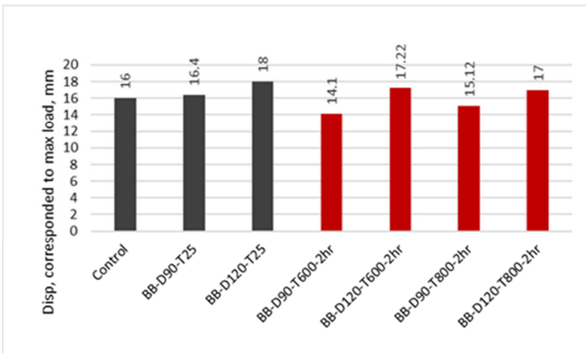


Fig. 9. Mid-span deflection value of various reinforced concrete beams.

Figure 9 displays the variation in mid-span deflection corresponding to the ultimate load of various tested reinforced concrete beams. It can be observed that subjecting the samples to elevated temperatures decreased the deflection values, whereas with higher temperature degrees, the beams reflected lower mid-span deflection values. Moreover, a slight increase in the previously mentioned values was noticed when increasing the internal void's diameter compared to that of the reference beam without burning.

### *C. Yield Load*

The yield point in a behavior stress-strain curve of a reinforced concrete beam can be identified by using a load-deflection curve to the point at which there is a transition between the elastic and inelastic properties of the material [23, 24]. The yield point can be determined by deploying the graphical method [25, 26]. Figure 10 demonstrates that in the specimens with bubble sizes of 90 mm and 120 mm, the yield load droped by approximately 9.4% and 14.5%, respectively. After exposing the bubble beams to the elevated temperatures of 600 °C and 800 °C, the beams with 90 mm diameter showed a significant drop in the yield load, 15% and 28.3% respectively. However, for the specimens with a bubble diameter of 120 mm the reduction in the yield load was 20% and 40% at temperatures of 600 °C and 800 °C, respectively.

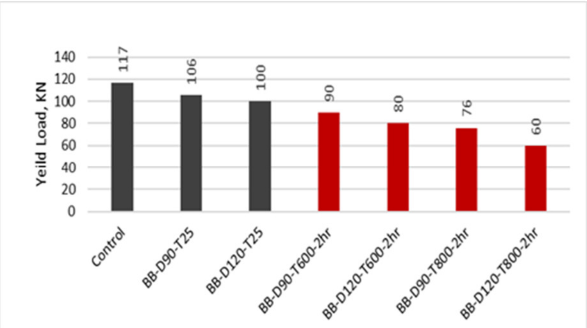


Fig. 10. Yield load value of various reinforced concrete beam.

### *D. Absorption Energy*

The area under load mid-span deflection of the various tested reinforced concrete beams, is called absorption energy. The area under the curve can be calculated through the graph software program for the absorption energy to be obtained. Concerning the unfired samples, it can be noticed that insertion voids inside the reinforced concrete beams resulted in a slight absorbed energy decrease that can be neglected for the beam with a void diameter of 90 mm. On the contrary for the 120 mm diameter void specimen, it can be noticed that the inclusion of a void of a specific diameter led to a slight decline in the absorption energy value, which is estimated to be 3.8%, compared to the control beam. After exposing the samples to elevated temperatures, and particularly after burning, the reduction in the absorption energy values of the beam varied, as showcased in Figure 11. Overall, exposing the sample to higher temperatures resulted in a noticeable reduction in the absorption energy properties. It is a fact that with higher temperature exposure, a higher reduction in the value can be observed for both samples, namely for samples with a 90 mm and a 120 mm void diameter. In general, the degradation rate of the energy absorption was increased during the exposure at a temperature of over 400°C. This can be attributed to the chemical decomposition of the $Ca(OH)_2$ at temperatures above 400°C, as previously highlighted [25, 27, 28]. Recently, it has been made possible to increase the absorbed energy by utilizing high-performance fiber-reinforced cementitious composites, as well as HPFRC spray mortars with extra reinforcing bars. This method revealed a rise in the absorbed energy [29-31].

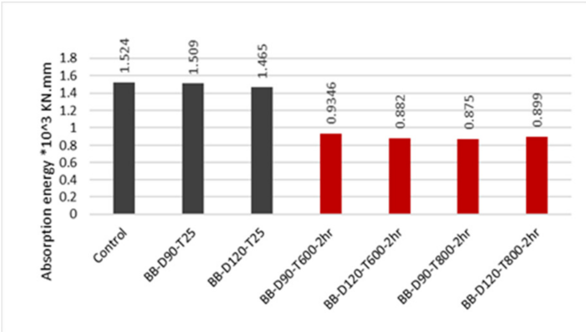


Fig. 11. Absorption value of various reinforced concrete beams.

### *E. Ductility*

Ductility is the capability of the concrete to withstand deformation beyond the elastic limit while maintaining a reasonable load bearing capacity until total failure. The ductility can be determined by the formula: $\Delta f/\Delta y$, where $\Delta f$ is the displacement at failure and $\Delta y$ is the yield displacement. Figure 12 manifests that considering the control beams, the ductility of the bubble beams is greater than that of the solid beams, and this ductility increases as the bubble diameter increases by 17.6% and 18% for the beam with a bubble diameter of 90 mm and 120 mm, respectively. After the burning of the samples, the concrete beam ductility decreases compared to that of the control specimens and the reduction percentage of the beam ductility varies. Figure 12 demonstrates that after exposing the samples to an elevated temperature for 2 hours, a higher reduction value is observed for the samples with a 90 mm diameter than for the samples with a 120 mm diameter.

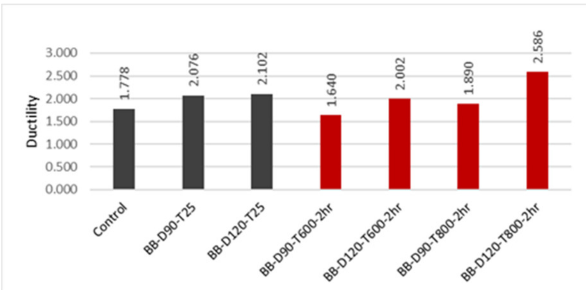


Fig. 12. Ductility value of various reinforced concrete beam.

### *F. Crack Pattern*

Cracks appeared in the control beams only as a result of the flexural strength test they underwent. The first crack appeared in the beam without bubbles at a load of 31 KN, whereas cracks in the beams with bubbles of 90 mm and 120 mm diameter appeared at 29 KN and 21 KN, respectively. Figure 13 illustrates the crack pattern in which the blue line refers to the cracks of the control beams due to the flexural strength test. After burning, cracks were observed on the surfaces of the beams exposed to the elevated temperatures of 600 °C and 800 °C after 2 hours of burning in the furnace, and they are marked in red color to be distinguished from the flexural cracks. After applying the load, it was noticed that the first crack began to appear earlier compared to the control samples. For the beams with bubbles of 90 mm in diameter exposed to temperatures of 600 °C and 800 °C, the reductions of the first crack load were 14% and 24%, respectively compared to the control specimens, whereas for the beams with 120 mm bubble diameter, the reductions were about 5% and 19%, respectively compared to the control specimens , as shown in Figure 14.

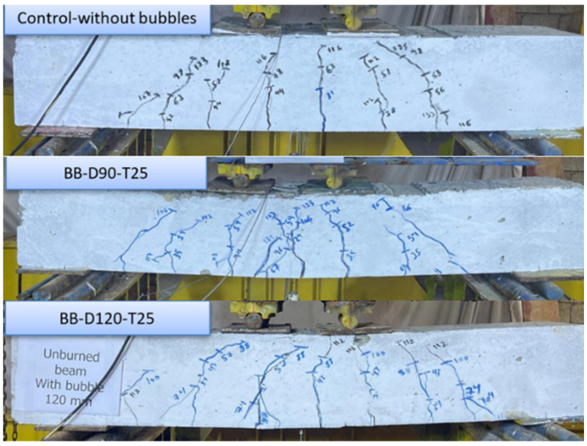


Fig. 13. Crack patterns of control reinforced beams.

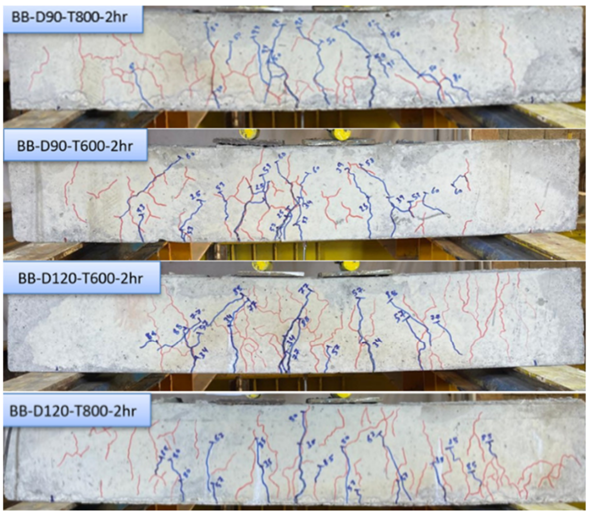


Fig. 14. Crack patterns of burning bubbled specimens after flexural test.

## VII. CONCLUSIONS

The behavior of the bubble beams that are exposed to elevated temperatures is not covered by much research. The present study aims to thoroughly investigate the maximum load bearing capacity of the concrete reinforced bubble beam after exposure to fire. The current study is an experimental research aiming to investigate the structural behavior of reinforced concrete beams containing bubbles with different diameter sizes after exposure to fire at different temperatures of 600 °C and 800 °C for 1 and 2 hours. Based on the outcomes of the experimental research, the following conclusions were drawn.

- The results revealed that the bubbles in the concrete beam led to a reduction in the load bearing capacity before exposing the specimens to elevated temperatures. This reduction depended upon the bubble size. The reduction in the load bearing capacity of the beam was estimated to be 5.56% and 16.3% for beams with a void diameter of 90 mm and 120 mm, respectively.
- The reduction in the load bearing capacity after exposing the bubble beams to the elevated temperatures of 600 °C and 800 °C for 2 hours, for the specimens with 90 mm void diameter was 22.35% and 31.76%, respectively, whereas for the specimens with 120 mm bubble diameter, the reduction was 18.58% and 32.74%, respectively.
- The reduction in the compressive strength of the cube after exposure to temperatures of 600 °C and 800 °C for 2 hours was 64 % and 53 %, respectively.
- The yield load faced a reduction in the specimens that contained bubbles. For the beam with bubbles of 90 mm and 120 mm in diameter the reduction in the yield load was about 9.4% and 14.5%, respectively.
- After exposure to elevated temperatures of 600 °C and 800 °C, specimens with 90 mm bubble diameters significantly decreased their yield load by 15% and 28.3%, respectively, whereas in the beam with 120 mm diameter a reduction of 20% and 40%, was respectively noticed.
- A negligible decrease in the absorption energy for the unburned bubble beam with 90 mm diameter was evidenced. Whereas for the 120 mm diameter void specimen, there was a slight reduction in energy estimated at 3.8%. After burning the specimens at 600 °C and 800 °C for 2 hours a varying percentage decrease of the absorption energy was noted.
- The ductility of the unburned beam with bubbles was greater than that of the solid beam. It has been observed that the ductility increased with the increase of the bubble size. On the other hand, an obvious decline in ductility expressed at varying values followed the specimens' burning.

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