Flexural Strength of Stirrup-less Voided Beams Made of Conventional and Reactive Powder Concrete

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Abstract

Light-weight beam has received considerable critical attention to decrease the stresses or to increase spans. This study was undertaken using double spherical plastic bubbles in a specific zone (shear zone) to evaluate the flexural behavior of the stirrup less beam. Two types of concrete (conventional concrete of ordinary Portland cement and high strength concrete of reactive powder (RPC) reinforced by steel fiber) were used to obtain four beam specimens' of 1300 mm in length, two beams have double spherical plastic bubbles and two beams in solid form as a reference. These beams were prepared to investigate the effect of plastic bubbles, concrete strength, and steel fiber on the shear behavior under a flexural moment. Results indicated that the flexural strength of bubbled beams was decreased for the two types of concrete. In contrast, the specific flexural strength was much closed due to the concrete density reduction by (6.22 and 6.24)% for conventional and high strength concrete respectively.

Keywords: Voided beam • Reactive powder concrete • Flexural behavior • Stirrup less beam

Introduction

A considerable amount of literature has been published on the reduction of concrete mass (by using a special form) and/or the reduction of concrete density, satisfying an environmental necessity (by reducing CO_2 emission corresponding to cement production and using recycled plastic bubbles). The reduction in concrete density would make larger span lengths achievable or minimum deflections [1]. Lightweight concrete can be prepared by many technologies (air-entraining agent, hollow form, porous aggregate, etc.) [1-3]. The bubbled deck can reduce 30% of the slab self-weight compared to the solid one of the same thickness and exhibit approximately the same deflection behavior [4]. The quantity of concrete reduction in bubbled beams depends upon the total volume of plastic balls [5]. Most studies in the field of self-weight reduction by bubbles have only focused on the bubble deck or wide beam [6-9]. Whereas, the ability to increase the effective depth could increase the beam stiffness [10].

The idea of creating voids in the middle zone of the beam creates an equivalent I section shape of stress distribution [11]. Due to the solid material replacement of RPC by plastic air bubbles, the cost, the raw material, and the dead load will be decreased. Consequently, a smaller dead load will decrease the columns and foundation size [3,12]. The deflection in the concrete beam is related to many parameters, one of them is the bending stiffness.

Voided beams have better flexural stiffness than torsional stiffness because the twisting angle can be more noticeable than deflection [13]. The Technical University of Denmark concluded that the stiffness of bubble deck lost 13% in bending when compared with solid one of the same dimensions. Therefore, the deflection will be less for the bubble deck [14]. The shear transfer resistance increased when used high strength concrete due to the good distribution of the stresses across the shear plane [15].

In this study, the beam density and compressive strength were determined. As well as, the flexural test was studied to characterize the carrying capacity and the first crack load in the shear zone.

Experimental Work

The experimental work includes two series of four reinforced beams; they were designed to fail at the shear zone. These beams having plastic bubbles to study the reduction of the density as well as study the effect of concrete strength on the flexural and shear strength (Table 1).

Materials

Deformed steel bars with nominal diameters of 12 mm were used in the tensile zone for the flexural test. While the 6 mm diameter deformed steel bars in the compression zone were used to hold up the balls. Table 2 shows the tensile test results of the used steel bars.

All beams are simply supported along the span and subjected to a four-point load. The plastic bubbles were made from recycled plastic with a diameter of 60 mm (weight 20g) of the average thickness of (0.8 mm). They were manufactured by using spherical steel molds.

Conventional (Normal) concrete

Ordinary Portland cement (Type I) was used in this work, chemical

Table 1. Characteristics of the tested beams.

Specimen	Thickness of Specimen, mm	Number of Spheres	Sphere Diameter, mm	Distance c/c of Spheres, mm	Number of Bars and/or Strands
Bn-0		0	-	-	4ϕ12 mm
Br-0		0	-	-	4ϕ12 mm
Bn-16	150	16	60	80	4ϕ12 mm 1ϕ6 mm

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Br-16	16	60	80	4ϕ12 mm 1ϕ6 mm

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compounds; physical properties were checked according to the Iraqi specification No.5 / 1984. Crushed gravel maximum particle size of 12 mm was used as coarse aggregate. The sieve analysis and chemical tests were done to meet the requirements of the Iraqi Standard specification No. 45/1984. While the natural sand of 4.75 mm maximum size was used as fine aggregate. The grading and chemical tests were done to satisfy the requirements of Iraqi specification No.45/1984.

Reactive powder (high strength) concrete

The reactive powder concrete was made by using very fine sand with a maximum size of 600μm. Silica fume was used (20 %) of the cementitious material mass. While the steel fibers used in this study were straight steel fibers manufactured by (Bekaert Corporation in China) R. The fibers have physical and mechanical properties as shown in Table 3.

The super plasticizer (high water reducing agent HWRA) based on polycarboxylic ether is used. In fact, Glenium 51 was free of chlorides corresponding to ASTM C494, type A and type F. It is compatible with all Portland cements that meet the recognized international standards.

Mixing and casting

Wooden molds were used for beams with inner dimensions of 150 mm in width, 200 mm in depth, and 1300 mm in length. The steel reinforcement was placed in its position in the mold and the plastic bubbles hold up by wire rope. The distance between bubbles was (20 mm) in the shear zone. The mixing procedure which was proposed by Wille [16] was adopted in this study to produce RPC simply without any accelerated curing regimes. Fine sand and silica fume were first mixed for 4 minutes, then cement was added and the dry components were mixed for 5 minutes. Superplasticizer was added to the water, then the blended liquid was added to the dry mixture during the mixer rotation and the mixing process continued for another 3 minutes. Finally, steel fibers were added during mixing within 2 minutes. The total mixing time of RPC was about 15 minutes.

Results and Discussion

The first question in this experimental study sought to determine the compressive strength of the conventional and high strength (reactive powder) concrete. Then, the beam density and its flexural strength were studied to characterize the first crack and carrying capacity

Compressive strength

Compressive strength was determined by using a universal testing machine for a cubic sample of 150 mm according to the ASTM C39. It was calculated by testing 10 cubic samples of 28 days for conventional concrete of ordinary Portland cement as well as for high-strength concrete of reactive powder reinforced by steel fiber. In detail, 5 cubic samples for each mixture, as shown in Table 4. The difference in compressive strength of RPC compared with conventional one was about 4 times. Steel fiber works as a reinforcement that restricts the initiation and the development of the cracks.

Flexural strength and failure pattern

All beams were tested as simply supported beams throughout 1200 mm under four-point loads using a universal testing machine of 3000 kN capacity according ASTM C651 (Figures 1 and 2). The load was applied gradually up to failure. The first crack load was recorded as the load at which the first visible crack was detected. The midspan deflection of the tested beam was recorded by a dial gauge of 0.01 mm accuracy and (30 mm) capacity. The dial gauges were placed underneath the bottom face at the center. The flexural strength was calculated by testing 2 beams of 28 days for conventional concrete of ordinary Portland cement and 2 beams for high strength concrete of reactive powder reinforced by steel fiber (Table 4).

At the initial stages of loading, all of the beam specimens being stiff and absorb applied stresses without significant deterioration until the appearance of the first crack at the shear zone of the beam. The decrease in the stiffness being clearly after the appearance of cracks, these cracks extend towards the compression zone of the beam yielding of steel bars. After yielding of steel bars, the crack propagation at the flexural zone stopped and new cracks initiate near the supports with an inclination of about 40° toward the upper face. The cracks continued until the beam failure by diagonal shear, as shown in Figures 3 and 4. These results were satisfying the main idea of this study (keeping failure in the shear zone) which helps the beam to resist the shear stresses when putting the spherical air bubble in the middle of the beam.

Through the observation of the failure pattern, it is noted that the failure in solid beams is more ductile than bubble beams, as shown in Table 4. The carrying capacity of testing beams was increased by using high-strength concrete (RPC) for the solid or voided beam. On the other hand, the carrying capacity was affected by the existence the voids in concrete beams. Therefore, the ratio of reduction or increment in carrying capacity was shown in Table 5. The reduction in carrying capacity is (6.38%) and (10.07%) for normal strength, and high strength concrete beams respectively. This reduction is due to the effect of air bubbles in the beam. While the increase in the carrying capacity due to using high strength concrete is (99.93%) for solid beam and 92.05% for bubbled beam when compared with the carrying capacity of the conventional solid beam.

The presence of bubbles within the beam specimen increased the crack appearance. The decreasing cracking capacity of bubbled beam is due to a decrease in the moment of inertia due to concrete quantity at the tension zone of the section, as showing in the Table 6. The reduction of cracking capacity reached (12.87%), and (12.18%) for normal strength and, high strength concrete beams respectively in comparison with the solid beam. While the increase in the cracking capacity due to using high-strength concrete is (24.54%) for solid beam and (25.53%) for bubbled beam in comparison with the cracking capacity of the conventional solid beam.

From the previous results (Tables 5 and 6) of the specific carrying capacity and the specific first crack load, it can be concluded that the bubbles caused a small reduction for the conventional and high strength concrete (Figures 5a and 6a). While the steel fiber improves very well the beam resistance especially for the carrying capacity of high strength concrete (Figures 5b and 6b). Steel

Table 3. Properties of steel fibers.

Length (mm)	Diameter (mm)	Density (kg/m³)	Tensile strength (MPa)	Aspect ratio
13	0.2	7800	2600	65

Table 4. Compressive and flexural strength results.

Beam Designation	Fcu (Mpa)	Loading (kN)	(F.C.L)/(U.L)	Deflection (mm)	Ductility ratio*	Failure Mode	Beam Designation	Fcu (Mpa)
		First Crack (F.C.L)	Ultimate Load(U.L)	(%)	First Crack	Ultimate Load	(ψ)	
BCon-0	29	32.5	70	46.4	0.475	5.22	10.99	
BRPC-0	110	43	148.7	28.9	0.24	4.12	17.17	
BCon-16	30	27	62.5	43.2	0.82	3.75	4.57	
BRPC-16	112	36	127.5	28.2	0.57	6.35	12.44	shear

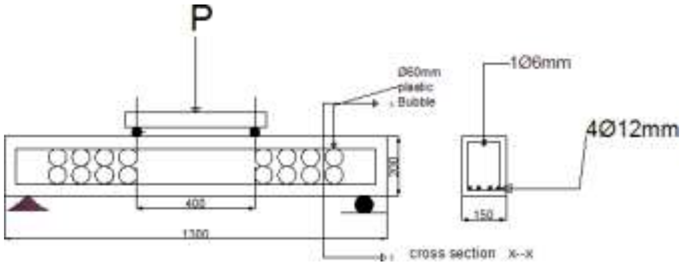

Figure 1. Illustrate the beam reinforcement and dimensions.

Figure 2. Testing machine.

Figure 3. Crack patterns and failure mode of solid beam (Bn-0) and bubbled beam (Bn-16).

Figure 4. Crack patterns and failure mode of solid beam (Br-0) and bubbled beam (Br-16).

fiber works as a reinforcing element in the solid beam, as well as surrounding the bubble; its effect had been more evident to retard the first crack initiation.

The load versus deflection response of the testing beam was illustrated (Figures 5 and 6). All specimens possess three main stages; the first stage starts at the beginning of loading until the appearance of the first crack, this stage represents the elastic behavior of the specimen.

The second stage starts after the appearance of the first crack, the relationship between load versus deflection remains approximately linear with a different slope of the tangent. The number, length, and width of cracks start to increase and the stiffness of the specimens decreased gradually until the yielding of steel bars.

The third stage starts after the yielding of steel bars. The deflection of the beam starts to increase rapidly accompanied by increasing width of cracks until failure of beams by diagonal shear. This stage is characterized by nonlinear

Table 5. Carrying capacity of tested beams.

Specimen No.	Specific density	Carrying capacity (kN)	Specific carrying capacity	Ratio of reduction (%)	Ratio of increasing (%)
BCon-0	2.325	70	30.11	Reference	Reference
BCon-16	2.217	62.5	28.19	6.38	
BRPC-0	2.47	148.7	60.2	Reference	99.93
BRPC-16	2.355	127.5	54.14	10.07	92.05

Table 6. Racking load of tested beams.

Specimen No.	Specific density	Cracking load (kN)	Specific Cracking load	Ratio of reduction (%)	Ratio of increase
BCon-0	2.325	32.5	13.98	Reference	Reference
BCon-16	2.217	27	12.18	12.87	
BRPC-0	2.470	43	17.41	Reference	24.54
BRPC-16	2.355	36	15.29	12.18	25.53

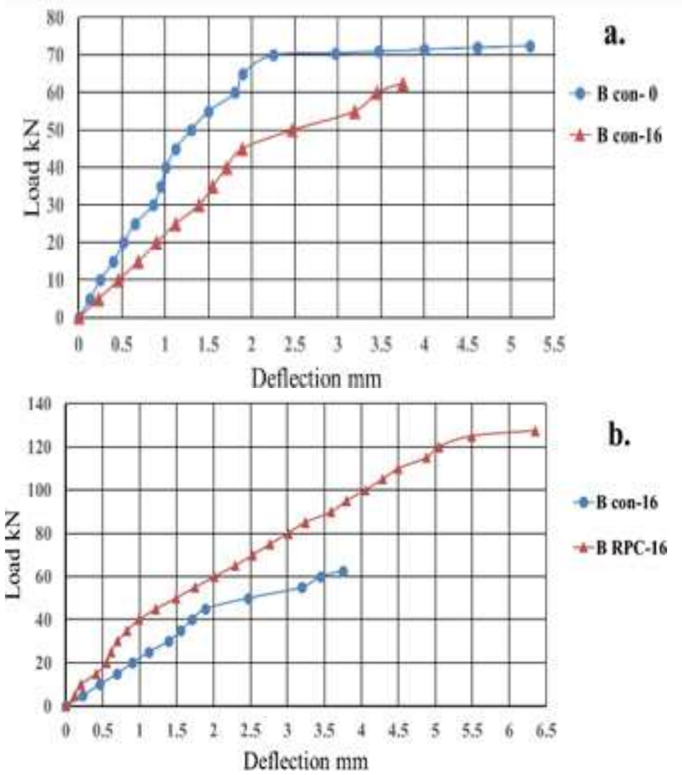

Figure 5. Load-deflection curves for beam B con-0, B con-16, and B RPC-0 (a) Bubble effect in conventional concrete and (b) Concrete type effect.

behavior and the specimens lost a large part of their stiffness due to a lack of bonding between steel bars and concrete.

Through the observation of load versus deflection (Figures 5 and 6) for each type of concrete, it can be remarked that the deflection at the initial stages of loading is approximately identical; the difference appears after crack appearance, which means that the effect of bubbles may be negligible at the elastic stage of behavior. Moreover, it can be concluded that the beam ductility was decreased when using the plastic bubbles in each type of concrete. In contrast, the ductility increased for high-strength concrete in comparison with the conventional one due to the concrete strength (high cement content, fewer voids, etc.) as well as the steel fiber effect. These results are in contrast to the high- strength concrete, which is made without using steel fiber [17].

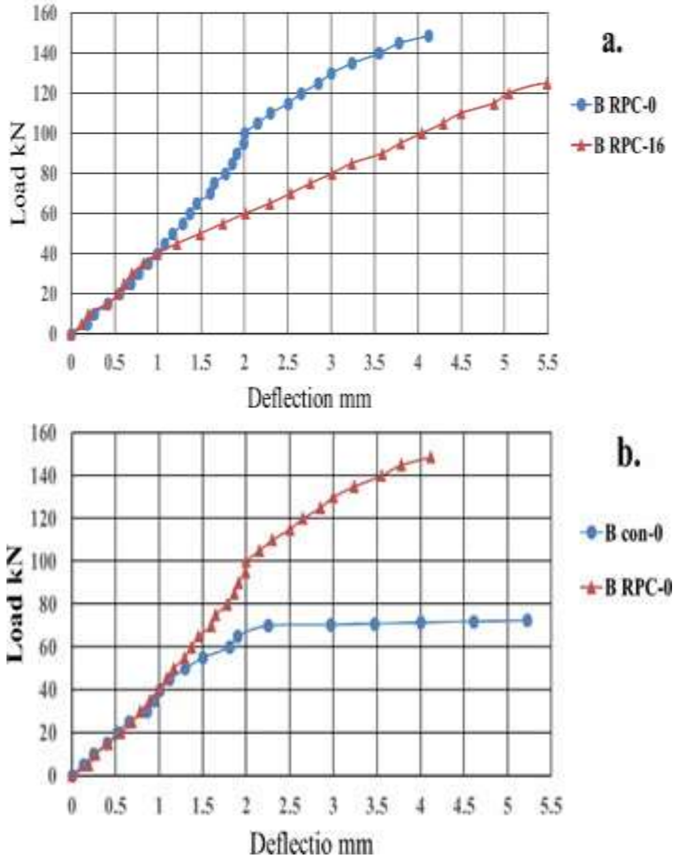

Figure 6. Load- Deflection Curve for Beams B RPC-0; B RPC-16 and B con-16 (a) Bubble effect in high strength concrete and (b) Concrete type effect.

Conclusions

The evidence from this study points towards the main idea to use plastic bubbles in concrete beams for reducing concrete quantity (dead load), especially for high resistance concrete satisfying economic issues. This experimental work demonstrates the following points:

1 The bubbles in the shear zone reduced the overall density of the beam by (6.22 and 6.24) % for the normal and high strength concrete respectively.

2 The presence of plastic bubbled reduced beam ductility.

3 The presence of plastic bubbles in the beam increases the number of cracks in comparison with solid specimens at the ultimate stress for each one.

4 The effect of bubbles can be neglected at the elastic stage because the deflection at the initial stages of loading is approximately identical.

5 The reduction in carrying capacity of the bubbled beam of conventional or high strength concrete is (6.38%), and (10.07%) respectively when compared with the solid beam. While, the reduction in cracking capacity of the bubbled beam of conventional or high strength concrete is about (12.87 %), and (12.18 %) respectively in comparison with the solid one.

6 The increment in carrying capacity due to using high-strength concrete reinforced by steel fiber is about (92.05%) and (99.93%) for bubbled and solid beams respectively in comparison with the conventional solid beam.

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