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

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Abstract: *This paper presents an experimental study to investigate the effect of hybrid strength concrete (two types of concrete, 25 MPa and 70 MPa) on the behavior of one-way hollow core concrete slab ordinary reinforced with steel rebars. The hybrid HCSs showed an enhancement in shear strength capacity, cracking load and ductility as compared with to HCS with normal strength concrete (25 MPa). The increase in shear strength capacity and cracking load were about (16%) and (29%) respectively higher than normal strength hollow core slab. Also, from experimental results, the crack width of hybrid HCS was narrower than that for normal strength slab at all stages of loading. At service load stage, the width of crack was narrower than normal strength slab by about (10-31%). The failure mode still brittle diagonal shear failure.*

Symbols:

HCS: Hollow Core Slab

NSC: Normal Strength Concrete

HSC: High Strength Concrete

HYSC: Hybrid Strength Concrete.

Keywords: hollow core slab, hybrid strength, shear strength capacity, cracking load, mode of failure.

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1. INTRODUCTION

Hybrid reinforced concrete slabs", it is a term usually referrers to one of the following types of reinforced concrete slabs:

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].

The hybrid concrete term is applied for repairing purposes stemming from casting a new layer of concrete on an old layer (using one or two different types of concrete) Kawamata, 2003 [2].

In this study, the term ‘‘Hybrid Strength Concrete (HYSC) slabs’’ refers to a new principal concept of casting two different concrete types, normal strength concrete (NSC) with high strength concrete (HSC) simultaneously in the same concrete slab.

Normal strength concrete is cast in the tension zone (lower layer) and the HSC is cast in the compression zone (upper layer). Such technique can be used to produce precast simply supported slabs subjected to positive bending moments, in order to decrease the cost of the slabs, as the role of concrete in the tension zone is mainly limited to fixing the steel reinforcement and protecting it from corrosion. Casting operation of HYSC slabs requires more careful techniques, and casting of the two layers must be carried out while the two types of concrete are still in their fresh condition, to insure full bond between the two layers of concrete.

Kheder et al, 2010 [3] investigated the ultimate load capacity and flexural cracking behavior of HYSC beams and compare them with similar NSC and HSC beams, also to check the compatibility of using two types of concrete in the same beam. They were noticed that ultimate load carrying capacity of the HYSC beams were considerably higher than NSC beams and only slightly lower than corresponding HSC beams. Also, he found that the using of HYSC beams with concrete of strength 70 MPa casted in the compression zone of the tested beam sections permitted the increase of the balanced steel ratio of the beam to be similar to that of the high strength concrete used (70 MPa). Implementing the HYSC beams concept resulted in an average reduction in crack widths at service and ultimate load levels in these beams by 19.5 and 26.0% compared with NSC beams and a reduction of 9.2 and 15.1% compared to HSC beams.

Pisanty, 1992 [4] was investigated experimentally and analytically the shear strength of extruded PPHCS and study the accurate of assessment of shear strength estimated by ACI-code [5] and FIP recommendation [6]. Ten slab specimens have been tested, all failing in the shear mode (six in shear tension mode). The analysis explores ways of employing existing procedures for predicting the shear capacity. It was concluded that modification of the FIP recommendations would lead to a better approximation of the test results.

The major aim of this study is to investigate the shear strength capacity, flexural cracking behavior and ductility of HYSC hollow core slabs and compare them with similar normal strength concrete slab, and also to check the compatibility of using two types of concrete in the same slab, for the reason that these types of concrete (normal strength and high strength) have different properties at elastic stage and also have different cracking behavior. The investigation of formation of flexural crack behavior in concrete with increasing load is necessary for a appropriate design of concrete structures [7]. Traditional steel rebar is provided to carry tensile stresses in a slab due to applied load.

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. or from hybrid R.C. (i.e., placement of different types of

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concrete (NSC and HSC) in the same section). Three percentages of replacement were used here (25, 50 and 75 % by casting a layer of HSC in the compression zone of slab of thickness 25, 50 and 75 mm respectively).

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 rebars in tension zone with tensile steel ration equal to 0.5%. This ratio taken larger than minimum and lower than maximum ratios specified by ACI 318M-11 [5]. 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	Thickness of HSC layer mm	
$OS.H_{26}.HR_{0}.HC_{0}$	26	NSC	Steel	0	1
$OS.H_{26}.HR_{0}.HC_{25}$	26	NSC HSC	Steel	25	1
$OS.H_{26}.HR_{0}.HC_{50}$	26	NSC HSC	Steel	50	1
$OS.H_{26}.HR_{0}.HC_{75}$	26	NSC HSC	Steel	75	1

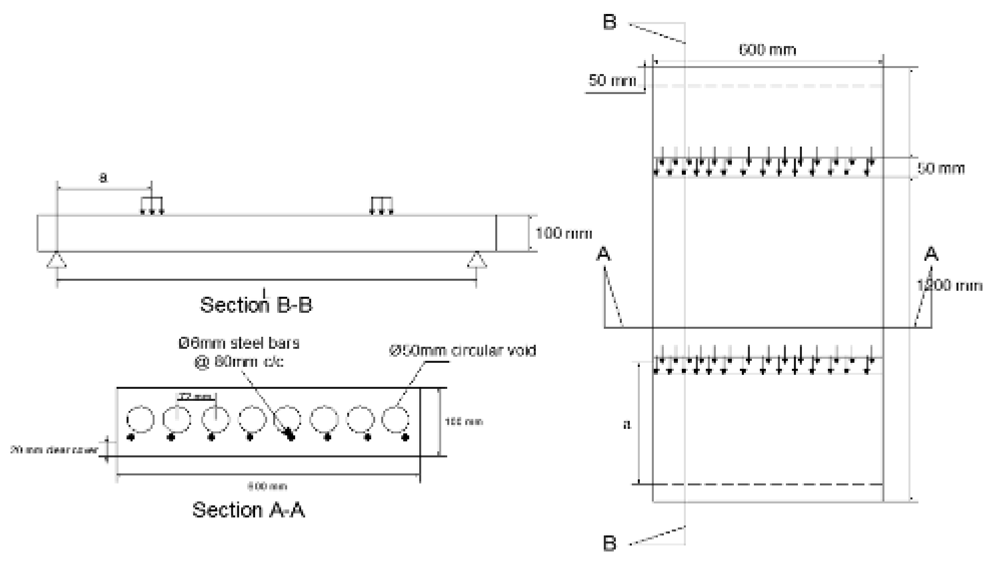

Figure 1 Dimensions Details of Tested Slabs

2.2. MATERIALS

Hybrid concrete was produced from using of both normal and high strength concrete materials. The HYSC HCS shear strength capacity depends primarily on the properties of high strength concrete used in the compression zone of the slab. The production of HSC that consistently meets requirements for workability and strength development places requirements that are more stringent on the selection of materials than for normal strength concretes. Super plasticizers are used to achieve a low (W/C) ratio. The following is a general explanation of the used materials

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) [8] 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) [9] and (ASTM C33) [10] 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. SILICA FUME (MINERAL ADMIXTURE)

Microsilica fume (SF) one of production of Sika Company in U.A.E under commercial name (Sika® Fume S 92 D).

2.2.4. SUPERPLASTICIZER

Superplasticizer based on modified polycarboxylic ether used throughout this work was "Glenium 54" with nominal dosage of (2.5-0.5 liter per 100kg of cement) as recommended by the manufacturer. The material is classified as type (A) and (F) in ASTM-C494 (94) [11].

2.2.5. ULTRA-BOND (SBR)

Is an aqueous dispersion of Styrene Butadiene Copolymer when mixed with cementitious products giving high performance water resistant properties. SBR always using in concrete to improves workability, strength and abrasion resistance, adhesion and bonding and allows reduction in water content.

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2.2.6. MIXING AND CURING WATER

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

2.2.7. 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).

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

2.3. MIX PROPORTIONS

Mixture of normal and high strength concrete used in this study was designed in accordance with British Standard BS 5328 [12]. Nominal 28-day target compressive strength for NSC was (25MPa). It was found that the selected mixture (Table 3) produced good workability and homogeneous mixing of the concrete without separation.

Table 3 Trial Mixes for NSC and HSC

	NSC	HSC				
Mix No.	1	1	2	3	4 (Selected)	5
Cement (Kg/m^3)	310	450	460	525	535	550
Silica fume (Kg/m^3)	N/A	45	40.5	42	43	40
Sand (Kg/m^3)	700	680	675	720	700	705
Gravel (Kg/m^3)	1150	1020	1000	1000	1050	1050
SP. (Lt./m3)	N/A	4	5	5.25	5.30	5.5
SBR (Lt/m3)	N/A	6	8	9	9.3	8
Water (Lt./m3)	139.5	142.5	135.5	170	164	163
W/C	0.45	0.3	0.27	0.3	0.28	0.29
$f'c$ (28 day) MPa	27.11	45.28	43.47	58.11	69.54	82.9

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The employed chemical admixtures (super plasticizer), low ratio of water-cement and high content of cement make the design of the mixture of HSC a more critical process with respect to the design of NSC mixtures [12]. Thus, several trial mixtures have been carried out through the earlier stages of this work. The control samples taken from these mixtures were tested at (7, 14 and28 days). From the experimental mixture experiments, it was found that the mixing proportions given in Table 3 were good enough to provide sufficient strength and workability. Using of super plasticizer gives enough time for mixing and permits to produce homogenous mixing of concrete and prevent segregation. The selected HSC mix gives an average compressive strength of (69.54MPa) at (28 days).

3. EXPERIMENTAL RESULTS

The experimental results of the tested slabs (NSC, and HYSC slabs) were compared to study the effect of using hybrid concrete 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 4 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.

Table 4 Test Results of the Tested Slabs

No.	Slab Designation	R*	Pcr (kN) (Flexura)	Pcr (kN) (Shear)	Pu (kN)	Pcr/Pu % (Flexural)	Pcr/Pu% (Shear)	Mode of Failure
1	OS.H26.HR0.HC0	---	21	35	78.7	26.7	44.5	Diagonal flexural-shear
2	OS.H26.HR0.HC25	1	23	43	74.36	30.9	57.82	Diagonal flexural-shear
3	OS.H26.HR0.HC50	1	26.5	44	90.3	29.3	48.72	Diagonal flexural-shear
4	OS.H26.HR0.HC75	1	27	44.6	91.8	29.4	48.58	Diagonal flexural-shear

CONTROL SPECIMEN OS.H26.HR0.HC0

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 is regarded as reference (control) specimen for

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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 propagated rapidly. With increasing of load, major diagonal shear crack opened more and sudden flexural diagonal shear failure occurred at load of about (78.7 kN) as shown in Plate 1. Figure 2 illustrates load deflection response for this control HCS.

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

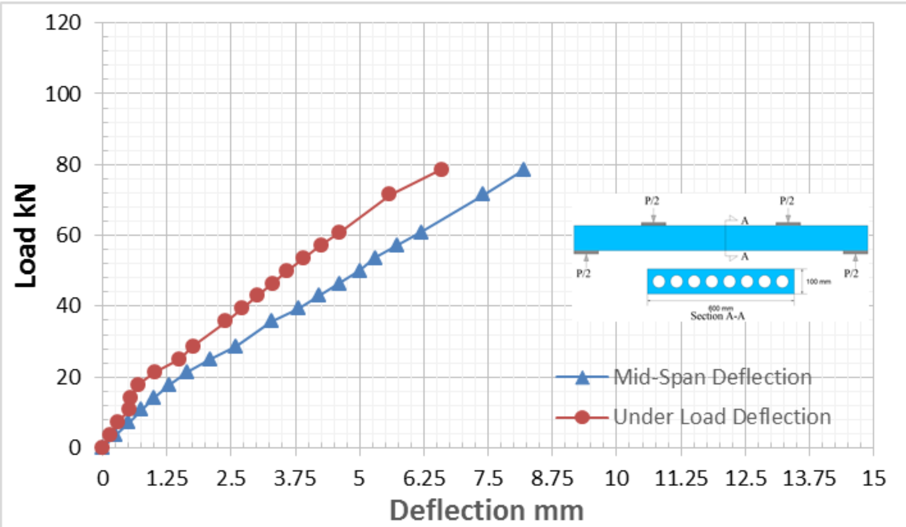

Figure 2 Load Deflection Response of OS.H26.HR0.HC0 Specimen

SPECIMEN OS.H26.HR0.HC25

This slab specimen was fabricated from HYSC by casting layer of HSC of 25 mm thickness in compression zone monolithically over layer of NSC of 75 mm thickness in tension zone. Traditional steel bars was used to reinforce this specimen in tension zone. The first visible crack was formed at relatively high load of (23 kN) (30.9% of ultimate load) at the tension face of slab within the constant moment region. With respect to control specimen (OS.H26.HR0.HC0), cracking load increased by about 9% due to the increasing in compressive strength of concrete that led to increasing uncracked moment area despite that the tension

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zone of slab were cast with NSC. Later more cracks were generated at the region of max constant moment as shown in Plate 2. Diagonal shear crack observed within shear span at load about (43 kN) With increasing of load, major diagonal shear crack opened more until sudden bond splitting failure between two layers of different concrete type were occur at load of (74.36 kN). Figure 3 illustrates load deflection responses of (OS.H26.HR0.HC25) specimen. It's clearly that the hybridization in strength of concrete led to increase the post-cracking stiffness of specimen.

Plate 2 Mode of Failure and Cracks Pattern of Specimen OS.H26.HR0.HC25

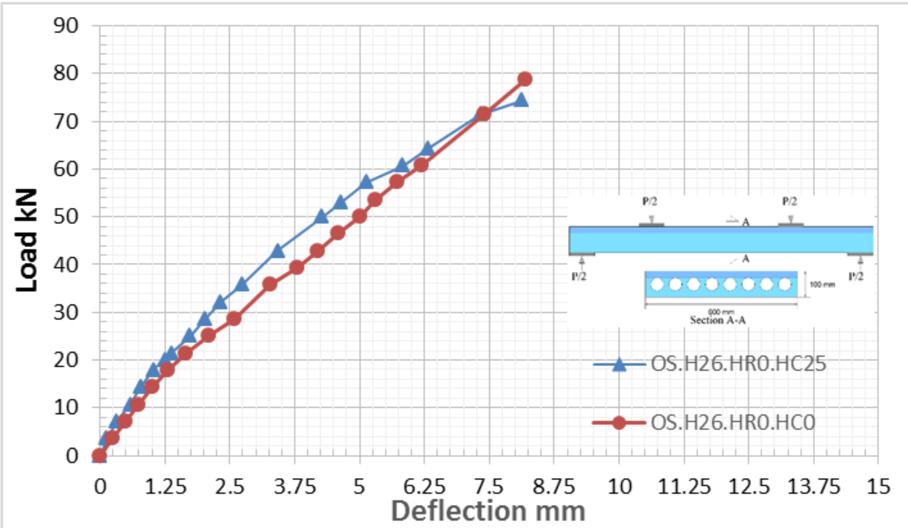

Figure 3 Load Deflection Response of OS.H26.HR0.HC25 Specimen

SPECIMEN OS.H26.HR0.HC50

This slab specimen was made from hybrid strength concrete by casting layer of HSC of 50 mm thickness in compression zone monolithically over layer of NSC of 50 mm thickness in tension zone. Traditional steel bars was used to reinforce this specimen in tension zone. First visible crack was observed at load about (26.5 kN) (29.3 % of ultimate load) in the maximum moment region. Compared with the control (OS.H26.HR0.HC0) specimen and (OS.H26.HR0.HC25) specimen, cracking load was higher by about 26.5% and 15.2% respectively. This increasing is due to the increase in the moment area (uncracked

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moment of inertia) of section due to the increasing of the compressive strength of the compression zone. With increasing of load, cracks of flexural shear expanded to the shear span. Some of these cracks depth was increased gradually and tended to incline towards the points of loading. With increasing of applied load, major diagonal shear crack was opening up over the entire width of slab until the final shear failure was took place at (90.3 kN) as shown in Plate 3 larger than the control (OS.H26.HR0.HC0) specimen by about 14.74%. The increase in ultimate load is due to the change in the internal couple lever arm. Figure 4 illustrates load deflection curve for this specimen.

Plate 3 Mode of Failure and Cracks Pattern of Specimen OS.H26.HR0.HC50

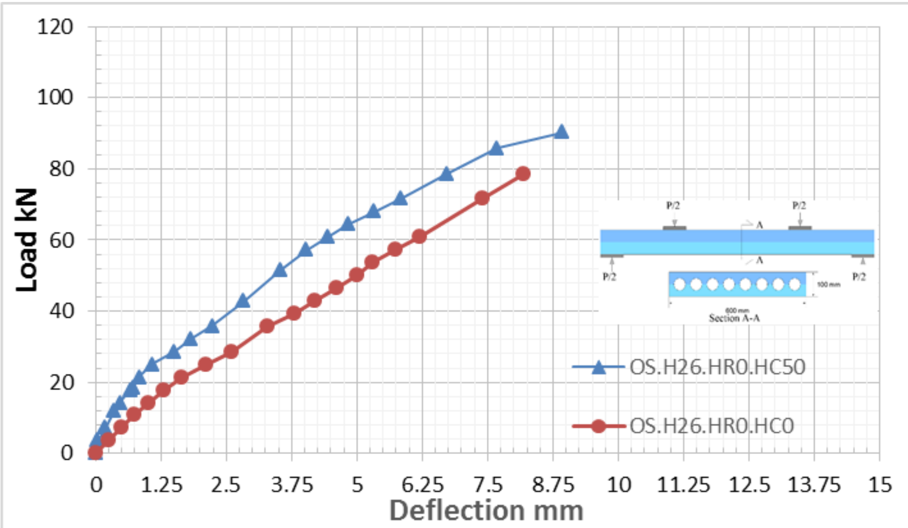

Figure 4 Load Deflection Response of OS.H26.HR0.HC50 Specimen

SPECIMEN OS.H26.HR0.HC75

Same as other specimens this test group, OS.H26.HR0.HC75 specimen was made from hybrid strength concrete by casting layer of HSC of 75 mm thickness in compression zone monolithically over layer of NSC of 25 mm thickness in tension zone. Traditional steel bars was used to reinforce this specimen in tension zone. First visible crack was flexural cracks observed at significantly higher load of about (27 kN)

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(29.4% from ultimate load) at the tension face within constant moment region. Comparing with reference OS.H26.HR0.HC0 specimen, first cracking load was higher by 28.6%. Subsequent increasing in applied load led to formation of several flexural and flexural shear cracks and the constant moment region become heavily with cracks as shown in Plate 4. With advance stages of loading, main flexural shear crack opening up and propagate rapidly until flexural shear failure was occur at load of (91.8 kN) which consider more ductile failure with respect to reference slab OS.H26.HR0.HC0. Figure 5 illustrate load deflection response of this specimen.

Plate 4 Mode of Failure and Cracks Pattern of Specimen OS.H26.HR0.HC75

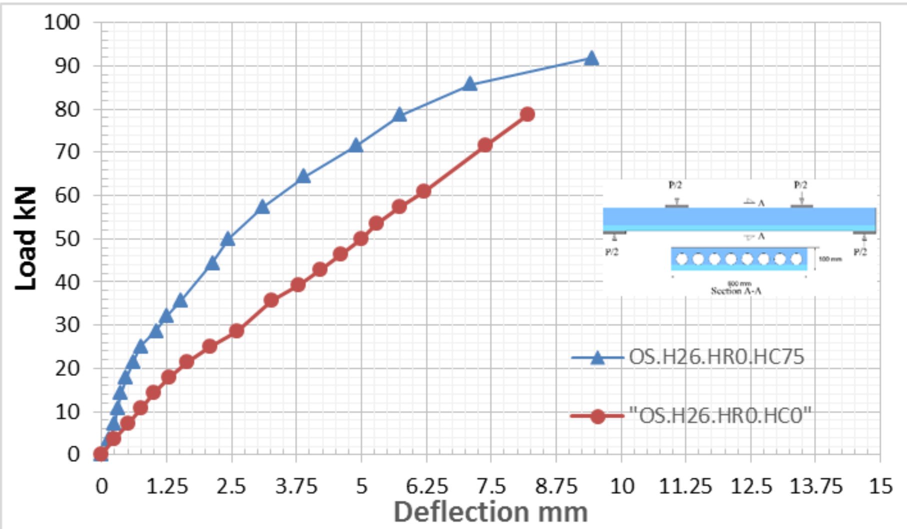

Figure 5 Load Deflection Response of OS.H26.HR0.HC75 Specimen

From Figure 6, it can be noticed that the stiffness of specimen increased when the concrete compressive strength of compression zone increased also with increasing the depth of HSC in compression zone (ratio of hybridization). This behavior attributed to the flexural rigidities of hybrid strength concrete (HYSC) slabs are higher than NSC slabs, these slabs exhibit smaller curvature and deflection and therefore narrower cracks. As illustrated in plates (1, 2, 3 and 4), crack spacing of HYSC slabs were found to be larger than NSC slabs because the difference in elastic properties of the two types of concrete. First cracking load of HYSC slabs were significantly higher than NSC slab ranged between (9%-28.6%) due to the significantly increasing in uncracked moment of inertia. Also, the ultimate load carrying capacity of the HYSC slabs were significantly higher than NSC slabs by 14.75% and 16.7% for OS.H26.HR0.HC50 and OS.H26.HR0.HC75 slab specimens respectively and slightly lower than NSC by 5% for OS.H26.HR0.HC25 because of the splitting bond failure between the two layers of HSC and NSC. However, the precocious shear failure prohibited the slab specimens from attaining their ultimate flexure strength because the holes make section weaker in shear.

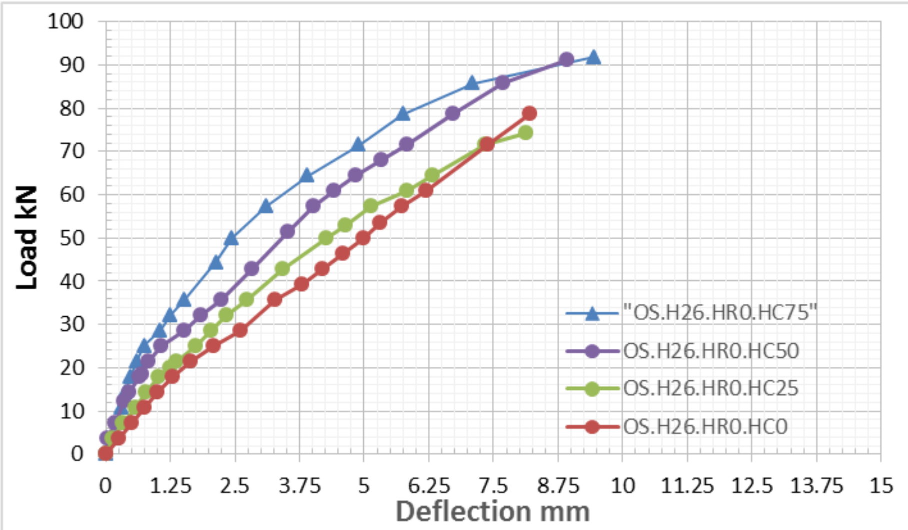

Figure 6 Load Deflection Response of OS.H26.HR0.HC75 Specimen

3.2. DUCTILITY

Ductility is usually welldefined as the energy that absorbed by the materials up to the failure has been completed [13]. In the current study, ductility factors are evaluated according to the vertical disp. at ultimate load divided by vertical disp. at the service load [14]. 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. Presence of high strength concrete layer in the compression zone and its ability to sustain high compressive force in general, lead to increase the stiffness of slab, the cracking load and load carrying capacity, while the deflection decreases at the same load. This behavior may be attributed to increasing of un-cracked moment of inertia and the internal lever arm.

2. For one-way HCS group. cracking load and ultimate shear strength are increased about (26%-29%) and (16%-17%) respectively for tested slab with 50 mm and 75 mm thickness of HSC top layer respectively. These smaller increases in ultimate load may be attributed to remaining the tension zone of slab constructed with NSC.

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3. The best results of hybrid strength system for one way slab group were obtained from slab with 50 mm thickness of HSC top layer. From experimental results mentioned in chapter four, it can be noticed there is a slight difference in the ultimate shear strength between this model and the other constructed with 75 mm thickness of HSC top layer, therefore, this model regard a best hybrid strength model with respect to structural and economical purposes.

4. The tested specimens constructed with hybrid strength concrete exhibited an increase in ductility between (25%-60%).

5- REFERENCES

1. **Fukuyama H., Matsuzaki Y., Sato M. and Suwada H.**, "*Structural performance of engineered cementitions composite elements*", Proceedings of 6th ASCCS conference, ASCCS-6 Secretariat, March 2000, pp 969–976

2. **Kawamata A., Mihashi H. and Fukuyama H.**, "*Properties of hybrid fiber reinforcement cement-based composites*", Journal of Advanced Concrete Technology, Vol. 1 (2003) No. 3 P 283-290, Japan

3. **Kheder, G. F., Al Kafaji, J. M. and Dhiab, R. M.**, "*Flexural strength and cracking behavior of hybrid strength concrete beams*", Materials and Structures Journal, 2010, Vol. 43: 1097-1111, DOI 10.1617/s11527-009-9569-9

4. 30. **Pisanty, A**., 1992 "*The shear strength of extruded hollow-core slabs*", Materials and Structures, 25: 224-230

5. **ACI-318-11, ACI- Committee**, "*Building Code Requirements for Structural Concrete*",ACI-318M-14.and.commentary ACI-318M-14, American Concrete Institute.

6. **FIP Recommendations**, "*Precast Prestressed Hollow Core Floors*", FIP, 1988

7. **Mansor AAH** (2001) *Flexural cracks in high-strength reinforced concrete beams*. MSc thesis, Al-Mastansiriya University, College of Engineering, March 2001, p 111

8. **Iraqi Specification Standards IQS** No. 5, 1984 "*Portland Cement*", Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ

9. **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

10. **ASTM C33-13** "*Standard Specification for Concrete Aggregates*", American Society for Testing and Materials, 2013

11. **ASTM C 494/C 494M-05**, 2005 "*Standard Specification for Chemical Admixtures for Concrete*", Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04. 02.

12. **British Standard Institution** (1997), "*Concrete. Methods for specifying concrete mixes*", BS 5328-2

13. **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.

14. **Jeffrey S. Russell** "*Prestrectives in Civil Engineering*", Commemorating the 150th Anniversary of the American Society of Civil Engineering, ASCE Publications, 2003. p.375.