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Investigating the Effect of Concrete Strength on the Behaviour of Composite Steel-concrete Beams

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Abstract: The present study investigates the effects of increasing the compressive strength of concrete deck on the deflection at midspan and slip at ends of steel-concrete composite beam. In the present study, four groups of steel concrete composite beam were tested to investigate the effects of variation of concrete compressive strength on the deflection, slip, yield strength and ultimate strength of composite beam, using concrete cylinder compressive strength of 21, 42 and 64 MPa. The study also investigated the effect of adding steel fibers to concrete deck on deflection and slip of steel-concrete composite beam. The experimental results obtained are compared with the theoretical ultimate strength calculated using the AISC-LRFD specifications. The results show that increasing compressive strength would enhance the overall behavior of the beam by decreasing deflection and slip to certain limits.

Key words: High strength concrete, high performance concrete, fiber, composite, compressive strength

INTRODUCTION

Recently, research works and utilization of high concrete strength have increased tremendously. The High Strength Concrete (HSC) is a relatively new product and its characteristics differ from that of normal strength concrete which is usually produced by using conventional mixing proportions or additives. The requirements are mainly related to the concrete characteristics especially the compressive strength. Using such type of concrete would also enhance the mechanical properties of concrete such as tensile strength and enhanced modulus of elasticity. However, high strength concrete offer an opportunity for gaining better structures by providing a specific performance advantages in comparison with the normal concrete. Whereas, high strength concrete is stronger and more durable than normal concrete and as a result, high strength concrete structures potentially cost less to build and maintain. While research laboratories are still exploring ways to exploit such type of concrete, the use of high strength concrete in composite beams are rarely investigated (Zain *et al*., 2002).

The results of a series of experimental tests on partially-encased composite steel/concrete beam-columns are presented by Elghazouli and Treadway (2008). The encased members are examined under lateral loading in combination with axial gravity loads, using members with three different cross-sectional sizes, utilizing grade S460 steel. Experimental results from testing ten composite models were presented and discussed by the researchers aiming to provide essential data for validating future analytical and design studies which mainly are regarded to the assessment of several important factors such as yield and ultimate capacity as well as the ductility and residual strength (Elghazouli and Treadway, 2008).

Bing *et al*. (2011) studied the effects of using fly ash as a replacement of sand with fine silica fume and Polypropylene (PP) fiber to improve properties of foamed concrete. The study included mainly the compressive and splitting tensile strength and drying shrinkage of foamed concrete with compressive strength of 10-50 MPa. It was found that, the fine silica fume and PP fiber greatly improved the compressive strength of foamed concrete. In addition, adding PP fiber significantly improved the splitting tensile strength and drying shrinkage resistance (Bing *et al*., 2011).

The effect of high performance concrete with the consideration of fiber contents were investigated by Kang *et al*. (2010). The effect of fiber volume ratio varied from 0-5% were investigated by conducting 3-point bending tests. It was found that the flexural tensile strength increased linearly with increasing the fiber volume ratio. The study also includes predicting numerical model to investigate the effects of tensile fracture and softening (Kang *et al*., 2010).

The effect of concrete type on the behavior of Laminated Veneer Lumber (LVL)-concrete floor T-beams was experimentally investigated among several parameters.

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Different span length (8 and 10 m) were investigated through four points bending tests. The midspan deflection, slips and strain were measured during tests. Two types of connectors (triangular and rectangular) were used. It was found that the composite beam with higher concrete exhibited higher collapse load than normal concrete beam with the same stiffness and degree of composite action. Similarly, it was found that the triangular connectors represent a good alternative comparing with the other type of connectors (Yeoh *et al*., 2011).

The main objective of the study is to investigate the effects of increasing the compressive strength of the concrete deck on the flexural resistance, midspan deflection and slip at ends of steel-concrete composite beam.

MATERIALS AND METHODS

Materials preparation: Using different mixing proportions to produce the high performance concrete is a rational and simple procedure. Moreover, using additives, such as Flowcrete, would increase the concrete strength. Compared with ordinary concrete the HSC needs more ingredients, stricter construction technology and higher quality of administrative personnel and construction operating staff. The workability of fresh concrete, as well as the mechanical properties of HSC is greatly improved.

Locally available cement and aggregates with maximum size of 20 mm are used in concrete. A cement manufactured by Badosh factory, in Mosul City, Iraq is used. Local aggregates from location called Khazer, lies at about 60 km to the east of Mosul City is used. The cement, aggregate and water used in concrete are tested and prepared before construction of composite beam samples. A physical and chemical tests are conducted to ensure that the cement are comply with the requirements of Iraqi standards (Iraqi Specification IQS No. 5,1984). The chemical and physical tests results of cement are shown in Table 1.

A local river sand is used as a fine aggregate in concrete admixture, after making a sieve analysis and fined to be within the range of fine sand in accordance with the British Standards-882 (B.S.882), with a fineness modulus of 2.83 and clay percentage 1.0% as shown in Table 2. A local river gravel with maximum aggregate size of 20 mm, according to B.S.882 (BS 882, 1992), having sieve analysis shown in Table 2 is used as a coarse aggregate in concrete admixture. Another physical properties of coarse and fine aggregate are shown in Table 3. A normal drinking (tap water) is used for mixing of concrete.

Several mixes are prepared to get the required compressive strength of concrete. The final mix proportions (cement: sand: gravel/water) used with a slump of (100 mm) for each type of used concrete, as shown in Table 4.

The NC group is chosen to represent the concrete with normal compressive strength. Aitcin and Mehta (1990) classified the high compressive strength as that exceeding 40 MPa, (Aitcin and Mehta, 1990; Zain *et al*., 2002). Two more groups were designed for a compressive strength greater than 40 MPa designated HSC and HSFC groups which are constructed without and with fiber,

Table 1: The physicochemical tests results of ordinary Portland cement

Chemical test			Physical test		
Elements	Results (%)	IQS:No.5/1984%	Properties	Results	IQS:No.5/1984
Al_2O_3	5.1	3.0-8.0	Fineness retained on sieve 170	5%	≤10%
SiO_2	19.7	17.0-25.0	Initial Setting minute	100	≥45 min
Fe_2O_3	4.5	0.5-6.0	Final Setting minute	660	≥600 min
CaO	62.0	60.0-67.0	Compressive strength MPa - 3 days	17.8	≥16 MPa
SO_3	2.5	≤2.8 %	Compressive strength MPa-7 days	25.4	≥24 MPa
MgO	2.5	≥5%	Tension strength MPa-3 days	1.8	≥1.6 MPa
C_3S	38.4	31.03-41.05	Tensile strength MPa-7 days	2.8	≥2.4 MPa
C_2S	32.5	28.61-37.90			
C_3A	12.1	11.96-12.30			
C_4AF	7.9	7.72-8.02			

Table 2: Gradation of aggregate

Sand			Gravel		
Sieve size	Passing (%)	B.S.882 (%)	Sieve size (mm)	Passing (%)	B.S.882 (%)
5 mm (No. 4)	100	89-100	20	100	90-100
2.36 mm (No. 8)	84	60-100	14	65	40-0.80
1.18 mm (No. 16)	72	30-100	10	56	30-60
600 μm (No. 30)	55	15-100	5	1	0-10
300 μm (No. 50)	7	5-70	-	-	-
150 μm (No. 150)	3	0-15	-	-	-

Table 3: Physical properties of aggregate

Type of aggregate	Density (kg m^{-3})	Specific gravity	Absorption (%)
Sand	1670	2.68	3.10
Gravel	1686	2.71	1.02

Table 4: Groups notations and mixes ratios

Group	Group notation	Mixture weight ratios
Normal concrete	NC	1:2.46:3.3/0.45
High strength concrete	HSC	1:1.5:2.25/0.4
High strength fiber concrete	HSFC	1:1.5:2.25/0.4
High strength flowcrete concrete	HSCC	1:1.7:2.25/0.32

respectively. In order to investigate the effect of fiber on compressive strength, a total of twelve standard concrete cubes, 150×150×150 mm, divided into four groups with four fiber percentages 0.5, 1.0, 1.5 and 2.0% are prepared and tested according to standard method specified by ASTM specification (ASTM C39/C39M-03, 2003). The fibers were in 10 mm sieve put and added gradually (spread) to concrete while mixing the concrete. The test results are plotted in terms of fiber percentage-compressive strength, as shown in Fig. 1. Accordingly, the optimum fiber percentage of 2% are chosen to be used. The last group referred to as HSCC adopted in the test program to represent a high strength concrete as stated by the ACI-Code, 2011 (ACI Committee 318M, 2011).

The average concrete compressive strength is calculated by testing three standard concrete cubes, 150×150×150 mm, for each group tested according to the method specified by ASTM (ASTM C39/C39M-03, 2003). The results are listed in Table 5 with their standard deviation. The average results converted to standard cylinder compressive strength (f'c), by considering the standard cylinder compressive strength equivalent to 80% of the standard cube compressive strength.

The composite beams having a total length of 1600 mm is composed of standard hot rolled steel shape (W6×12), (AISC, 1994) connected to 120 mm thickness concrete slab with 500 mm width, as shown in Fig. 2.

An average steel yield strength (fy = 341 MPa) and ultimate strength of (fu = 475 MPa) are obtained from uniaxial tensile test of six strips taken from flange and web of the steel section. The same test is carried out for the 10 mm diameter reinforcement bars giving a yield strength (fy = 485 MPa) and ultimate strength of (fu. = 655 MPa). The results of steel section, reinforcement and concrete strength are shown in Table 5. Using, uniaxial tensile test results, the modulus of elasticity is found to be Es = 198850 MPa and Er = 197660 MPa for steel section and steel reinforcement, respectively. A steel headed stud mechanical shear connectors (12.5 m diameter and 80 mm height) are used to connect the steel section to the concrete deck. An average yield strength and ultimate strength of the connectors are also obtained from uniaxial tensile test which show an average yield strength (fy = 472 MPa) and ultimate strength of (fu. = 667 MPa)

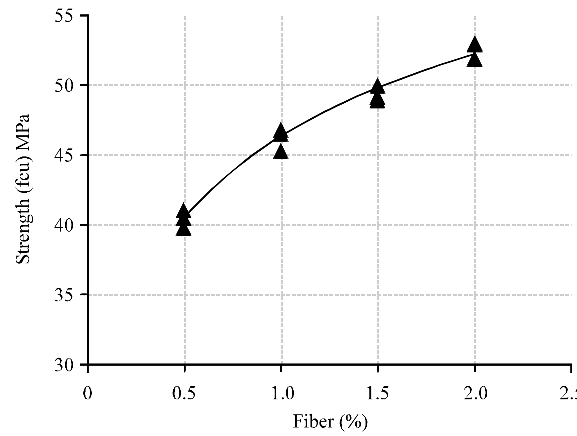

Fig. 1: Effect of fiber percentage on compressive strength

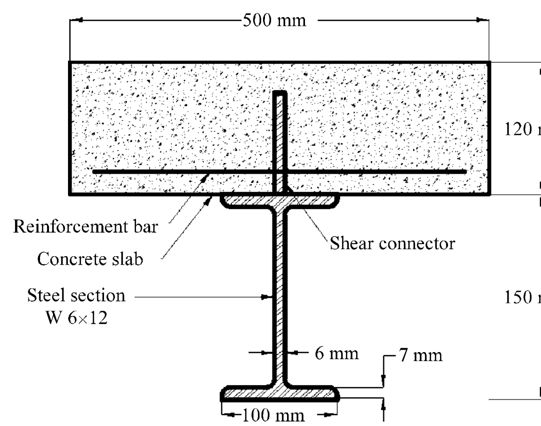

Fig. 2: Geometry of composite beam sample

gained from testing three samples. The res modulus of elasticity of stud connector, was found to be Est = 208110 MPa.

Testing method: A total of twelve composite beams are constructed and tested at the civil engineering laboratory, Mosul university, the samples are divided into four groups, each of three beams. The present study considering the effects of using different compressive strength of cornet with or without fibers and their effect on slip and deflection of composite beam. The headed stud shear connectors are welded to the flange of steel beam by qualified welders, following a standard procedure. The connectors spaced at 150 mm C/C, shown in Fig. 3. Reinforcement mesh consists of a minimum number of rebars with 10 mm diameter which are placed at the bottom of concrete flange for both longitudinal and transverse directions. The concrete flanges are cast by using wooden forms, as shown in Fig. 3. After concrete casting the concrete surfaces of the beams were kept

Table 5: Concrete cube compressive strength for groups NC, HSC, HSFC and HSCC, yield strength of steel section and yield strength of reinforcement with standard deviations

Group	fcu (MPa)	Av. fcu (MPa)	Av. f'c (MPa)	Standard deviation	Reinf. bar No.	fy (MPa)	Strip No.	fy (MPa)
NC	27.7	26.6	21.3	1.15	1	465	1	335
	25.4				2	455	2	346
	26.6				3	478	3	357
HSC	53.9	52.9	42.3	0.90	4	520	4	343
	52.1				5	480	5	329
	52.8				6	511	6	334
HSFC	54.2	53.3	42.7	0.80	Average yield strength	485	Average yield strength	341
	53.1							
	52.6							
HSCC	80.1	80.1	64.1	0.25	Standard deviation	25.6	Standard deviation	10.13
	80.3							
	79.8							

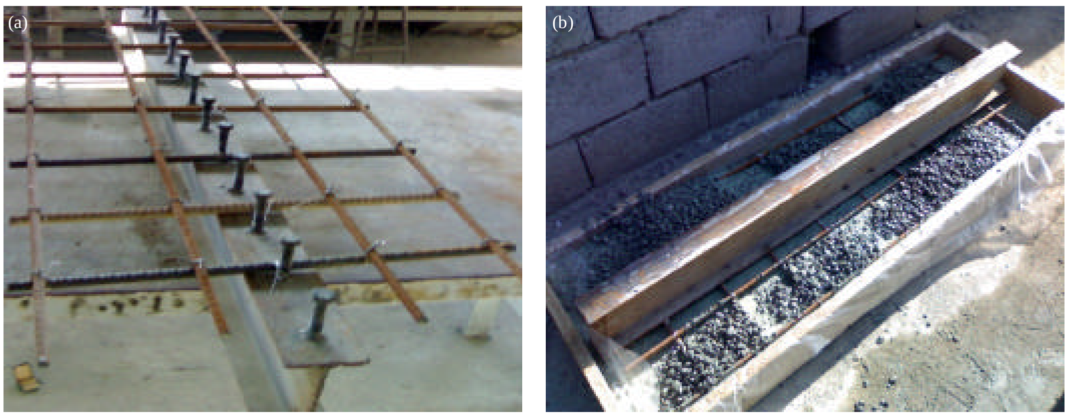

Fig. 3(a-b): (a) Section, studs and reinforcement and (b) Concrete casting of composite beam

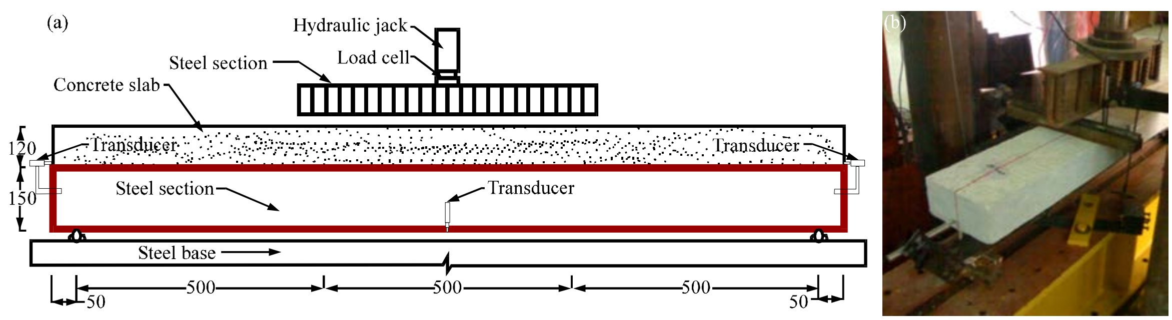

Fig. 4(a-b): Beam test setup, (a) Testing setup (side view) and (b) Beam testing, dimensions in mm

moist with wet burlap for 3 days. The wood forms are then removed and the specimens are cured in an air-dry conditions until testing. The composite beam specimens are supported at its ends, with a span of 1500 mm between supports. A 500 kN hydraulic jack is used to apply a two point load with a monotonic load applied at the top of concrete flange through a distribution beam and two cross shafts, generating the loading condition shown in Fig. 4. The test setup generates a two shear zones near the ends and a pure bending zone in the middle of the simply supported beam. The load is gradually applied, monitored and recorded using a load cell. The slip at ends of the beam and deflections at mid-span are recorded using three transducers with an accuracy of (0.0001 mm).

RESULTS AND DISCUSSION

Mode of failure: During testing of the specimens, with the increasing of the applied load the deflection at the mid-span of the beam observed and recorded at each load

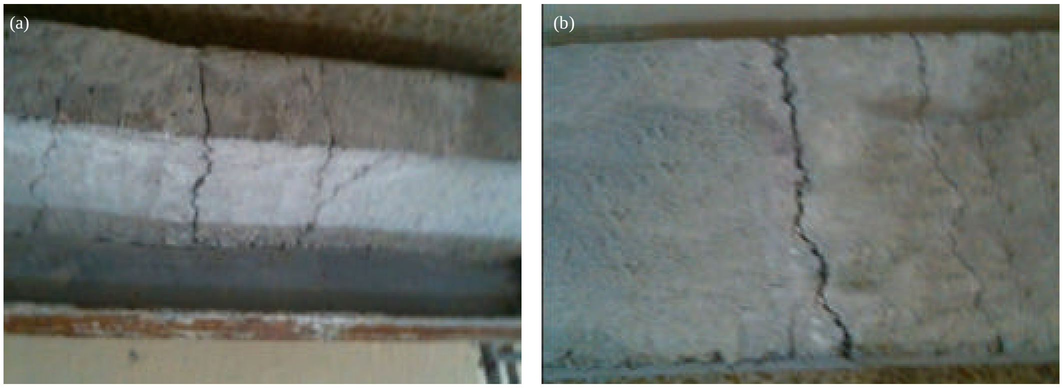

Fig. 5(a-b): Cracks generated in concrete deck, (a) Side and (b) Top view

Table 6: Testing matrix and experimental results

Group No.	P_{yield} exp (kN)	P_{ult} exp (kN)	Diff. (%)	δ_{ult} (mm)	Diff. (%)	Slip (mm)	P_{ult} kN (AISC)	Diff.(%)
NC	152	191.78	-	1.211915	-	0.01109	245.43	27.97
HSC	200	242.87	26.64	0.687213	-43.30	0.06585	291.35	19.96
HSFC	212	269.23	40.38	0.751531	-37.99	0.05475	291.70	8.34
HSCC	238	310.16	61.73	0.920368	-24.06	0.04058	307.05	-1.00

step. The slip between the concrete deck and the steel section is measured and recorded for each load step. The deflection at mid span is started and increased gradually with the increasing of load value which is also measured and recorded.

The cracks were initiated at the bottom of the concrete flange in most of the specimens, at the early stage for group NC and at more advanced stages for group HSC, due to the higher tensile strength of concrete gained in HSC group (Zain *et al*., 2002). For the other groups cracks are initiated at different load stages. The cracks are then extended further by increasing the applied load. Another longitudinal cracks at top middle portion are observed in some specimens. The final failure modes of the specimens are the flexural failure in concrete flange after generating major cracks, as shown in Fig. 5. These failure modes are gained by positioning the load to comply with the conclusions stated by Liang *et al*. (2005).

Deflection at mid span of the beams: The deflection at mid span of the specimens of the four groups are recorded throughout all loading stages up to failure of each beam. The results are plotted in terms of load-deflection curves, as shown in Fig. 6.

The deflection in NC group started at the early stages of loading, as well as in HSFC group deflection started from the beginning of test but the deflection values are less than that observed in NC group. For HSC group, the deflection started at load stage of about 45% of the ultimate load, whereas the beams of group HSCC started deflection at load stage of about 23% of the ultimate load. These differences can be ascribe to the inelastic behavior of the concrete as specified by Elghazouli and Treadway (2008).

Slip at the end of the beam: The slip at the ends of the beam of the four groups are recorded at different stages of loading up to failure. The results are plotted in terms of load-slip curves as shown in Fig. 7.

In general, the results show that the slips in NC group are also at the early stages of loading, while, in the other groups the slips are delayed to an advanced stages of loading. These results show that slip resistance are gained at different load stages after cracks taking place which is agreement with the conclusion stated by Luo *et al*. (2012) that the concrete has the ability to transfer shear force after cracking. However, HSCC group gives a considerable slip resistance compared with the other groups.

Effect of concrete compressive strength: The effect of concrete compressive strength is highlighted by comparing the average deflection and slip values for groups: NC, HSC and HSCC. The results are plotted in terms of load-deflection and load-slip curve, as shown in Fig. 8 and as listed in Table 6. It can be clearly noticed from these results, that the compressive strength has a great effect on ultimate strength, whereas the ultimate strength of the beams are increased comparing with group NC by about 26.6 and 61.7% for groups HSC and HSCC,

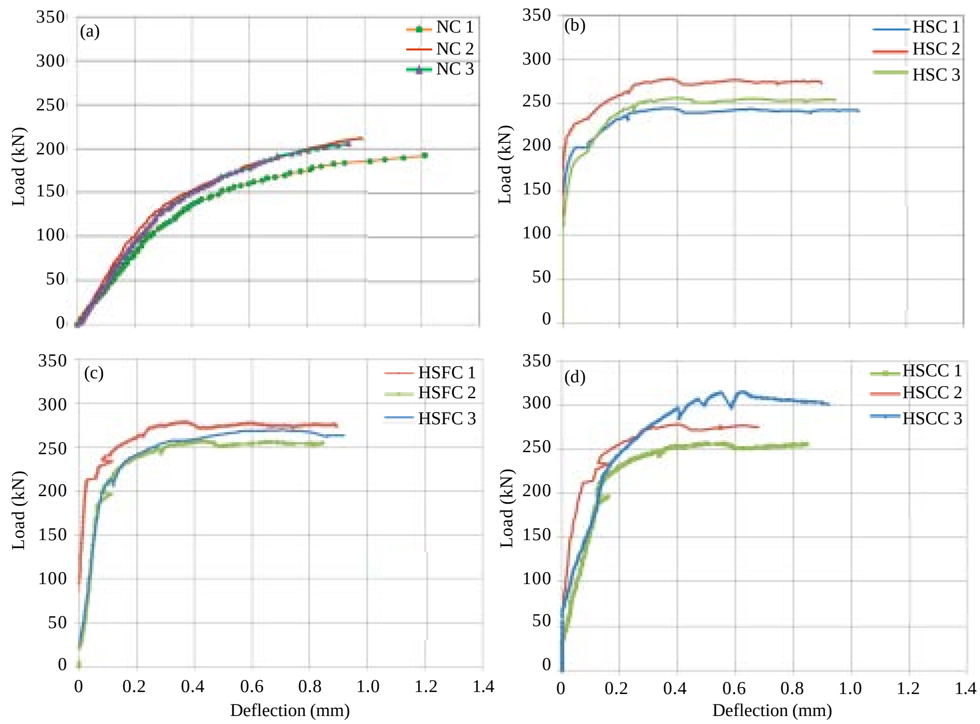

Fig. 6(a-d): Load-deflection curves for the four groups (a) NC, (b) HSC, (c) HSFC and (d) HSCC

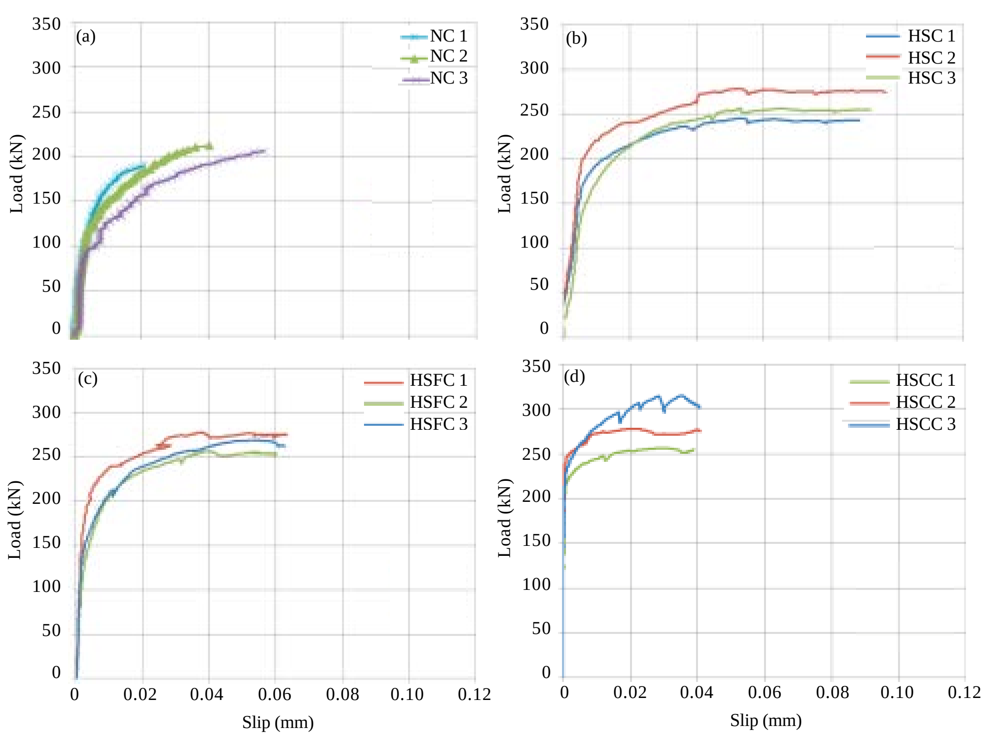

Fig. 7(a-d): Load-slip curves for the four groups (a) NC, (b) HSC, (c) HSFC and (d) HSCC

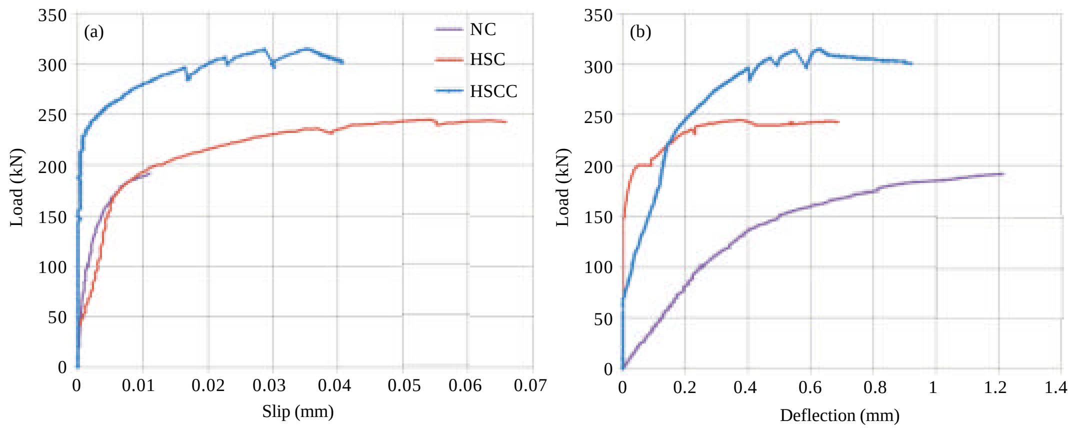

Fig. 8(a-b): (a) Load-slip and (b) Load-deflection curves for groups NC, HSC and HSCC

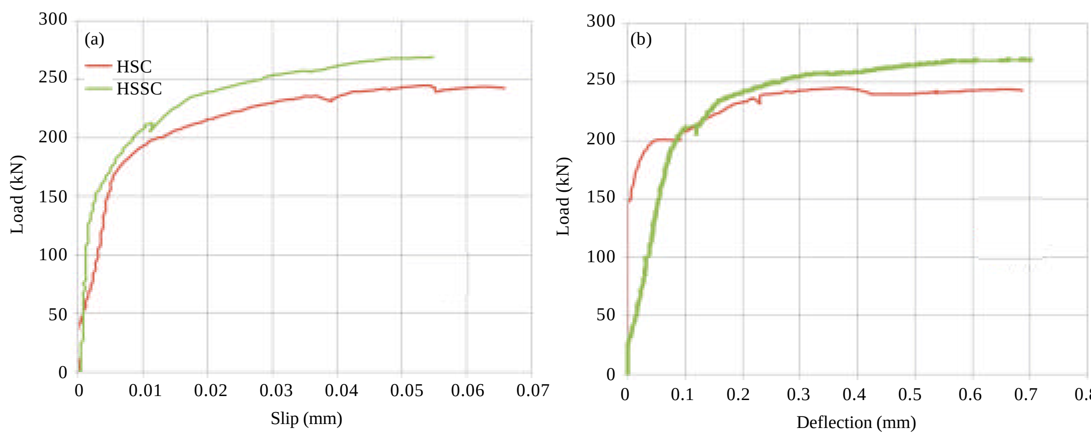

Fig. 9(a-b): (a) Load-slip and (b) Load-deflection curves for groups HSC and HSFC

respectively. As well as the deflection at mid span of the beam at ultimate stage are decreased compared with group NC by about 43.3 and 24.1% for groups HSC and HSCC, respectively. The results plotted in Fig. 8 show that the slip resistance is greatly improved by increasing the compressive strength especially for group HSCC and a lesser effect in group HSC comparing with group NC. It is shown that at a load of 180 kN the slip of groups NC and HSC are about 0.01 mm meanwhile group HSCC has no slip and the slip of group HSCC started at load of about 220 kN, These results also agreed with those obtained by Luo *et al.* (2012).

The effect of adding fiber to concrete is also investigated by comparing the average values of deflection and slip for groups HSC and HSFC. The results are plotted in terms of load-deflection and load-slip curve, as shown in Fig. 9. This figure shows that the addition of fiber enhance the slip resistance. It was found that the deflection would not be enhanced by adding fiber, contrary to the typical assumption considered contributing of adding fiber on the nonlinear behavior of concrete (Ali, 2011).

Using the formula specified by the AISC-LRFD for composite beam (AISC, 1994), the ultimate load of each beam are calculated and compared with the ultimate loads obtained for each groups, as listed in Table 6. The results show that the AISC formulas overestimate the ultimate strength by about 28, 20 and 8.3% for groups NC, HSC and HSFC, respectively but underestimate the ultimate strength for group HSCC with difference of -1%.

CONCLUSIONS

Using results gained from experiments, the following conclusions are stated:

- The resistance of deflection of the composite beam would be increased by increasing compressive strength or adding fiber to concrete comparing with the normal concrete
- Slips at the end of the beam are greatly affected by increasing the compressive strength, the slip decreased by increasing the compressive strength. The experimental investigations giving a lesser values than that calculated by AISC's formula for the three groups NC, HSC and HSFC and almost the same results is obtained for group HSCC.
- Adding steel fiber to concrete deck would decrease the slip between the concrete and steel

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