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Strength of Reinforced Reactive Powder Concrete Hollow Beams

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A B S T R A C T

The main objective of this research is to investigate the structural behavior and strength of reinforced reactive powder concrete beams with a hollow section subjected under two point concentrated loading. The experimental work consist of ten beams with dimensions (150mm width×200mm height×1000 mm length), eight of them are hollow beams and two solid beams were cast and tested up to failure. The major parameters adopted in the current research includes the hollowness ratio (10% and15%), hollow location (at top or at bottom), and hollow shape (circle or square). The amount of longitudinal and transverse reinforcement, concrete strength and the other parameters were kept constant for all the specimens. The comparisons between all specimens (hollow and solid) are based on the load carrying capacity, deflection, crack pattern and mode of failures**.** Results showed that the strength capacity of hollow beam when the hollow lies in the bottom is much higher than for top hollow, and the square hollow will lead to more decrease in the beam strength compared with the circular hollow and this is more evident when the hollowness ratio increases from (10% to 15%).

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مقاومة عتبات خرسانة المساحيق الفعالة المجوفة المقطع

الخلاصة

الهدف الرئيسي من هذا البحث هو التحري في سلوك ومقاومة عتبات خرسانة المساحيق الفعالة ذات المقطع المجوف تحت تأثير احمال مركزة. البرنامج العملي يشمل فحص عشر عتبات ذات مقطع عرضي بأبعاد(150mm×200mm) وطول (1000 mm) ثماني منها مجوفة واثنتان منها صلدة تم اختبارها حتى الفشل. شملت المتغيرات الرئيسية المعتمدة في البحث الحالي نسبة التجويف (10٪ و 15٪) وموقع التجويف (في الأعلى أو الأسفل) وشكل التجويف (دائري أو مربع). المقارنة بالنتائج بين جميع العينات (المجوفة والصلبة) اعتمدت على قابلية التحمل والهطول وانماط التشقق واطوار الفشل. من خلال الفحص العملي أوضحت النتائج أن قابلية تحمل العتبات المجوفة في الموقع الاسفل أعلى من تلك الحاوية على التجويف في الاعلى، وان التجويف المربع يقلل من قابلية التحمل وزيادة الهطول بالمقارنة مع التجويف الدائري، ويبدو ذلك أكثر وضوحا عند زيادة نسبة التجويف من (10٪ إلى 15٪).

1. INTRODUCTION

Nowadays, hollow cross section beams has been widely used in building and bridge structures. It is known that most hollow cross sections are used for their economic benefits. A longitudinal hole is used to construct hollow beams cast in site, precast or prestressed concrete member to reduce weight, cost and as a side benefit, to passing electrical and mechanical services or other utilities. Sometimes, hollow cross sections may be used for the beauty of their shape and for the purposes of the architectural requirement, or in some cases where their use is determined by their engineering characteristics. Applications of hollow structural sections covered various fields. These sections are used in several fields, such as buildings, bridges, marine structures, halls and towers [1].

Reactive Powder Concrete (RPC) is one of the most important and latest progresses in concrete technology, it has been given a great attention in the recent years due to its high mechanical properties. In addition, using of RPC decreases the beams dimensions, and offers a stronger structural elements. It is also classified as a form of Ultra High Performance Concrete (UHPC) [2] which is characterized by a dense mixture of high cement content, superior mechanical properties, excellent environmental resistance (high durability), toughness of fracture, fire resistance, and in most cases containing a steel fiber to reduce its brittleness [3]. The idea behind the RPC is to decrease the defects such as micro cracks, the interior voids which help increasing the homogeneity of the mix and reducing the different tensile strain in the concrete and subsequently lead to an increase of load carrying capacity and great durability of RPC [4].

2. LITERATURE REVIEW

Joy and Rajeev (2014)[5] conducted an experimental study on the influence of reinforced concrete beam with hollow at neutral axis on flexural behavior. Nine beams were casted with dimensions of (150mm×230mm×980 mm). Three of them were just singly reinforced concrete beams and were used as a reference, three specimens of singly reinforced concrete beams that were hollow at neutral axis using PVC pipe of 40mm ϕ and the lasting three specimens were singly reinforced concrete beams that were made hollow at neutral axis using PVC pipe of 50mm ϕ. The test results indicated that the hollow section decrease in load capacity and increase in corresponding deflection for the same properties when compared with solid control beams.

Al-Shimmeri and Al-Maliki (2014)[6] investigated the behavior of reinforced concrete hollow beams with dimensions of (1000mm length ×180mm height×120mm width) tested under partial uniformly distributed load. Four of tested beams were containing long opening of varied section (40x40mm) or (40x80mm).Test results showed that the presence of hollow in reinforced concrete beams led to decrease the load carrying capacity about (37.14% to 58.33%) and increase the deflections by about 71.6% (hollow ratio 7.4%) to 75.5% hollow ratio (14.8%) for same applied load compared with solid beams. When increasing the hollow ratio from (7.4% to 14.8%) the load carrying capacity is decreased and deflection is increased about (28.5% and 14%) respectively for same other properties.

Manikandan, et al. (2015)[7] investigated experimentally the flexural behavior of the reinforced concrete beams with hollow core. The experimental work consists of six RC beams of size (1500mmx150mmx200mm) solid and with a hollow core using polystyrene in circular 75mm diameter and square 70mm in tension zone. Results showed that the flexural strength, deflection at yield and at ultimate point of RC beams contain circular hollow core is a close to that of RC solid beams. The flexural strength and yield deformation of RC beam contain square hollow is lesser compared with solid and circular hollow beams. The failure pattern in the beam tested was detected as a flexure-shear failure.

Ghadbban et al.(2017)[8] studied the behavior of reinforced concrete inverted hollow dapped end beams under static loads. Seven simply supports beams tested under concentrated load at two points. The specimens dimension is (1220 x 240 x 130mm) with different section (solid or with hollow). The variables are section type (with or without hollow), hollow location (at top or at bottom of beams) and the beam (strengthened or unstrengthen) with longitudinal normal bars (bolts of diameter 12.5 mm) work as installed after casting normal bars installing after finish curing of specimens at top fibers. The results showed that the hollow beam providing by PVC pipe (diameter of 50mm and length 500 mm) led to decrease in load capacity about (6.5-9%) and an increase in deflections about (33- 35%) at bottom and top respectively compared with the solid beams. The failures mode of all girders are compound (flexure and shear failure).

3. THE WORK SIGNIFICANCE

3.1 Scope of the Study

The idea of providing a hollow section in the beam is generally one of the solutions to decrease the weight of the structure, as well as reducing the building height, material and construction costs. Consequently, an experimentally tests are necessary in order to prove the strength reduction of the beam. From the studied literature reviews, most of the studies conducted in this filed focused on the normal concrete, but no information is available yet to investigating the behavior of the reinforced reactive powder concrete beams having a longitudinal hollow.

3.2 Objective of the Study

The objective of this study is to investigate the strength and behavior of a simply supported reinforced concrete hollow beams cast from Reactive powder concrete RPC under effect of static loads.

4. EXPERIMENTAL STUDY

4.1 Materials

The reactive powder concrete (RPC) mixes that used in this study requires a high-quality material. Table 1 presented in brief the description of the used materials. Reinforcing steel bars tht used in this work are deformed (Ukrainian) origin with a nominal diameter of 6mm and 12mm. The bar properties are shown in Table 2 which were conform to the ASTM A615 requirements [13].

4.2 Experimental program

The experimental program included testing of ten simply supported beam specimens, two of them are solid beams (as a reference) and eight hollow beams with different variables of hollow, Table 3 shows the fully details of the tested beams, the type and value of the variables. In the present study, three variables related to hollowness is adopted and studied which includes:

1- hollow shape (circular or square).

2- hollowness ratio (10% or 15%).

3- hollow location (at top or at bottom of the section).

Here, the hollow shape and ratio is changed through using different dimensions of PVC pipe (for circular hollow) or polystyrene blocks (for square hollow) to make different areas of hollow. For the hollowness ratio 10%, the circle diameter was (62.5) mm while the square side dimension were (55.38) mm. For the hollowness ratio 15%, the circle diameter was (75) mm while the square side dimension were (66.46) mm.

4.3 Beam Specimens Details

For all specimens, the cross section is 150mm in width, 200mm in depth and the overall length is 1000mm, with a clear span of 900mm. (3-Ø12mm) steel bars were used in the longitudinal direction in the lower part, while 6mm diameter steel bars as stirrups at 80mm center to center. As well as (2-Ø6mm) steel bars were used in longitudinal direction in the upper part to assist the formation of the required steel cage. Figs. 1, 2 show the details of the reinforced RPC beams that tested in this study.

4.4 Concrete Mix Design

To produce the RPC, the material mix proportions stated in Table 4 is used in this work. This proportion is based on previous research [14]. However, several trial mixes have been made through the earlier stage of the present study to produce RPC with compressive strength more than100 MPa, and appropriate workability (flow table of 110 ∓5%) (ASTM C 109/C 109M-99) [15]. The workability for all types of RPC mixes are tested using the flow table test, The flow table spread value was 110 ∓5% for all mixes. The volume percentage of steel fibers were used in this mixed is $\mathbf{V_f}$ = 1%).

Table 1

Description of Materials

Material	Descriptions
Cement	Ordinary portland cement (Type I) produced by Almas cement factory, satisfied to the Iraqi specification No.5/1984 [9]
Siliceous Sand	Al-Ukhaidher natural siliceous sand (sieved over 0.6mm sieve) conforms to the B.S. specification No. 882/1992 [10]
Micro silica fume	It is an ultra-fine gray powder commercially named (Mega Add MS(D)) conforms to the ASTM C 1240-03 [11]
Super Plasticizer	The admixture Sika® Visco crete 5930-L supplied by Sika company, conforms to ASTM-C 494 Types G and F [12]
steel fibers	straight steel fibers, gold-colored, ultimate tensile strength up to 2600 MPa and a diameter 0.2mm and length of15mm.
Water	Clean tap water (used for mixing and curing)

Table 2

Test Results of Steel Bar Reinforcement

Bar Diameter (mm)	Yield Stress f_y (MPa)	Ultimate Stress f_u (MPa)	Elongation%
6	581	654	7.3
12	660	778	10.6

Table 3

General Details and Variable of The Tested Beams

Beams Symb.	Type of beams and hollow	Hollow shape	Hollow ratio	Hollow location
Solid	(Ref.)	______	______	______
HCB1	Hollow-PVC	Circle	10%	Bottom
HCT1	Hollow-PVC	Circle	10%	Top
HCB2	Hollow-PVC	Circle	15%	Bottom
HCT2	Hollow-PVC	Circle	15%	Top
HSB1	Hollow-polystyrene	Square	10%	Bottom
HST1	Hollow-polystyrene	Square	10%	Top
HSB2	Hollow-polystyrene	Square	15%	Bottom
HST2	Hollow-polystyrene	Square	15%	Top

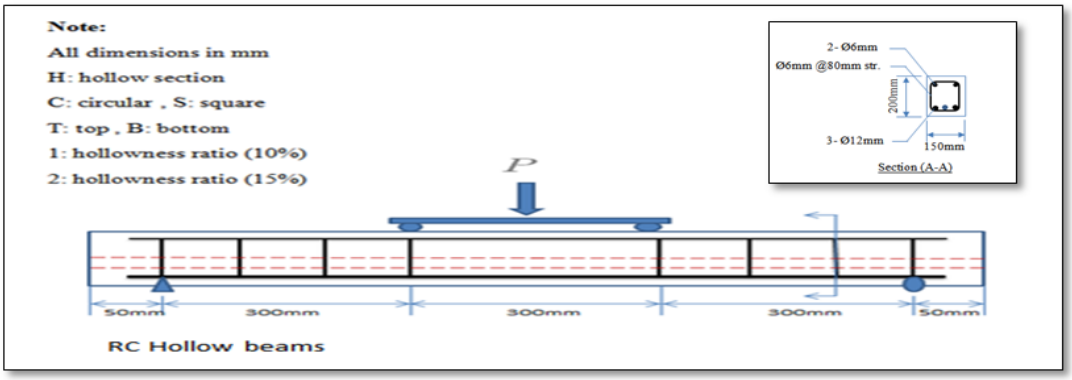

Fig. 1. Dimensions and reinforcement details of reinforced RPC tested beams

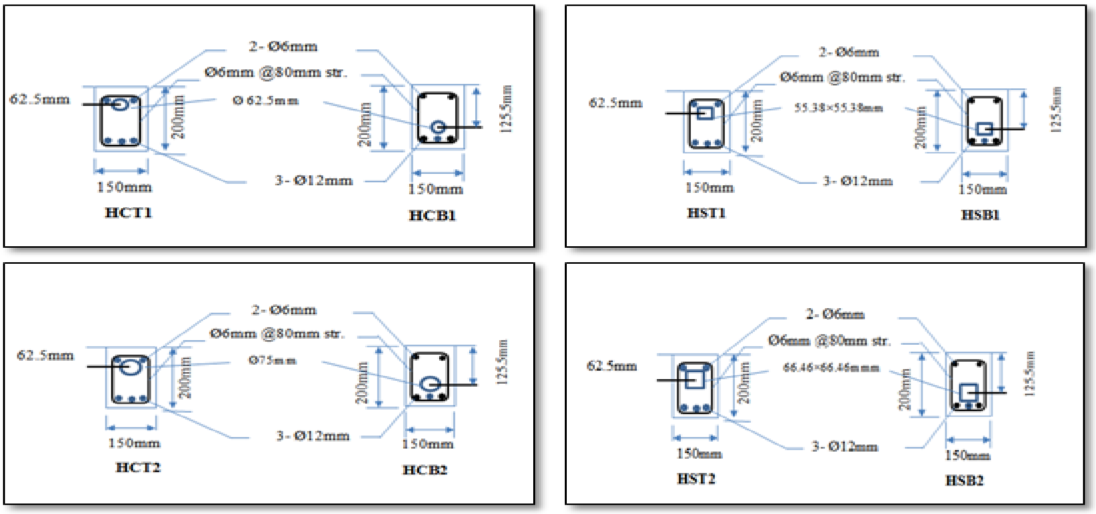

Fig. 2. Details of hollows within the sections

Table 4

Mix proportions

Constituent	Fine sand (600 µm)	Binder		Water**	SP***	Steel Fiber
		Cement	micro silica*			
Amount(kg/m^3)	1070	963	107	214	32	78

* 10% partial replacement by weight of cement. ** Water/binder (w/b) ratio = 0.2. *** 3% of binder (cement + micro silica) weight

4.5 Concrete Mixing and Curing

Mixing procedure is important to gain the required workability and homogeneity of concrete mixes. Mixing was done using a rotary mixer of (0.05) m^3 capacity. Mixing procedure which proposed by Wille et al.[16] was adopted in this study to produce RPC in a simple way without any accelerated curing regimes.

They recommended the following mixing procedure:

1. Mixing of micro silica fume and siliceous sand first for 5 minutes.

2. Adding other dry components (cement) and mix for another 5 minutes.

3. Superplasticizer is added to the water, then the blended liquid is added to the dry mix during the mixer rotation and the mixing process continued for another 3 minutes

4. Finally, steel fibers are added in small quantities while the mixer is rotating within 2 minutes as shown in plate 1.

After (2 days), Beams and another specimen (cubes, cylinder and prism) are demolded and cured by water at room temperature until the testing age of 28 days. However, this normal curing was proposed by Wille et. al.[16] as part of their proposed simpler way to produce RPC and the mixing procedure used in this study. This makes RPC production more economical and practical, especially in field applications.

Plate. 1 Casting of Hollow Beam

4.6. Mechanical Properties of RPC

The control specimens were mixed and casted to determine the mechanical properties of the concrete see Plate 2, three cubes (70mm×70mm×70mm) was examined in accordance with BS (1881-116)[17], three cylinders (100mm×200mm) was examined in accordance with ASTM C496/C496M-04 [18] and three prisms (40mm×40mm×160mm) tested accordance to ASTM C293-02[19], to determine the compression strength, splitting strength and modulus of rupture respectively. The test results are shown in Table 5.

Plate. 2 Control Specimens of RPC After Testing

Table 5

Mechanical Properties for (RPC) Mixes*

Compressive strength f_{cu}(MPa)	Splitting tensile strength f_{st} (MPa)	Modulus of rupture f_r (MPa)
112.43	14.6	21

* The average of three specimens test results was adopted for each test.

4.7 Beam Test

All beam specimens have been tested as a simply supported beams under static loading with two concentrated loads applied at the two third-points of the beam. The beam specimens have been placed on the machine with a clear span (900mm). All tests were carried out using the two columns Universal Testing Machine with a load capacity of (5000) kN and a loading rate of (1.75) kN/sec. The deflection has been measured at mid span of the beam specimens using a dial gauge of (0.01mm) accuracy at every load stage. The deflection is recorded with the corresponding load and the loading continued until the final failure of the beams.

5. RESULTS AND DISCUSSION

During the experimental work, test results of the solid and hollow beam specimens including; general behavior, the effect of hollow on the cracking loads behavior, ultimate loads, load-deflection response at mid span. As well as crack patterns has been monitored and the failure mode was observed. The test results are presented in Table 6.

5.1 First Cracking Load (P_{cr})

Table.6 stated the first cracking load values and it can be seen that these values varied from (11%) to (22%) as a percentage of the ultimate load values (pu). The test results show that the first cracking loads for (HCB1, HCT1 ,HCB2 and HCT2) are decreased about (32%,35%,36% and 44%) respectively compared with that of the solid beam, and for the beams (HSB1, HST1, HSB2 and HST2) are decreased about (31%, 34%, 45% and 49%) respectively compared with the solid beam.

5.1.1 Effect of Hollow Shape

From the obtained result, it can be concluded that the existence of a hollow (circular or square sections) have a significant effect on first cracking load. However, for hollowness size (10%) it seems that the hollow shape does not effect the first cracking load. While for hollowness size (15%) it is clear that the square section have greater influence on the first cracking load than that of circular hollow for any hollow location, this can be attributed to the presence of the sharp corners of this shape of hollow which yield stress concentration at corners causing decrease in the first cracking loads.

5.1.2 Effect of Hollowness Ratio

Regarding the beam hollowness ratio, It can be noticed that increasing of the hollowness ratio from 10% to 15% will decrease the first cracking load of beams and this deceasing range between (4-9%) for a circular hollow section and ranges about 14% for square hollow section i.e the effect of hollowness ratio is increased for the square hollow than that for circular hollow section. In general the increase of the hollow area cause a decrease in the beams stiffness and this lead to accelerate the first cracks formation so decreasing the first cracking loads.

5.1.3 Effect of Hollow Location

It could be concluded that the presence of the hollow in the top will lead to a more decrease in the beam first crack load compared with that hollow in the bottom location. This can be attribute to that the top fibers are in compression stresses zone, i.e the presence of hollow will lead to decreasing the compression force which lead to decrease the internal moment of the section. While the bottom fibres lies in tension stresses zone and the presence of hollow in this region will not reduce the section stresses as the concrete have a small contribution in tension resistance.

5.2 Ultimate Load (P_u)

All beams specimens have been tested up to failure. The recorded ultimate loads of the tested beams are presented in Table.6, the test results show that the ultimate loads for (HCB1, HCT1, HCB2 and HCT2) are decrease about (17%, 10%, 6% and 15%) respectively compared with that of solid beam, and for the beams (HSB1, HST1, HSB2 and HST2) are decreased about (6.4%, 9%, 7% and 19%) respectively compared with solid beam.

5.2.1 Effect of Hollow Shape

It could be seen that the presence of the hollow circular or square have a little effect on the ultimate load. However, for both hollowness ratio (10%) and (15%) it seems that the hollow shape have same influence on the ultimate load.

5.2.2 Effect of Hollowness Ratio

It could be concluded that the increase of the hollowness ratio from 10% to 15% was decrease the ultimate load of beams. And this decrease is about (5%) for circular hollow section and ranges between (3-10%) for square hollow section i.e the hollowness ratio effect is increased for square hollow higher than that for circular hollow section.

Generally, the increasing of hollow area lead to reduce a considerable portion of concrete and subsequently causes reduction in stiffness and the ultimate loading capacity of hollow beams.

5.2.3 Effect of Hollow Location

It can be noticed that the existence of hollow in the top of the section will lead to a more decrease in beam ultimate load compared that of the hollow in the bottom. This decrease about (9%) for circular and range between (3%-12%) for square hollow sections.

Table 6

Test Results of Beams Specimen

Beam Symb.	Hollow shape	Hollow-ness ratio	Hollow location	Load (kN)		Deflection mm	Mode of failure
				P_{cr}	P_u		
Solid (Ref.)*	_____	_____	_____	99	445	8.3	Flexural
HCB1	Circle	10%	Bottom	67	368	8.65	Shear
HCT1	Circle	10%	Top	64	401	9.24	flexural-shear
HCB2	Circle	15%	Bottom	63	420	9.8	flexural-shear
HCT2	Circle	15%	Top	55	380	10.05	flexural-shear
HSB1	Square	10%	Bottom	68	417	10.14	flexural-shear
HST1	Square	10%	Top	65	405	10.26	flexural-shear
HSB2	Square	15%	Bottom	53	413	11	flexural-shear
HST2	Square	15%	Top	50	360	11.13	flexural-shear

* The results of solid beam are average for two specimens

5.3 Load-Deflection Relationships

The load versus mid span deflection curves of the tested beams at all stages of loading up to failure have been constructed and drawn in Fig. 3. Each curve initiated in a linear form (the beam is in elastic state) with a constant slope, then change to a nonlinear form with varying slope after of the first crack initiated. Then, the third stage starts when the deflection increases very fast with small increase in the applied load up to maximum (at failure). From Table 6 and Fig.3 show the effect of the presence of hollow on the load- mid span deflection response, it can be seen that the maximum deflection of beam (HCB1, HCT1, HCB2 and HCT2)were increased about (4%, 11.3%, 18% and 21%) compared with the solid beam. Also, the maximum deflection of beam (HSB1, HST1, HSB2 and HST2) were increased about (22%, 23.6%, 32.5% and 34%) compared with the solid beam.

5.4 Crack Patterns and Mode of Failure

The crack pattern for all the tested beams are shown in Plate 3, and the failure modes of all the tested beams are presented in Table 6. It have been noticed that the solid beam failed with flexural failure mode while all hollow beams had similar failure modes under compound failure (flexural and shear), except beam (HCB1) which failed with shear failure only and lack of support. In hollow beam the shear failure may be occurred due to presence of the hollow where a large part of the concrete was occupied and the effective compressive area of the concrete were reduced, i.e, solid section without a hollowed part permits beams to carry an additional shear load as the shear strength depend on the section area and this leads to an increase in the stiffness of solid beam. As mentioned before, the presence of hollow in specimen changes the mechanism of failure from flexural in solid beam to combined flexural and shear failure in the hollow beam.

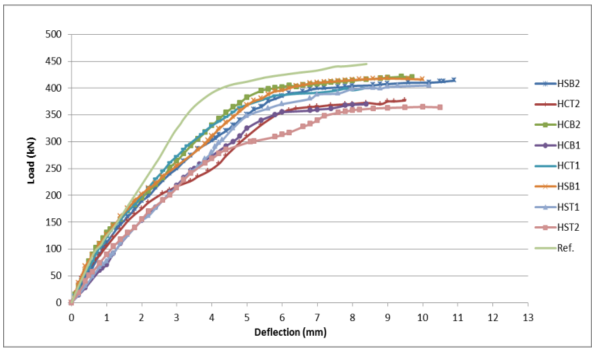

Fig. 3. Comparison Between Relationship of Load-Deflection Curve for Reference And Hollow Beams

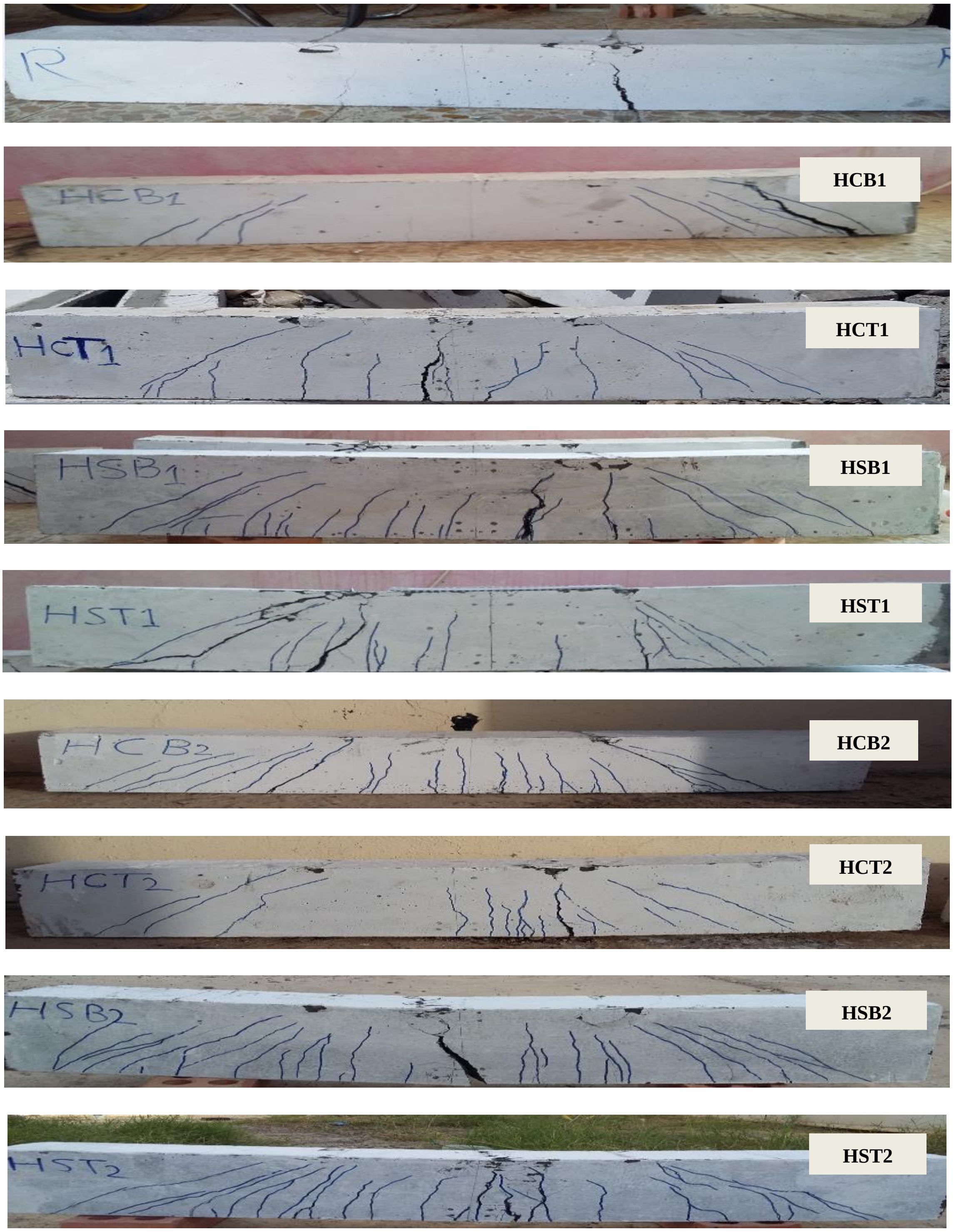

Plate. 3. Crack Patterns for the Tested Beam Specimens

6. CONCLUSIONS

1-In general, hollow in beam decrease the first cracking load and ultimate load capacity and have the ability to change the failure mode. As well as the number of cracks was larger in the hollow sections than in the solid ones under loading.

2-Increase the hollowness ratio from (10% to 15%) led to a decrease in the first cracking loads and the ultimate loads while increasing the deflection of these beams.

3-The square section hollow leads to a more decrease in beam strength compared with the circular one. This is due to stress concentration and initiation of cracks at square corner.

4-It was shown that the strength capacity of the hollowed beam when the hollow lies at bottom position is much higher than of the top position.

5-Presence of hollow in beams leads to a change in the failure mechanism of the solid beams from flexural failure to a combined flexural- shear failure for the hollowed beams.

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