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Research paper

Laboratory tests of solid and hollow concrete beams made with glass waste

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Abstract: The application of used glazed waste in concrete production can improve the performance of the structure of the building. Flexural and shear behavior and action of reinforced Hollow Glass Concrete Beams (HGCB) and Solid Glass Concrete Beams (SGCB) made with glass waste under a two-point load are studied in this paper. In this work, 6 reinforced concrete solid and hollow beams were tested under a four-point bending test to evaluate and calculate the flexural behavior of SGCB and HGCB. For that purpose, Beams were prepared with 1000 mm length, 230 mm height, and 120 mm. All beams were divided into groups and named according to the space stirrups steel bar. The experimental work investigates five main variables which are: first: the comparison between SGCB and HGCB with the concrete beams made with glass waste (Glass Concrete Beam GCB), second: comparison between Solid Concrete Beams for Normal Concrete Beams (NCB), and GCB, three: comparison between Hollow Concrete Beams for NCB and GCB, four: the comparison between HGCB and HCB, last: the comparison between SGCB and SCB. The test results indicated that GCB was offered higher strength than NCB, but the load–slip behavior of all specimens is similar for both types of concretes, and the bond strength is not influenced by steel specimens. Furthermore, the results of this study indicated that the contribution of GCB to the load is indicated to be considerable. The results indicate that the hollow opening affected the ultimate load capacity and deflection of HGCB.

Keywords: hollow concrete beams, solid concrete beams, steel, flexural strength, shear strength, cracks, mechanical

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1. Introduction

Due to numerous factories and industries, a huge volume of waste is generated daily. The waste produced from industries has become a serious problem solid waste management is one of the main environmental alarms in the world [1–6]. On the off chance that such glass could be used in concrete production. It would impressively diminish the transfer of glass and take care of some of the environmental issues. Utilizing glass waste as a progress material in concrete reduces the cost of glass transfer and concrete production. This inclusive decreased bond strength between the aggregate and the cement paste [7,8]. In this point, numerous investigates [9–12] have focused on that the recycling of waste glass as a partial replacement can be possible. As a consequence of its high silica content [11–15], the waste glass has the potential for improving the physical and mechanical properties of mortars [16], such as drying shrinkage [15]. The partial replacement of mixed concrete by 10% of glass powder will raise the compressive strength by 52.6% in 3 days [17]. The investigator has studied the strength of concrete at 7 & 28 days of curing specimen for M2o grade with variable percentages of waste glass like 10%, 20%, and 40%. The results indicate that at 20% partial replacement the maximum compressive strength is achieved [18]. The investigation studied the behavior of shear on the Reinforced Concrete Beams (RCB). In comparison to the solid RCB, hollow RCB are more common in construction buildings because of their low cost and less weight [19]. In the last decade, Hollow RCB beams were used for monorail bridge girders [20, 21]. Through analyzing twelve test RCB beams, the major of this study is to investigate the effect of diverse factors on the ultimate shear strength of these beams. Additionally, the flexural response of the reinforced Hollow Concrete beams (HGCB) made with glass waste and Solid Concrete Beams (SGCB) made with glass waste represent the effects of the existence of HGCB on flexural and behavior under the load-carry capacity; mid-span deflection; the shear behavior of the HGCB and CB under combined shear strength and flexure strength. Additionally, the investigational results of this work were compared with HCB and SCB [3].

2. Experimental program

In this work, RCB were made, the raw materials used are fine aggregate (NS) and coarse aggregate (NG), and glass waste (GW) as fine aggregate, steel reinforcing bars, box plastic, and Portland cement content (365) kg/m^3.

2.1. Materials and testing procedures

In the investigation work, portland cement was utilized. The compressive strength of portland cement is 33 and 41 N/mm^2 in 3 days and 7 days respectively. Natural sand of 4.75 mm maximum size was used was as Fine Aggregate (NS). The gravel with a maximum size of (10 mm) must be clean and 100% crushed and used in the experimental work as Coarse Aggregate (NG). Glass Waste (GW) has to be ground to its powder form Before adding to the concrete mixture. In this research, glass powder milled in a ball/pulverizer for a period of (30–60) minutes led to the particle sizes less than size 150 µm and separated into 75 µm. The glass powder is indicated in Fig. 1. Table 1 indicates the grading of glass powder. The physical, chemical properties and chemical composition are presented in Table 2. Also, tap water was utilized in the experimental work.

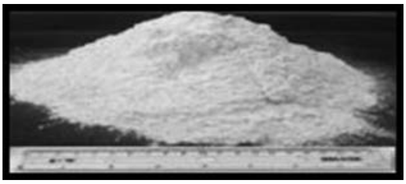


Fig. 1. Crushed Waste Glass [8]

Table 1. Grading Crushed Waste Glass

Sieve size, mm	Cumulative % passing
4.75	100
2.36	100
1.18	100
0.6	98.4
0.425	95.3
0.3	86.9
0.15	42.5
0.075	29.6
Pan	0.0

Table 2. Physical and Chemical Properties of Crushed Waste Glass

Physical Properties of Glass powder	
Relative density SG (OD)	2.42
Absorption	0 %
Density (kg/m^3)	2556
Blaine surface area (kg/m^3)	3229
Chemical Properties	
pH	10.2
Colour	Grayish white
Chemical composition	% by mass
CaO	12.52
SiO_2	68.31
Al_2O_3	2.64

Continued on next page

Table 2 – *Continued from previous page*

Fe_2O_3	1.51
MgO	2.81
Na_2O	12.28
TiO_2	0.149
ZrO_2	0.016
P_2O_5	0.051
K_2O	0.631
P_2O_5	0.057
ZnO_2	0.006
SrO	0.015
NiO	0.014
CuO	0.007
Cr_2O_3	0.022

2.2. Steel reinforcement

In this work, all the beams are longitudinally reinforced by 12 mm, 16 mm diameter sized steel bars with four bars and 6 mm as indicated in Fig. 2. The properties of steel reinforcement bars are given in Table 3 and all the examination of the steel bars complies with the ASTM.

Table 3. Mechanical Properties of Steel Bars

Diameter (Steel Bar) mm	Type of Bar	Yield Strength (fy) MPa	Ultimate Strength (fu) MPa	Maximum Elongation (%)
16	Ribbed	519	617	18
12	Ribbed	618	734	20
6	Round	447	476	28

Fig. 2. Steel Reinforcement Bars and Plastic Box [4]

2.3. Box plastic

Box plastic was utilized with dimensions of 50 × 75 × 1000 mm for HCB [4] as indicate in Fig. 2.

2.4. Mixtures

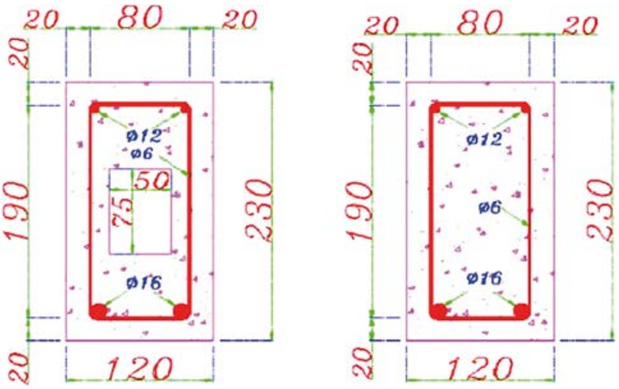
Table 4 indicate the concrete mixture by weight.

Table 4. Mixtures

Mixture No.	Portland Cement (C), (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine sand (F.S) (kg/m^3)	Crushed Waste Glass (kg/m^3)		w/c	Density (kg/m^3)
				Sand Replacement of Crushed Waste Glass (%) by weight	Crushed Waste Glass (kg/m^3)		
Group 1	364	980	813	0%	0.0	0.54	2401
Group 2	364	980	610	25%	203	0.54	2300

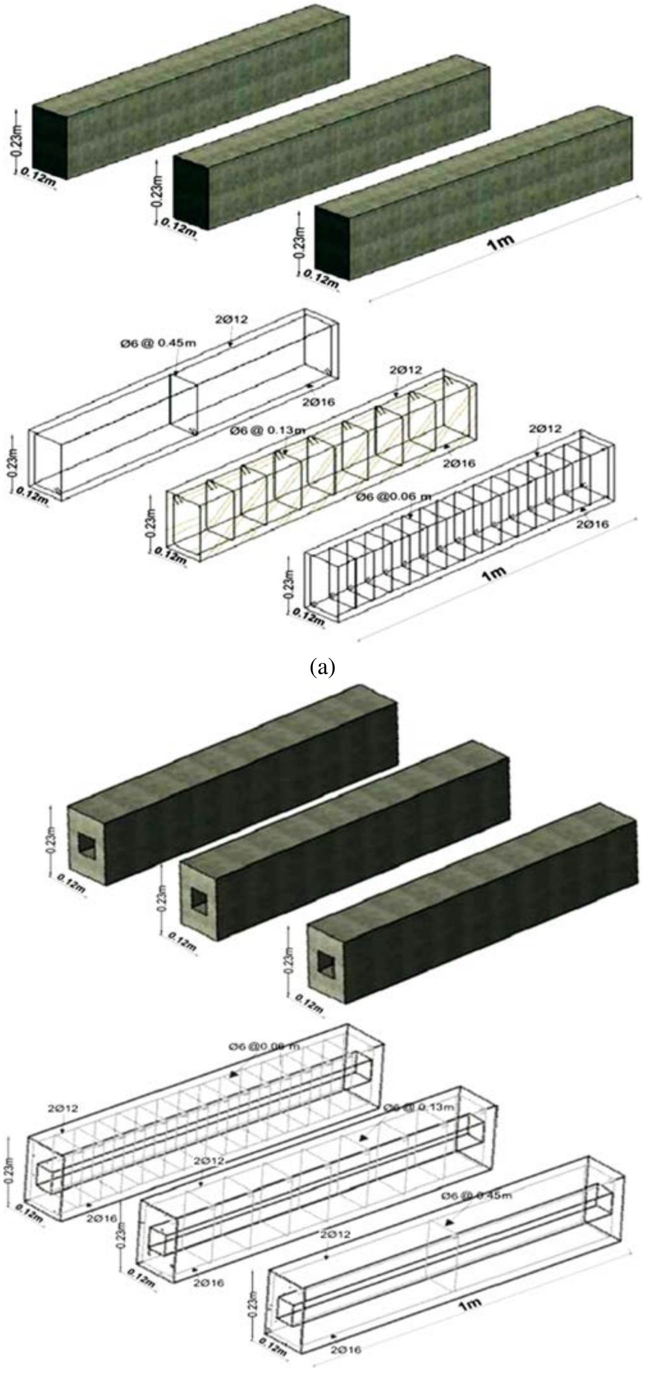
2.5. Specimens

Specimens utilized are reinforced HGCB having a cross section of width × full depth = 230 × 120 mm. In the center of the section of the beam, the hollow part 75 × 50 mm is prepared. Specimens without a hollow section named SGCB were also made for comparison and evaluation. The details of the cross-section of RCB indicate in Fig. 3 and 20 mm is the concrete cover or the distance from the edge of the crosssection to the stirrup. The average (*fcu*) of normal weight concrete (Group 1) was (29 MPa) and (35 MPa) for concrete made with glass waste (Group 2). The steel reinforcement Bars with (6 mm) diameter vertical stirrups steel bar were prepared at the distance of 450, 130, 60 mm as indicated in Fig. 4.



(a) (b)

Fig. 3. Cross Section of CB: (a) SGCB and (b) HGCB [3]. Note: All Dimensions are in mm



(a)

(b)

Fig. 4. Cross Section of CB: (a) SGCB and b) HGCB [4]. Note: All Dimensions are in mm

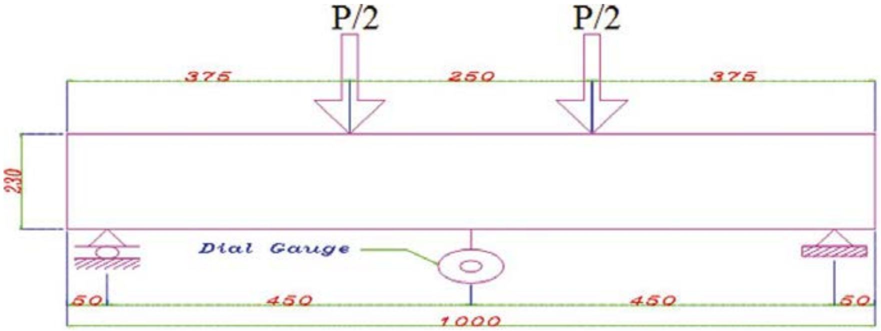
2.6. Specimen preparation

All specimens were prepared at the lab. Mixed concrete was utilized to cast all HGCB and SGCB. After one day, beams were removed from the curing water tank at a specific time at 28 days. Cube concrete specimens (15×15 cm) were also cast to get the compressive strength as indicated in Fig. 5.

Fig. 5. HGCB and SGCB out of the Water [3]

3. Test program

The structural responses of the HGCB and SGCB, one dial gauge (ELE type). It was set up below RCB at the mid to verified downward deflection as indicated in Fig. 6.



(a) Side View

(b) Top View

(c)

Fig. 6. Test Instrumentation: (a) Side View, (b) Top View and (c) Testing Machine [3]

4. Analysis results

In this work, six GCB specimens were examination test. RCB were identical in length, width, and thickness. The diverse steel bar with (6 mm) diameter stirrups were prepared at the distance of 450 mm, 130 mm, 60 mm as web reinforcement. six RCB models contain three SGCB without a hollow (S 45 GCB, S 13 GCB, S 6 GCB). The additional three HGCB poured cavity 50×75 mm along the al beam of 1000 mm (O 45 GCB, O 13 GCB, O 6 GCB).

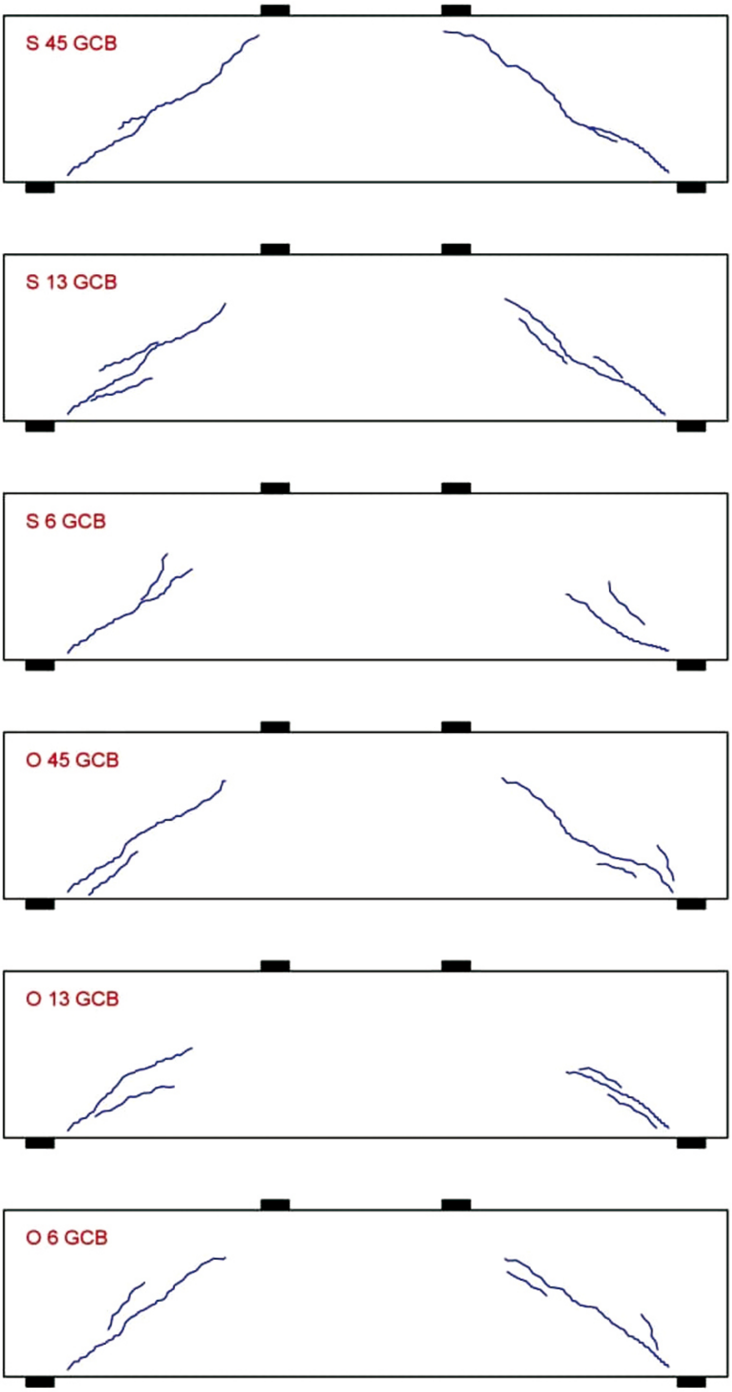
4.1. Cracking of solid and hollow rc beams

The test results of cracking and the load-carry capacity are shown in Table 5. The ultimate load carry capacity was applied to the HGCB and SGCB specimens, the first cracks formed at about (14–25%) of the ultimate load carry capacity for RCB.

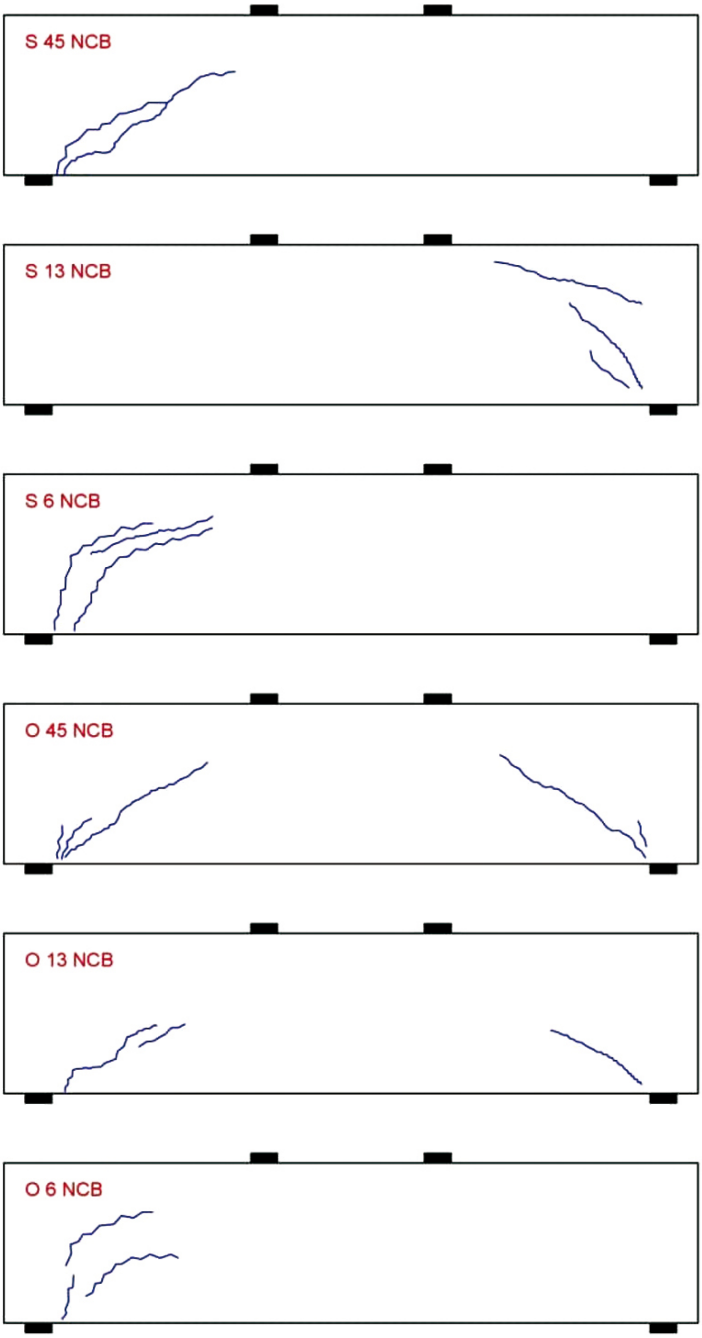
RCB models include three SGCB without a hollow (S 45 GCB, S 13 GCB, S 6 GCB). The values of the first crack load (P_{cr}) are (13.5, 14.5, and 15.5) kN. The additional three HGCB (O 45 GCB, O 13 GCB, O 6 GCB) are (14, 16, and 18) kN respectively.

The value Ultimate Load (P_u) for three SGCB (S 45 GCB, S 13 GCB, S 6 GCB) were (73, 104, and 108) kN, but Ultimate Load (P_u) for three HGCB (O 45 GCB, O 13 GCB, O 6 GCB) were (56, 67 and 82) kN.

RCB models including three SGCB (S 45 GCB, S 13 GCB, S 6 GCB), and three HGCB (O 45 GCB, O 13 GCB, O 6 GCB), the shear cracks after yielding steel reinforcement and the RCB in the compression zone crush finally, indicate in Fig. 7. all these test results of GCB more than about 15%, when compared with the six normal weight NCB [3].



(a)



(b)

Fig. 7. Beams Failure in Terms of Crack Pattern: (a) Beams Failure in Terms of Crack Pattern (HGCB and SGCB), (b) Beams Failure in Terms of Crack Pattern (HCB and SCB) [3]

Table 5. First Crack and The Load-Carry Capacity (HGCB and SGCB)

Group Name	Beam Designation	f_{cu} (MPa)	First Crack Load (P_{cr}) (kN)	Ultimate Load (P_u) (kN)	$\frac{P_{\text{cr}}}{P_u}$ (%)
SGCB	S 45 GCB	35	13.5	73	18.5
	S 13 GCB	34.5	14.5	104	14.0
	S 6 GCB	34	15.5	108	14.4
HGCB	O 45 GCB	34.5	14	56	25.0
	O 13 GCB	35	16	67	23.9
	O 6 GCB	35	18	82	22.0

4.2. Ultimate loads

The test results of ultimate loads to all RCB as indicated in Table 4 show that the ultimate loads for HGCB (O 45 GCB, O 13 GCB, O 6 GCB), were less strong than the ultimate loads for SGCB (S 45 GCB, S 13 GCB, S 6 GCB) respectively, indicated in Fig. 8. As indicated in Figures 9 and 10 [3], the comparison between GCB and NCB.

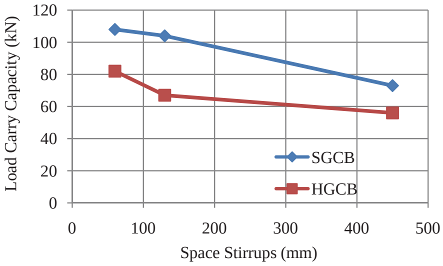


Fig. 8. Ultimate Load Carry Capacity-Space Stirrups Steel Bar (60, 130, 450) mm Relationships Between SGCB and HGCB

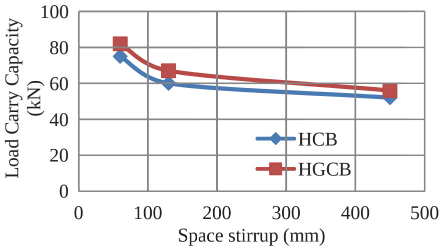


Fig. 9. Ultimate Load Carry Capacity-Space Stirrups Steel Bar Relationships Between HCB and HGCB

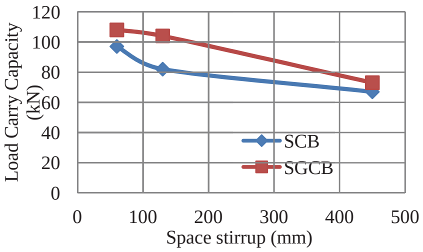


Fig. 10. Ultimate Load Carry Capacity-Space Stirrups Steel Bar Relationships Between GCB and SGCB

The distance vertical stirrups bar reinforcement (6 mm diameter) reduces the load-carry capacity for all beams (SGCB and HGCB) rise indicated in Figures 11 and 12. As indicated in Figures 13 and 14 [3], the comparison between GCB and NCB.

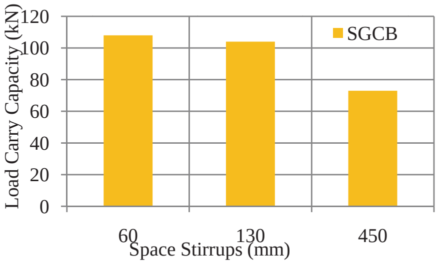


Fig. 11. Ultimate load Carry Capacity-Space Stirrups Steel Bar Relationships with SGCB

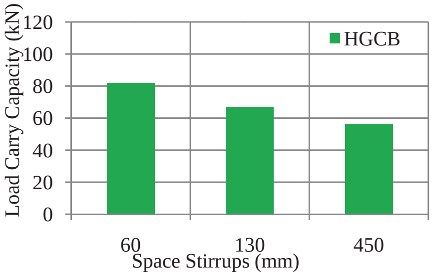


Fig. 12. Ultimate Load Carry Capacity-Space Stirrups Steel Bar Relationships with HGCB

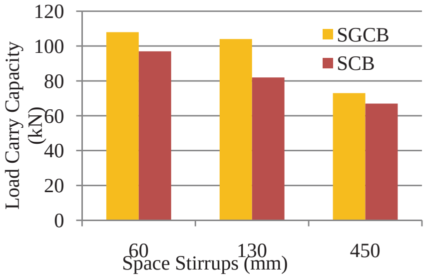


Fig. 13. Ultimate Load Carry Capacity-Space Stirrups Steel Bar Relationships with SGCB and NCB

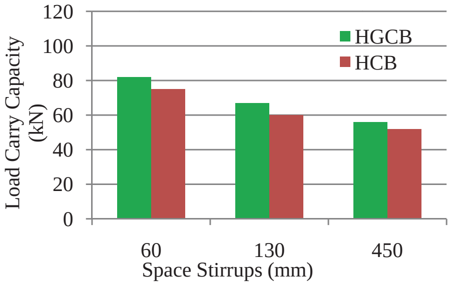


Fig. 14. Ultimate load Carry Capacity-Space Stirrups Steel Bar Relationships with HCB and NCB

The decrease in the load-carry capacity for solid beams (S 45 GCB, S 13 GCB, S 6 GCB), are about (average 20 %) smaller than the load-carry capacity of hollow beams (O 45 GCB, O 13‘GCB, O 6 GCB), respectively, indicated in Fig. 9 [3].

4.3. Load–deflection behavior and ductility of solid and hollow RC beams

The mid-span deflection results of SGCB and HGCB are shown in Table 6. The test results indicated that for SGCB the maximum mid-span deflection at ultimate load-carry capacity happens when the Space stirrups steel bar (6 mm diameter) equals 60 mm, while the minimum mid-span deflection is at 450 mm, similar to the HGCB.

Table 6. The Mid Span Deflection at First Crack and Load Carry Capacity

Group Name	Beam Designation	Mid Span Deflection at First Crack (mm)	Mid Span Deflection at Ultimate Load (mm)
SGCB	S 45 GCB	0.08	2.07
	S 13 GCB	0.09	2.35
	S 6 GCB	0.1	2.84
HGCB	O 45 GCB	0.09	2.15
	O 13 GCB	0.14	2.73
	O 6 GCB	0.17	3.97

Figures 15 and 16 indicated the load carries capacity-mid-span deflection relationships for the beams (SGCB and HGCB). As indicated in Figures 17–22, the comparison between GCB and normal weight NCB [3].

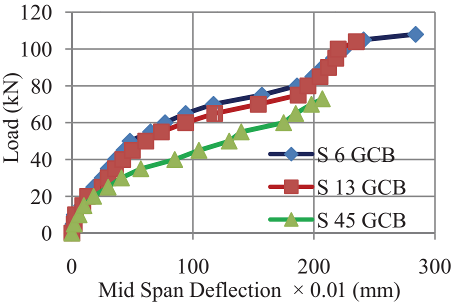


Fig. 15. Load–Deflection Relationships for SGCB (S 6, S 13, S 45)

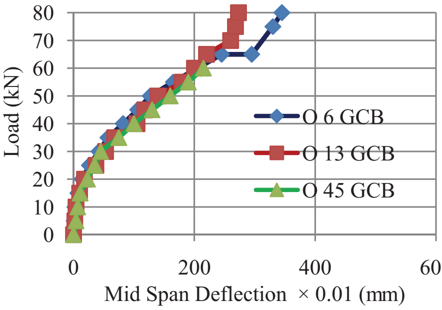


Fig. 16. Load–Deflection Relationships for HGCB (O 6, O 13, O 45)

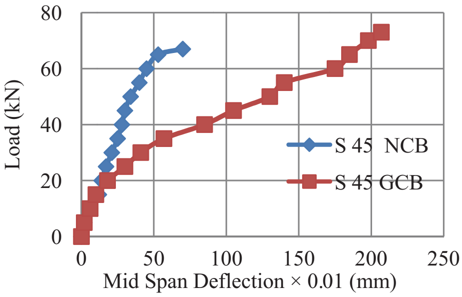


Fig. 17. Load–Deflection Relationships for SGCB and NCB (S 45)

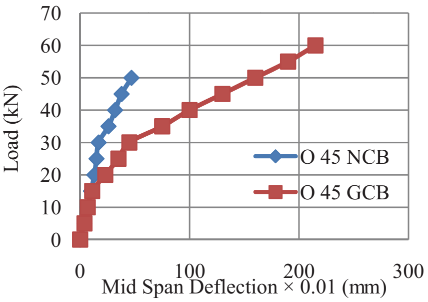


Fig. 18. Load–Deflection Relationships for HGCB and NCB (O 45)

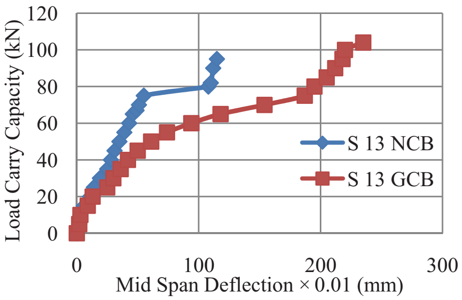


Fig. 19. Load Carry Capacity–Deflection Relationships for SGCB and NCB (S 13)

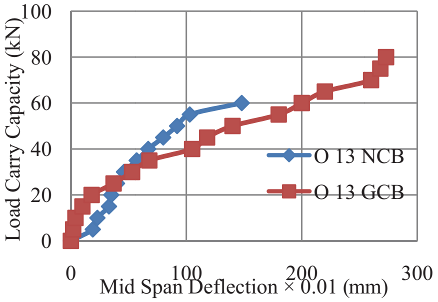


Fig. 20. Load Carry Capacity–Deflection Relationships for HGCB and NCB (O 13)

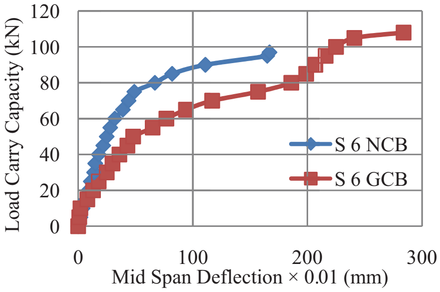


Fig. 21. Load Carry Capacity–Deflection Relationships for SGCB and NCB (S 6)

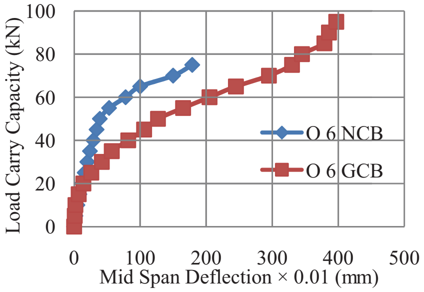


Fig. 22. Load Carry Capacity–Deflection Relationships for HGCB and NCB (O 6)

5. Conclusions

This work indicated the results of an experimental investigation shown on HGCB. A total number of six GCB were prepared and examined under a four-point. The HGCB explains the details of the cracking load beam at an ultimate load-carry capacity of 56, 67, 82 kN and a corresponding deflection of 0.09, 0.14, 0.17 mm. The results also verified that the hollow opening had an insignificant effect on the ultimate load and deflection of HGCB. The HGCB and SGCB maximum mid-span deflection at ultimate load-carry capacity occurs when the space stirrups steel bar is minimum. The space stirrups steel bar (6 mm diameter) reduces the ultimate load-carry capacity for all HGCB and SGCB.

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