AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 3
ISSN: 1998-4456

EXPERIMENTAL INVESTIGATION FOR THE BEHAVIOR OF HOLLOW CORE CONCRETE SLAB REINFORCED WITH HYBRID REINFORCEMENT

Labeeb S. Al-Yassri
University of Al-Qadisiah, Iraq
Email: Labeeb.Husein@qu.edu.iq

Ammar Y. Ali
University of Babylon, Iraq
Email: eng.ammar.yaser@uobabylon.edu.iq

Mohammed M. AL-Khafaji
University of Babylon, Iraq
Email: eng.mohammed.mansour@uobabylon.edu.iq

Received on 27 March 2017 *Accepted on 9 August 2017*

Abstract: *This paper provides an experimental study to investigate the effect of hybrid reinforcement on the behavior of hollow core slab casted with NSC. Experimental results showed that using of hybrid reinforcement (CFRP and steel bars) as internal reinforcement give better results of ductility compared with HCS reinforced with CFRP bars only. On the other hand, using of CFRP bars as an internal reinforcement have slightly effect on the shear strength capacity of hollow core slab. On the other hand, CFRP reinforcement lead to decrease the stiffness of slab at post cracking stage; therefore, deflection will increase at the same load after cracking.*

Keywords: hollow core slab, CFRP bars, hybrid reinforcement, shear strength capacity, cracking load.

1.INTRODUCTION

During the last two decades of the twenty century, the use of FRP forms in construction of R.C structures has been developed and it covers the new construction and rehabilitation of existing structures owing to their superior mechanical properties as mentioned previously. The number of projects utilizing the FRP forms to strengthening the structures around the world was increased as a result for developing of design guidelines and methods. However, in addition to its higher cost, the greater strength of the FRP is inducing fragile behavior at or close to failure. This fragile behavior is not recommended for structures in seismic regions [1]. Some studies which concerned in experimental investigations and in site applications of FRP forms for R.C. structures can be found in various publications [2-3]. Practical applications of FRP rebars were good reviewed in [4].Composite concrete slabs resulting from using concrete of one type of strength (either normal compressive strength concrete NSC or high compressive strength concrete HSC) in addition to reinforcement of type steel, polymer or any other types of FRP (artificial or natural) Fukuyama, 2000 [1].

Codrut. et al., 2010 [5] prepared and test four specimens of PPHCS two of them were strengthened by using CFRP sheet glued at the tension face to increase their flexural capacity. The experimental tests have proven that the failure of the slab was caused by shear efforts, and that the superior flexural capacity gained by strengthening of the slab was not harnessed at all. Nonetheless, the CFRP had an important influence in keeping the cracks from premature opening and further widening.

Nanni et al.1994 [6, 7] conducted a tests on bars of combination of a steel core covered by aramid fiber submerged in an epoxy matrix. Test results showed a bilinear behavior(stress–strain) for this type of hybrid reinforcement. They also noticed that such form of rebar had limited flexibility to the steel distribution within section when they were used in the RC members.

Bakis et al, 1996 [8] concluded that the material with high modulus could be dispersed within the entire area (cross sectional area of composite member) to maximize the bilinear (ductile)behavior. Distribution of material of stiffer rebar will be more uniform in cross section when using two or more types of rebars in that section. Using FRP rebars in over RC sections to increase the ductility appeared to be an attractive solution.

Fiber reinforced polymer FRP has become a practical active material for replacing traditional steel rebar which used as reinforcement construction of R.C. structures [9]. However, the brittle behavior of fiber-reinforced polymer reduces the ductility of FRPR.C. members greatly. So as to improve the flexural ductility of FRP R.C. members, it is proposed that the longitudinal reinforcement should be included on the steel rebars to form a hybrid reinforcement. Therefore, in this investigation studies the effect of CFRP bars on behavior of HCS in different forms of reinforcement.

2.EXPERIMENTAL WORK

Current experimental works include a series of tests conducted on several materials of building construction, control specimens such as (cubes, prisms and cylinders), and the slab specimens. The tested slabs were fabricated from normal strength R.C. The main objective of this paper is to investigate the effect of replacement of traditional steel bars by CFRP bars using different percentage of replacement (0%, 50% and 100%) to reinforcing hollow core model for flexural.

2.1. SPECIMENS DESCRIPTION

The experimental program consisted of testing four reinforced concrete slab models. All tested slabs were one way slabs with same dimensions of length (1200 mm), span (1100 mm c/c of supports), total width (600mm), overall depth (100mm) and clear cover of (20 mm).All hollow core slab tested here have the same cross section details of reinforcement and voiding ratio 26%. All slabs were reinforced with 6 mm deformed steel rebars and/or CFRP rebars in tension zone with tensile reinforcement ration equal to 0.5%. This ratio taken larger than minimum and lower than maximum ratios specified by ACI 318M-11 [10]. Full details of hollow core slabs are given in Table 1 and Figure 1. All specimens of this study was tested under two line loads as shown in Figure 1.

Table 1. Details of Tested Slabs

Sample Code	Description				No.
	Voids Ratio%	Concrete Type	Flexural Reinforcement		
			Steel	CFRP	
$OS.H_{26}.HR_{0}.HC_{0}$	26	NSC	100%	0%	1
$OS.H_{26}.HR_{50}.HC_{0}$	26	NSC	50%	50%	1
$OS.H_{26}.HR_{100}.HC_{0}$	26	NSC	0%	100%	1

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 3
ISSN: 1998-4456

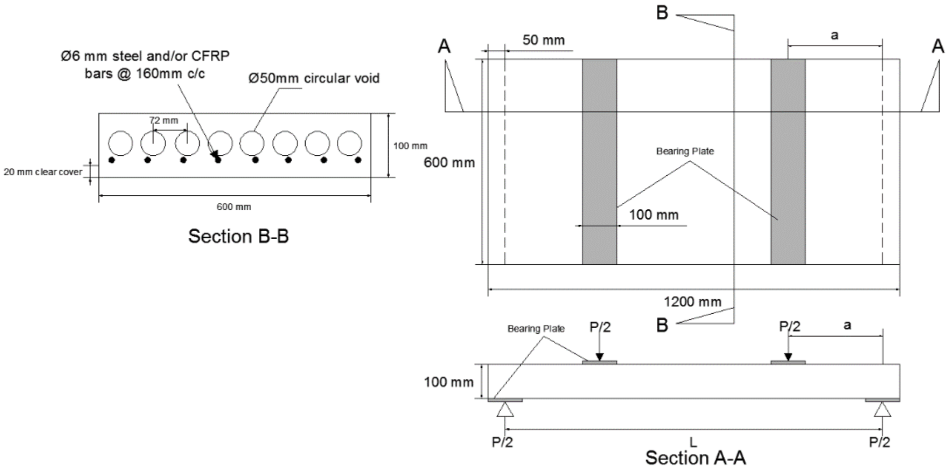

Figure 1. Dimensions Details of Tested Slabs

2.2. MATERAILS

All specimens were produced from using of normal strength concrete NSC. Two types of reinforcing bars were used steel and/or CFRP bars.

2.2.1. Cement

Ordinary Portland cement manufactured in Iraq named Al-Douh was used throughout this investigation. Properties of this cement were agree with the limits of Iraqi Specifications (I.Q.S.5/1984) [11] of Portland cement..

2.2.1. Fine Aggregate

Sand (nature fine aggregate) used in this research were from Al-Ukhaidher region in Iraq. Particles grading of this aggregate obtained from results of laboratory test were agree with the Iraqi (I.Q.S.45/1984) [12] and (ASTM C33) [13] specifications.

2.2.2. Coarse Aggregate

Maximum size of 10 mm for the coarse aggregate were selected to use in this research type crushed to ensure complete filling and consolidation around the holes. It was brought from Al-Nibaey region. The properties of this gravel were agree with the limits of Iraqi Specifications (I.Q.S. 45/1984) [11].

2.2.3. Mixing and Curing Water

Clean tap water of Al-Hilla, Babylon, was used for wishing the aggregates, Mixing and for curing all the specimens.

2.2.4. Steel Bar

Tensile test of steel reinforcement was carried out on (ø 6mm) hot rolled, deformed, mild steel bars employed as tension reinforcement for both, flexure and shear. Table 2 gives the results of tensile test for bar (6 mm).

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 3

ISSN: 1998-4456

Table 2. Physical Properties of Steel Rebar

Weight (Kg/m)	Nominal Diameter (mm)	Measured Diameter (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)
0.229	6	5.91	556	741

2.2.5. CFRP Bars

Carbon fiber reinforced polymer CFRP rebars used in this study to reinforced HCS spesimens. The 6 mm diameter CFRP rebar used here was Aslan 201. The Aslan 201 CFRP rebar physical properties for rebar of nominal diameter 6 mm listed in Table 3. The test results of this type of FRP used here were provided by the manufacturer. Figure 2 illustrate the typical stress strain relation ship for the behavior of CFRP rebars as suggested by Hughes Brothers [14].

Table 3. Physical Properties of CFRP Bar reinforcement

Physical Properties	Result	Limit of ASTM D7205[(105)]
Average Tensile Strength (MPa)	2704	≥ 2068
Average Modulus of Elasticity (GPa)	163	≥ 124
Ultimate Strain	0.017	0.017
Weight (kg/m)	0.0557	-

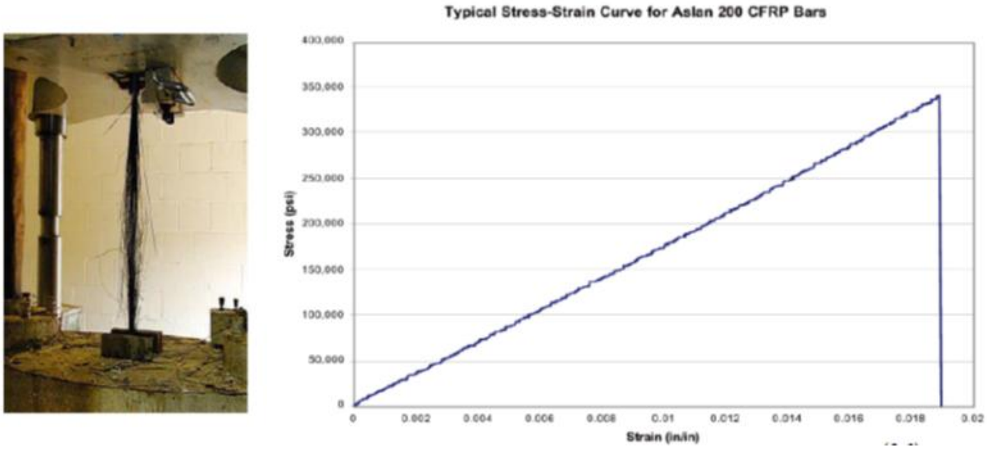

Figure 2. Stress-Strain Curve of CFRP Bars [14]

2.3. MIX PROPORTIONS

Mixture of normal strength concrete used in this study was designed in accordance with British Standard BS 5328 [15] with nominal 28-day target compressive strength of (25MPa). It was found that the selected mixture produced good workability and homogeneous mixing of the concrete without separation. It was found that the selected mixture (Table 4) produced good workability and homogeneous mixing of the concrete without separation.

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 3
ISSN: 1998-4456

Table 4. Trial Mixes for NSC and HSC

Selected Mix Proportions	
Cement (Kg/m^3)	310
Silica fume (Kg/m^3)	N/A
Sand (Kg/m^3)	700
Gravel (Kg/m^3)	1150
SP. (L/m3)	N/A
SBR (L/m3)	N/A
Water (L./m3)	139.5
W/C	0.45
$f'c$ (28 day) MPa	27.11

3. EXPERIMENTAL RESULTS

The experimental results of the tested slabs were compared to study the effect of using hybrid reinforcement concept on the structural behavior of the HCS such as ultimate and cracking loads, ductility, width of crack and the mode of failure.

3.1. CRACKING AND ULTIMATE LOADS AND FAILURE MODE

Table 5 summarizes the experimental results of tested HCS specimens. These results including, first cracking load of flexural and shear cracks and their percentages with respect to the ultimate load, ultimate load and mode of failure of specimens also reported.

3.1.1. Control Specimen $OS.H_{26}.HR_0.HC_0$

This control slab specimen was made from NSC for overall its section that voided by eight cores of diameter 50 mm with about 26% voiding ratio, which regard as reference (control) specimen for comparison with other specimens. The first visible crack observed within maximum moment region of the tension face of slab (flexural cracks) at lower load of (21 kN) (i.e. 26.7% of ultimate load). The first visible diagonal shear cracks appeared at (35 kN) (i.e. 44.5 % of ultimate load) within shear span. More flexural cracks and shear flexural cracks formed later at constant moment region with increasing of applied load and the inclined cracks became wider and propagate rapidly. With increasing of load, major diagonal shear crack opened more and sudden flexural diagonal shear failure occur at load of about (78.7 kN) as shown in Plate 1. Figure 3 illustrates load deflection response for this control HCS.

Vol. 10 , No. 3
ISSN: 1998-4456

Plate 1. Mode of Failure and Cracks Pattern of Specimen OS.H26.HR0.HC0

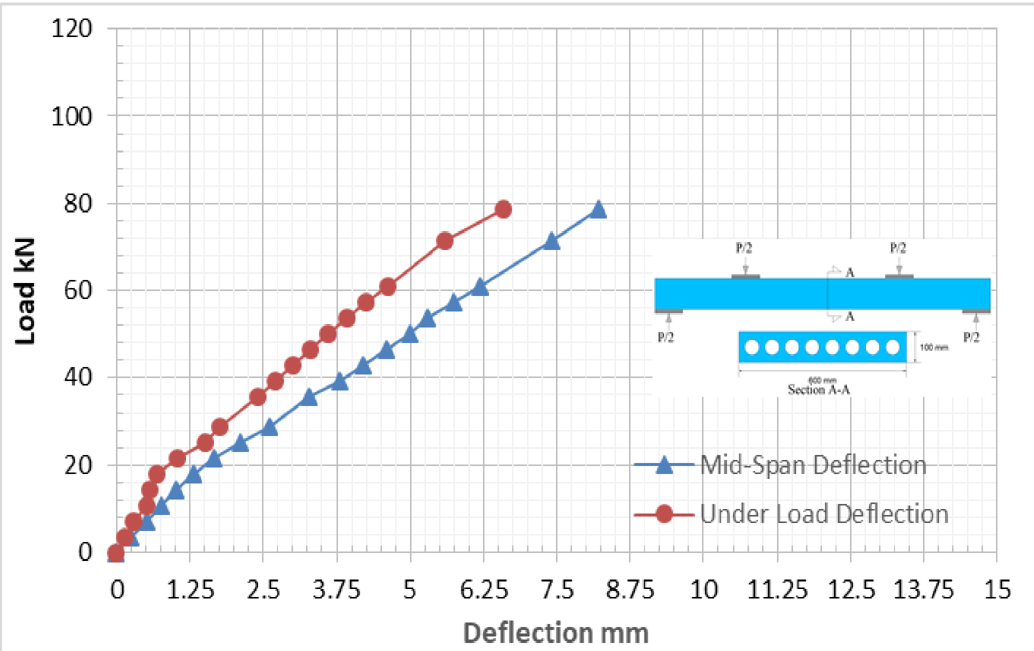

Figure 3. Load Deflection Response of OS.H26.HR0.HC0 Specimen

3.1.2. Specimen OS.H26.HR50.HC0

This slab specimen was fabricated with normal strength concrete and reinforced with hybrid reinforcement (50% CFRP bars and 50% steel bars) as mentioned in previous chapter. During the testing procedure of this specimen, first visible crack were observed at load (21.5) (26.2% of ultimate load) at the tension face of slab within constant moment region. Several cracks were formed with increasing of applied loading. Diagonal cracks were observed within shear span region at load about (36 kN). Major diagonal crack propagated rapidly with advance stages of loading until shear failure occur at load (82 kN) as shown in Plate 2. Figure 4 illustrates load deflection response of this slab specimen.

Plate 2. Mode of Failure and Cracks Pattern of Specimen OS.H26.HR50.HC0

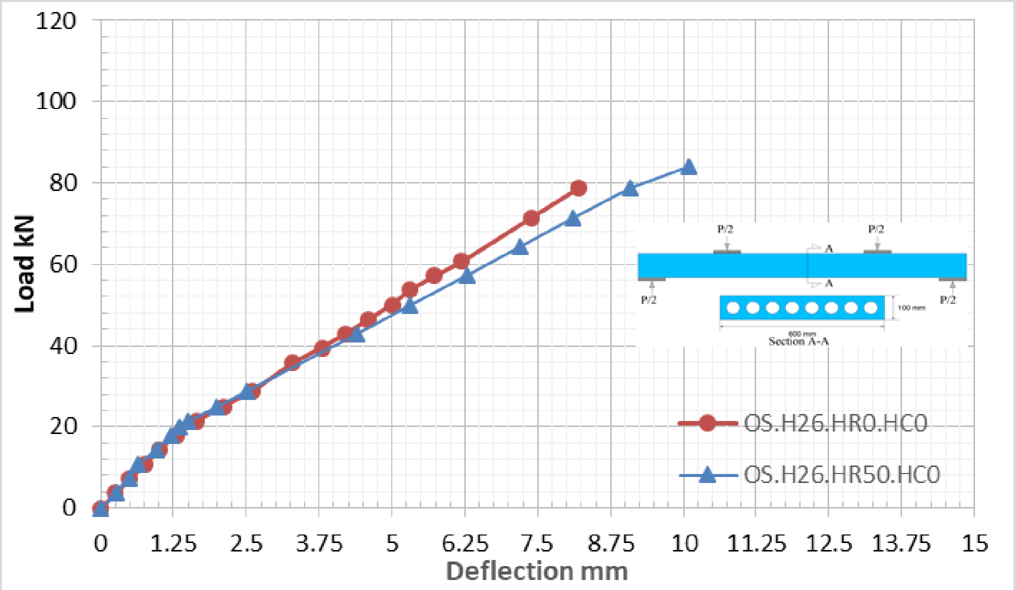

Figure 4. Load Deflection Response of OS.H26.HR50.HC0 Specimen

3.1.3. Specimen OS.H26.HR100.HC0

Load deflection curve and cracks pattern of this specimen are shown in Figure 5 and Plate 3 that fabricated with normal strength concrete and reinforced by CFRP bars. At first, early crack initiated at tension face of slab within the constant moment region at load about (20 kN) (24.1% of ultimate load). Comparing with control (OS.H26.HR0.HC0) specimen, cracking load decreased by small percentage about 4.7% which can be neglected. Hence, it is obvious that the cracking load mainly depending on the moment of gross sectional area of concrete (uncracked section) about centroidal axis. As the load increased, several cracks formed within region of max constant moment also flexural shear and shear cracks within shear span observed at load (45 kN). Depth of some of these cracks were increased gradually and tended to incline towards the points of loading. Finally, failure of specimen took place when the major diagonal crack suddenly opened over the entire of the slab depth within shear span at load (82.94 kN) as shown in Plate 3. From Figure 5, it can be noticed that the use of CFRP bars as a flexural reinforcement lead to decrease stiffness by increase the deflection at all stages of loading.

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 3
ISSN: 1998-4456

Plate 3. Mode of Failure and Cracks Pattern of Specimen OS.H26.HR100.HC0

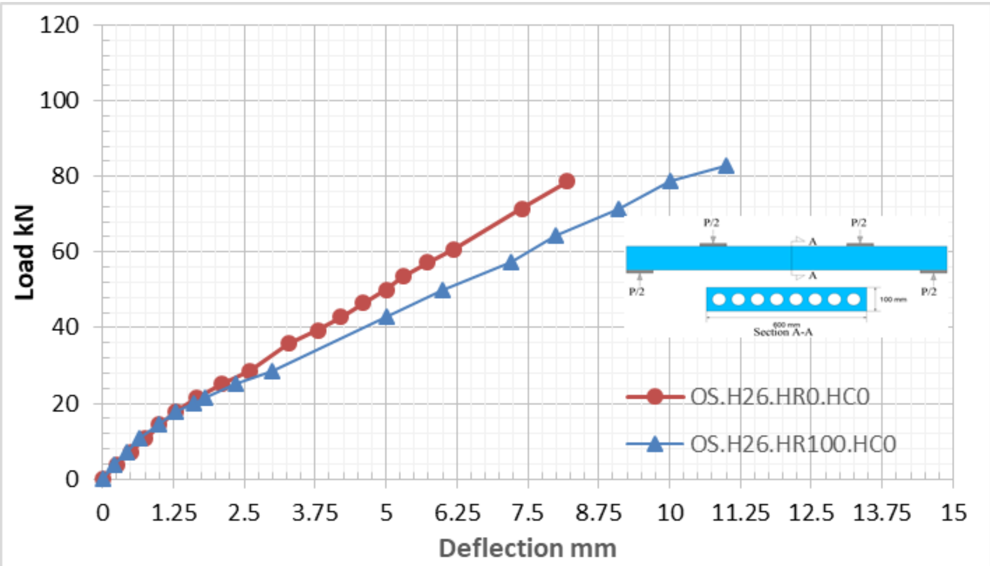

Figure 5. Load Deflection Response of OS.H26.HR100.HC0 Specimen

From Figure 6 load deflection responses of specimen of this test group and when comparing these responses a clear difference in shape of their load–Deflection responses is observed. It is obvious that the use of CFRP bars resulted in reducing stiffness of slab by increasing central deflection under the same moment. As expected theoretically, for same level loading, specimen (OS.H26.HR50.HC0) yields a midspan Deflection much lower than that for the specimen (OS.H26.HR100.HC0) but larger than slab (OS.H26.HR0.HC0). In fact, these differences in value of Deflection at the mid span between specimens can attributed to the difference in the flexural stiffness (Ec Ie, where Ec is the elastic modulus for concrete, kN/mm2, Ie is effective moment area for the section of slab, mm4). For a cracked section, the stiffness is proportional to ErArd2 [59], where Ar and Er are elastic modulus and cross-sectional area for the reinforcement respectively, while, d is distance from extremely fiber in compression to the tension reinforcement centroid). Therefore, the results of tests confirm activity of the steel reinforcement about improvement significantly both the ductility and stiffness of hybrid FRPR.C. slabs with respect to those pure FRPR.C. slabs. Nevertheless, the final failure still brittle failure with slightly increasing in shear capacity of HCS section.

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 3
ISSN: 1998-4456

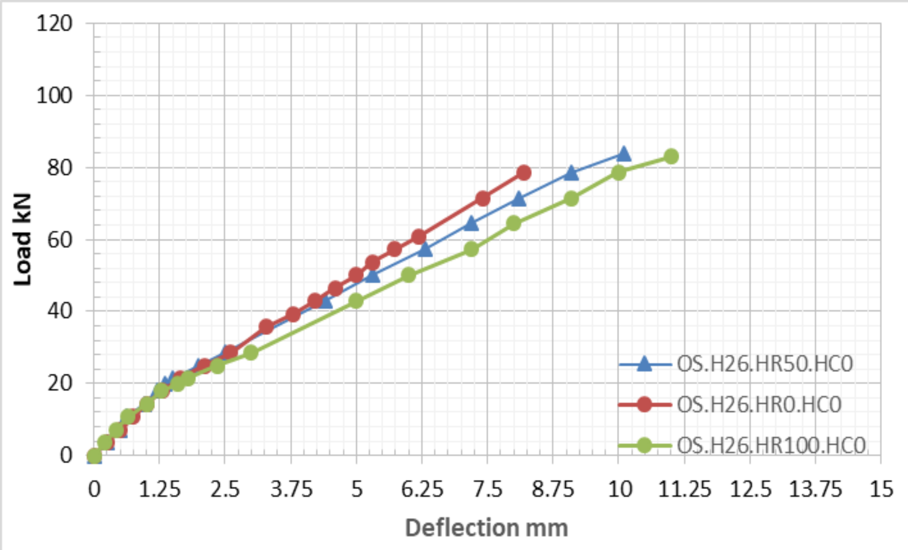

Figure 6. Load-Deflection Curves of (OS.H26.HR0.HC0, OS.H26.HR50.HC0 and OS.H26.HR100.HC0) Specimens

3.2. DUCTILITY

Ductility is usually well defined as the energy that absorbed by the materials up to the failure has been completed [16]. In the current study, ductility factors are evaluated according to the vertical disp. at ultimate load divided by vertical disp. at the service load [17]. As listed in Table 6, it can be noticed that for specimens (OS.H26.HR0.HC25,OS.H26.HR0.HC50 and OS.H26.HR0.HC75), ductility was increased by 25%, 31.25% and 60% respectively comparing with OS.H26.HR0.HC0, this increasing in ductility is due to the increasing in ultimate load capacity resulted from the hybridization in strength of concrete that led to increasing ultimate deflection.

4. CONCLUSIONS

Based on the experimental study carried out here for simply supported one way hollow core slabs, the following conclusions can be drawn within scope of this research:

1. Using of CFRP bars as an internal reinforcement have slightly effect on the shear strength capacity of hollow core slab. On the other hand, CFRP reinforcement lead to decrease the stiffness of slab at post cracking stage; therefore, deflection will increase at the same load after cracking.
2. Using of hybrid reinforcement (CFRP and steel bars) as internal reinforcement give better results of ductility compared with HCS reinforced with CFRP bars only.
3. Using of hybrid reinforcement (CFRP and steel bars) as internal reinforcement have slightly effect on shear strength capacity (increasing it by about 4.5%).

5. REFERENCES

1. **Hawkins N.M., Ghosh S.K., 2006** "*Shear strength of hollow-core slabs*", PCI Journal:110–114.
2. **Hollaway, L.,** "*Glass reinforced plastics in construction: engineering aspects*", John Wiley & Sons; 1978.

3. **Peece, M., Manfredi, G. and Cosenza, E.,** "*Experimental response and code models of GFRP RC beams in bending*" J Compos Constr, ASCE 2000; 4(4):182–90.
4. **Rizkalla, S.H. and Nanni, A.,** "*Field applications of FRP reinforcement: case studies*", American Concrete Institute (ACI) special publication SP-215; 2003
5. **Codrut, F.S., Tamas, N. G., Valeriu, S., Dan, D.** "*Strengthening of hollow core precast slabs using FRP composite materials – procedure, testing and rating*" Proceedings of the 11th WSEAS International Conference on Sustainability in Science Engineering, pp. 496-501
6. **Nanni, A., Henneke. M.J and Okamoto, T.,** "*Tensile properties of hybrid rods for concrete reinforcement*", Constr Build Mater 1994;8(1):27–34.
7. **Nanni, A., Henneke, M.J and Okamoto, T.,** "*Behavior of concrete beams with hybrid reinforcement*", Constr Build Mater 1994; 8(2):89–95.
8. **Bakis, C.E., Nanni, A. and Terosky, J.A.,** "*Smart, pseudo-ductile reinforcing rods for concrete: manufacture and test",* In: Saadatmanesh H, Ehsani MR, editors. Proceeding of first international conference on composite in infrastructure. Tucson (Arizona): University of Arizona; 1996, p. 95–108.
9. **Lau, D. and Pam, H., J.,** "*Experimental study of hybrid FRP reinforced concrete beams*", ELSEVIER, Engineering Structures 32 (2010) 3857–3865
10. **ACI-318-11, ACI- Committee,** "*Building Code Requirements for Structural Concrete*",ACI-318M-14.and.commentary ACI-318M-14, American Concrete Institute.
11. **Iraqi Specification Standards IQS No. 5, 1984** "*Portland Cement*", Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ
12. **Iraqi Specification Standards IQS No.45, 1984** "*Aggregate from Natural Sources for Concrete and Construction*", Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ
13. **ASTM C33-13** "*Standard Specification for Concrete Aggregates*", American Society for Testing and Materials, 2013
14. **Hughes Brothers, Inc., 2010** "*Carbon Fiber Reinforced Polymer (CFRP) Rebar Aslan 200/201*", Technical Data Sheet.
15. **British Standard Institution (1997),** "*Concrete. Methods for specifying concrete mixes*", BS 5328-2
16. **Hussain, M., Alfarabi, S., Basunbul A., Baluch M.H., Al-Sulaimani G.J.,** "*Flexural Behavior of Precracked Reinforced Concrete Beams Strengthened Externally by Steel Plates*" ACI Structural Journal, Vol.92, Issue.1, 1995.
17. **Jeffrey S. Russell "***Prestrectives in Civil Engineering*", Commemorating the 150th Anniversary of the American Society of Civil Engineering, ASCE Publications, 2003. p.375.