Structure Behavior of Beams Combining Ultra High Strength Concrete and Normal Strength Concrete

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Abstract:
The concept of "Composite structures or partial elements" was mainly carried out from an economical point view. The basic idea for using the composite elements is combining the Normal strength concrete and Ultra High Strength concrete (UHSC) or any recent advanced cementitious material in composite structures in order to exploit the advantages of the two materials in an optimal way. Ultra-high Strength concrete (UHSC) which was used in this research have exceptional material properties, however, their material costs are significantly higher than those of normal strength concretes. It is defined as a concrete which is meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituent materials and normal mixing, placing, and curing practices,(ACI Committee 116). UHSC is characterized by extraordinary mechanical properties and durability properties. The UHSC-Matrix is very brittle material behavior. In this research an experimental program is being carried out to study the behavior of UHSC beams and composite beams using UHSC (141MPa) and Normal strength concrete with studying the effect of different parameters tested under static loads. This program mainly aims to reach to the optimum thickness of ultra-high strength concrete layer in the composite beams, it also aims to make a validation for using the Egyptian code equation for the maximum reinforcement ratio of longitudinal steel in UHSC and composite beams. This paper presents the results of this experimental program, which consists of ten reinforced concrete beams. The main parameters of this program were: longitudinal reinforcement ratio, the type of used concrete and the thickness of UHSC layer. Particular attention is paid to the effect of each variable on the strength enhancement, stiffness degradation, toughness and ductility of the tested beams. Valuable conclusions were obtained from the research results which stated that; in case of high reinforcement steel ratios the optimum thickness of UHSC in the concrete beams cross section should be not less than the third of the cross section depth only in order to achieve the economic point of view.

Keywords:
Ultra High Strength Concrete,
Composite,
Normal strength concrete,
Beams,
Flexural behavior

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INTRODUCTION

In the past several years an advance in the science of concrete materials have led to the improvement and development in the concrete technology .Sustainable use of supplementary materials and revolutionary developments in super plasticizing admixtures have facilitated in the mechanical properties and durability of concrete .For example researches are using silica fume and high range water reducing admixtures to produce high density concrete .In addition to high strength, the concrete should exhibit greater durability characteristics. This means that the concrete should be high strength and high performance. One of the materials developed in recent years is ultra-High Strength Concrete (UHSC) also known as reactive powder concrete (RPC). This material possesses a compressive strength greater than 21,750 psi (150 MPa).**[1]**

It must be highlighted that through studying and investigating the mechanical properties of UHSC, it was concluded that for the development of ultra-high strength concrete only the compressive strength was the relevant factor. The deformation behavior, so e.g. the modulus of elasticity was only of secondary interest [2]. Shah.et.al 1998, [3] stated that, as the strength of the concrete increases, the material is more homogeneous; however it also becomes more brittle. Unreacted cement and aggregate particles produce significant heterogeneities in the standard high strength system, while the UHSC system is much more uniform at the same scale.

Also from the factors that affect the UHSC performance is the addition of steel fibers that transforms the brittle ultra-high strength cement composite into a more isotropic and ductile material and thus increases toughness and strength, consequently Markeset 2002 [4], study the influence of steel fibers on the compressive stress-strain curve of the ultra-high performance concrete it was observed that by adding 1.0% steel fibers by volume to the concrete mix a noticeable increase in ductility is obtained in the post peak region of the stress-strain curve. Longer fibers or fibers with enhanced anchorage may have

improved the post-peak ductility even more.
As mentioned before the UHSC material costs are significantly higher than those of normal strength concretes, so in order to optimize the uses of the UHSC in concrete beams the concept of composite "UHSC-concrete" structures can be applied to new structures and to conservation projects. It was denoted that the contribution of UHSC or Ultra-High-Performance Fiber-Reinforced Concrete in the composite beams increases their stiffness and ultimate resistance than the RC elements alone. Also it was observed that the addition of a tensile R-UHPFRC reinforcement can be used as an effective shear strengthening method,[5]. Furthermore, it was demonstrated that using the UHPFRC layers in concrete elements extend their durability due to the low permeability and tensile strain hardening properties of UHPFRC. The incorporation of rebar in the UHPFRC layer leads to a further increase in resistance and stiffness of the composite element and to a higher apparent magnitude of hardening in the UHPFRC. The investigated composite elements show monolithic behavior under service conditions [6].
The main objective of this research is to investigate the flexural structural behavior of UHSC and composite beams using Ultra High Strength Concrete (UHSC) (141MPa) and Normal strength concrete with the effect of different parameters under static loads. Also this study aims to reach to the optimum thickness of ultra-high strength concrete layer in composite beams.

Research Program

This paper presents the results of an experimental program which is being carried out to investigate the different parameters that affect the of UHSC and composite beams using UHSC (141MPa) and Normal strength concrete (NSC) under the effect of static loads; the experimental program consists ten beams were included and designated as B1 to B10 and subjected to concentrated loads. These beams divided into three groups composed of two NSC beams, five composites beams and three UHSC beams. All of these ten beams have a length of 6000 mm and a cross section of 300×150 mm. A clear cover of 15 mm was provided to all test specimens. Two types of concrete were used in casting these ten beams Ultra-High strength Concrete with a target compressive strength about (141MPa) and Normal Concrete (NSC) with a target compressive strength (30MPa).The studied parameters that affect the behavior, ductility, toughness and stiffness of the tested beams include the concrete type, thickness of UHSC layer and the longitudinal steel reinforcement ratio. Tables (1) show the configurations of experimental program of the ten specimens and Figure (1) shows the concrete dimensions and steel reinforcement details of specimen B1.

Table 1: Columns Configurations

Specimen	UHSC thickness (cm)	NSC thickness (cm)	Type of concrete	Main Reinforcement	% ρ	Stirrups
B1	0	30	Normal	6Φ16	3.17	10Φ10/m
B2	30	0	Ultra	6Φ16	3.17	10Φ10/m
B3	10	20	Composite	6Φ16	3.17	10Φ10/m
B4	30	0	Ultra	6Φ18	4.03	10Φ10/m
B5	30	0	Ultra	6Φ22	6.13	10Φ10/m
B6	10	20	Composite	6Φ18	4.03	10Φ10/m
B7	10	20	Composite	6Φ22	6.13	10Φ10/m
B8	7	23	Composite	6Φ22	6.13	10Φ10/m
B9	5	25	Composite	6Φ22	6.13	10Φ10/m
B10	0	30	Normal	4Φ16	2.11	10Φ10/m

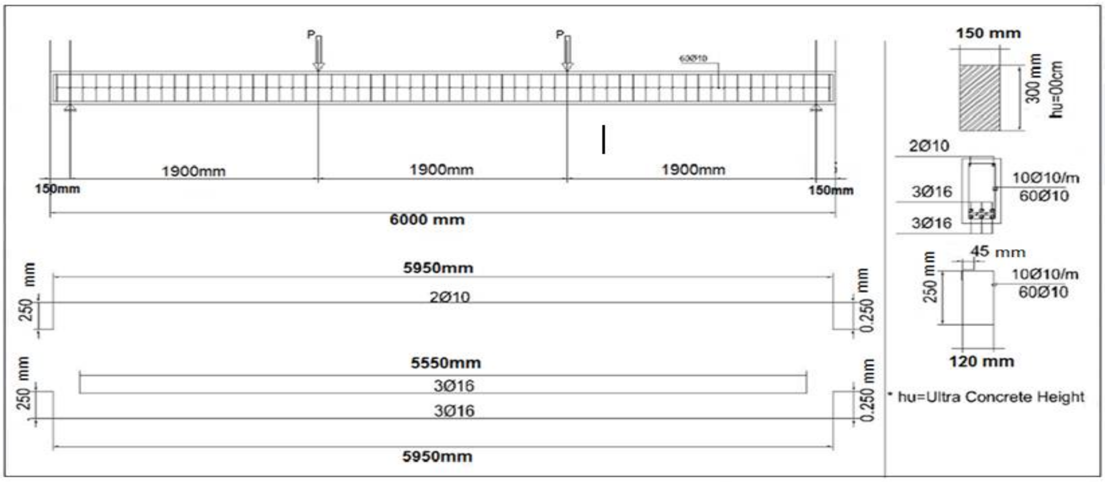

Fig.1: The concrete dimensions and steel reinforcement details of specimen B1

Materials Properties

The materials used in this study for both UHSC and NSC mixes were coarse aggregate which was local crushed dolomite from natural resources for UHSC and denoted as D5 had a nominal maximum size of 5 mm and natural crushed stone dolomite (NCA) for NSC, the fine aggregate was natural siliceous sand with grain size ranging from 0.15 to 0.5 mm, CEMI 42.5N of the Suez Company– Suez factory, Quartz powder used as a filler form with Blain fineness of 470 m2/kg, and a specific gravity of 2.63, Clean drinking fresh water free from impurities, and chemical admixture. All concrete ingredients complies with the requirements of the Egyptian standard specifications. Silica fume was used as addition for the cement to produce workable concrete with high cubic compressive strength. Super-plasticizer was used to produce self-leveling concrete with only the water necessary for the hydration of the cement; the super-plasticizer for the UHSC mix was high performance and was known as (Visocrete-20HE). And for the NSC the used super-plasticizer was known as sikament-163 M. Deformed high tensile steel of elastic strength of 420 MPa and ultimate strength of 630 MPa was used for all tested beams. Main reinforcement of 16,18 and 22 mm diameter bars was used, while 10-mm diameter bars were used in stirrups.

Fabrication of Test Beams

According to Khattab.E 2010 [7], the design cube compressive strength of the UHSC was 141 Mpa after 90 days. It's mixture proportions is shown in Table (2). The fresh UHSC had a 550 mm slump flow. It was closed to self-compacting concrete. While the design cube compressive strength of the NSC is 30 MPa and its mixture proportion is shown in Table (3). A steel form was prepared for casting the two types of concrete. They were cast in laboratory conditions and mixing was performed using a concrete drum mixer. The NSC specimens were moist cured after de-molding while the UHSC and composite specimens have a stem curing for 2 days.

Table 2: Mix proportion for UHSC

Constituents	Cement (kg/m3)	S.F%	Coarse Agg (Dolomite D5) / Total Agg	Siliceous Sand / Total Agg	Quartz powder / Total agg.	W/B	SP %
proportions	800	20	0.5	0.25	0.25	0.16	4

Table 3: Mix proportion for NSC

Constituents	Cement (kg/m3)	Coarse Agg / Total Agg	Siliceous Sand / Total Agg	W/c	Sp %
proportions	350	0.6	0.4	0.52	1.2

Setup of Tested Beams and Test Procedure

The specimens were located under the cross head of the testing machine such that the centerline of the specimen was oriented perpendicular to the centerline of the cross head. The specimen was supported over two steel rods (hinge support). The beams were tested using two concentrated loads. The locations of loading points were variable, depending on the shear span of each group of the tested beams. The load and location of the first crack were recorded and the propagation of crack was traced until failure .Data acquisition measurement system and control systems were used to perform the tests. Electrical strain gauges were used to measure strain in steel reinforcing bars. For each beam, the gauges were bonded to bottom longitudinal bars and stirrups which were considered adequate to measure the strain in the failure area, the strain gauges were covered by a waterproof coating to protect them from water and damage during casting concrete.Linear Variable Displacement Transducers Pigages. measured the compression and shear strain of the concrete. In addition, deflection at mid-span of the beams was measured by LVDT.The locations of LVDTs and Pigages points are shown in Figure (2)

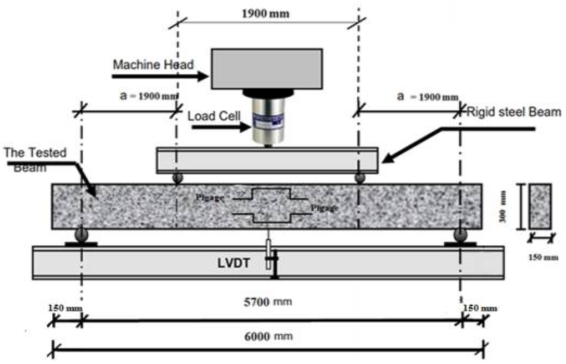

Fig. 2: Test Setup

All of the data gathered from load cells, LVDTs and strain gages were continuously recorded during the test by the data acquisition system. Cracks were observed and marked for each load level. The test ended when one of the following events occurred:

1. The beam was not able to sustain the applied axial load which can be noticed by a sudden drop in the reading of the digital reader
2. Loading dropped to less than 85% of the maximum experienced capacity.

TEST RESULTS

This section presents analysis of the test results to clarify the variation in cracking behavior, mode of failure, strength decay, stiffness degradation, ductility and toughness of the tested specimens. Moreover, measures are defined to quantify this variation of each specimen. Table (4) summarizes the outcomes of the experiments, the load at first crack (Pcr), load at first yielding of bottom steel (Py), ultimate experimental load (Pu), failure load at 0.85 of ultimate load (Pf), deflection at mid span at yielding (Δy) and deflection at failure load (Δf), Tables (5) shows the Stiffness, Ductility index and Toughness values for all tested beams.

Table 4: Values of Cracking Loads, Ultimate Loads, failure load (Pf), deflection at mid span at yielding (Δy) and deflection at failure load (Δf)

Specimen	P_{cr}(KN)	P_y (KN)	Pu (KN)	Pf (KN)	Δy (mm)	Δf (mm)
B1	6.9	65.03	110	82.95	64	136
B2	4.5	141.1	146.1	109.575	65	165
B3	4.0	134.3	141.1	105.825	60	117
B4	5.1	158.4	165.4	124.05	64.1	129
B5	5.2	256.1	266.6	199.95	75	266.6
B6	3.6	181	187.7	140.775	72	142.21
B7	3.2	251	257.6	193.2	80	88
B8	4.6	218	218.8	218.8	64.8	69.97
B9	4.5	188.2	188.2	141.15	70	76
B10	2.5	79.5	85.6	64.2	64	175

In General, The ductility of a structural member is defined as its ability to deform beyond the failure load without a significant loss in strength. In the case of a flexural member, sectional ductility based on curvature and/or deflection is usually considered [8]. In this study, the deflection ductility was investigated .According to Rashid and Mansur 2005, [8] ref and Teo et al, 2006 [9], the index of deflection ductility (μ Δ) is characterized as follows:

Index of deflection ductility $\mu\ \Delta = \Delta f / \Delta y$ ………. (1)

Where Δf is the deflection at the mid span at failure load and Δy is the deflection at yielding of the longitudinal tensile reinforcement. Herein, failure is assumed to have occurred at a load equal to 85% of the ultimate load in the descending branch of the load-deflection curve this is in agreement with the work of other researchers [10,8]. Also the other analysis measurements that contribute in evaluating the effect of each variable is the stiffness and toughness of the concrete beam. The stiffness is defined as a measure of its resistance to deformation (bending). It is defined as the initial slope of the linear zone of the load - deflection Curve, while the toughness is known as the resistance to fracture of a material when stressed. It is the amount of energy that a material can absorb before rupturing. Toughness is defined as the energy equivalent to the area under the load-deflection curve up to a specified deflection,[11].

DISCUSSION OF TEST RESULTS

Evaluation of the major test variables on the behavior of the tested beams is discussed in the following subsections. Variables covered in this evaluation include the longitudinal reinforcement ratio, type of reinforced concrete and the thickness of UHSC layers, Particular attention is paid to the effect of each variable on the strength enhancement, stiffness degradation, toughness and ductility of the tested beams. Table (5) show the arrangement of beams specimens groups according to the chosen parameters

EFFECT OF LONGITUDINAL STEEL RATIO (ρ)

Group1

This group represents the group of Normal strength concrete B1 and B10. The comparison that was carried out between their behaviors shows that the Variation of longitudinal steel had a significant effect on the flexural performance of the tested beams. These two beams had a longitudinal reinforcement ratio of 3.17% and 2.11% respectively. All these beams had the same dimensions, compressive strength, stirrups (10 Ø10/m) and the same top reinforcement ratio. Figure(4) show the load deflection relationship of the two beams such that the maximum load was 110 KN for B1 and 85 KN for B10 which seems to be normal for B10 to have a load capacity less than B1 due to decreasing the steel reinforcement ratio which lead also to an increasing in the ductility index from 1.86 to 2.86 for B1 and B10 respectively as shown in figure (4) also. The stiffness and toughness values for both B1and B10 were represented in figure (5), in which it was denoted that decreasing the longitudinal steel reinforcement ratio the stiffness decrease from 1.865 to 1.3905 in contrast with toughness value that increase from 9615.2 to 11564.4 for B1 and B10 respectively.

Table 5: Arrangement of Beams Specimens Groups According to the Chosen Parameters

Group No	Beams	Type of concrete	UHSC thickness(cm)	NSC thickness (cm)	Longitudinal Reinforcement Steel Ratio μ %
1	B1	NSC	0	30	3.17
	B10				2.11
2	B2	UHSC	30	0	3.17
	B4				4.03
	B5				6.13
3	B3	Composite	10	20	3.17
	B6				4.03
	B7				6.13
4	B2	UHSC	30	0	3.17
	B3	Composite	10	20	
	B1	NSC	0	30	
5	B4	UHSC	30	0	4.03
	B6	Composite	10	20	
6	B5	UHSC	30	0	6.13
	B7	Composite	10	20	
	B8		7	23	
	B9		5	25	

Table 6: Values of Stiffness, Ductility Index and Toughness for all Test Specimens

Specimen	Mu (KN. m)	Stiffness (KN/mm)	Ductility Factor Δμ	Toughness (KN.mm)
B1	209	1.865	1.82	9615.24
B2	277.59	2.2	2.2	18132.56
B3	268.09	2.17	1.95	11871.60
B4	314.26	2.628	2.012	15414.92
B5	506.54	3.43	1.120	14638.58
B6	356.63	2.627	1.94	14986.58
B7	489.44	3.31	1.1	11862.38
B8	415.72	3.34	1.04	8441.19
B9	357.58	2.76	1.02	7070.58
B10	162.64	1.3905	2.86	11564.36

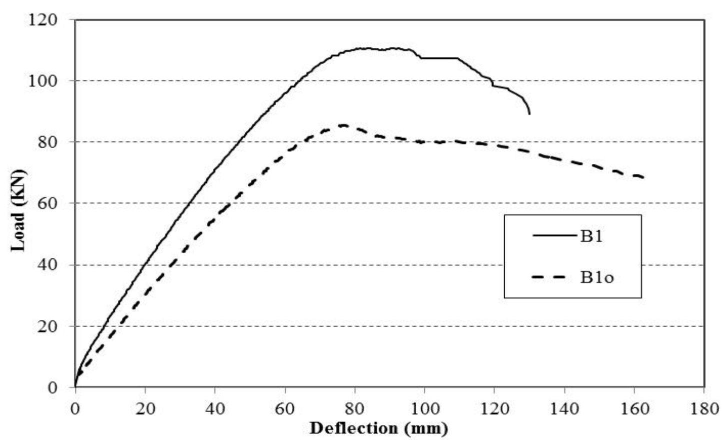

Fig. 3: Load-Deflection Relationship for B1 and B10

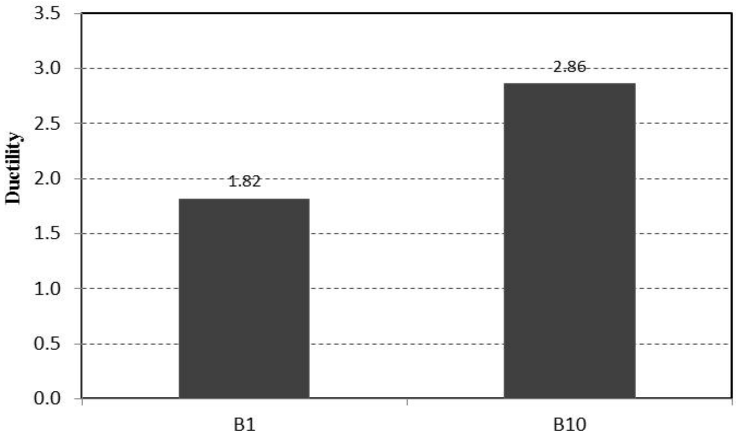

Fig. 4: Ductility index for B1 and B10

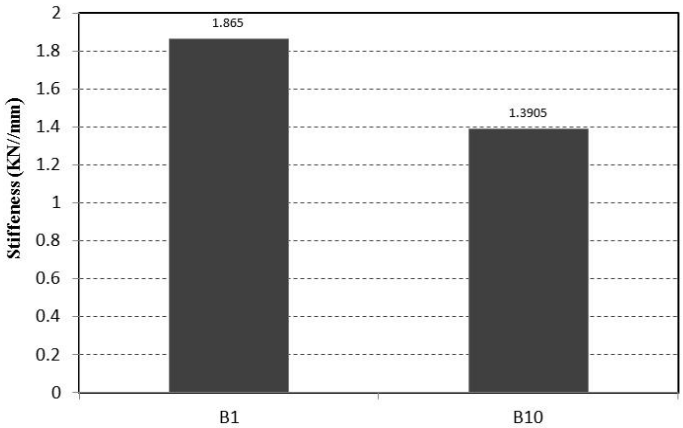

Fig. 5: Stiffness and Toughness for B1 and B10

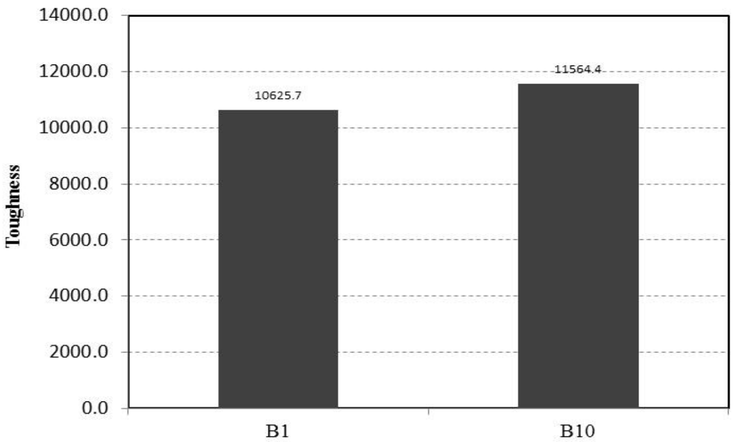

Fig. 6: Toughness for B1 and B10

Group 2

This group represents the group of the UHSC beams B2, B4 and B5 which had a longitudinal reinforcement ratio of 3.17, 4.03 and 6.13 % respectively. All these beams had the same dimensions, compressive strength , stirrups(10 Ø10/m) and the same top reinforcement ratio. The load deflection relationship and ductility index values of the three beams is shown in Figure (6), it was observed that the maximum loads for the UHSC beams increased by increasing the longitudinal steel reinforcement ratio. Such that the maximum loads were 143.1 KN, 165.4 KN and 266.6 KN for beams B2, B4 and B5 respectively. Consequently by increasing the steel reinforcement ratio the ductility decreased by 20% from 2.54 to 2.012 for B2 and B4 respectively and decreased also by 35% from 2.012 to 1.307 for B4 and B5 respectively.Figure (7) also express the stiffness and toughness for each of B2, B4 and B5 and it was denoted that by increasing the longitudinal steel reinforcement ratio the stiffness increase from 2.2 to 2.628 by a ratio of 16% for B2 and B4 respectively and from 2.628 to 3.43 by a ratio of 21% for B4 and B5 respectively in contrast with toughness value that decrease from 18132.6 to 15414.92 by a ratio of 15% for B2 and B4 respectively and from 15414.92 to 14638.58 by a ratio of 5 % for B4 and B5 respectively to 14638.58.

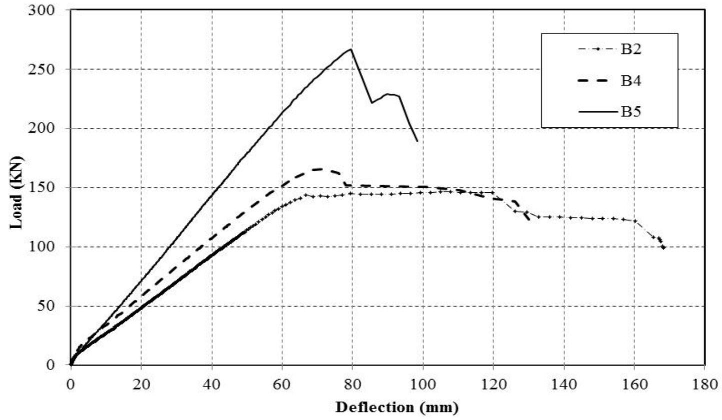

Fig. 7: Load-Deflection Relationship for B2, B4 and B5

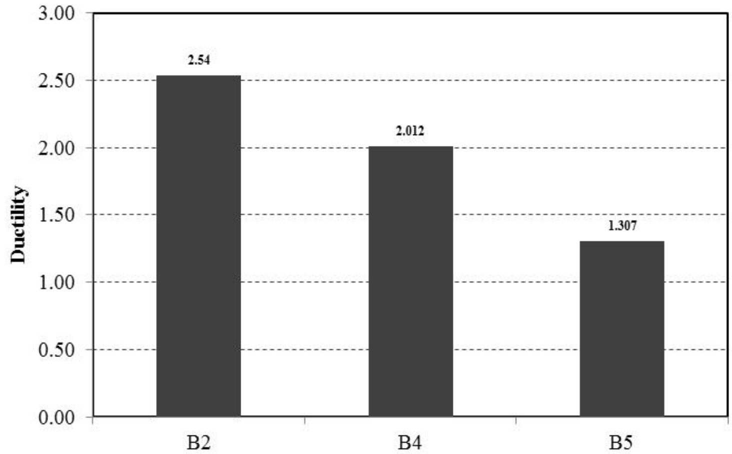

Fig. 8: Ductility index for B2, B4 and B5

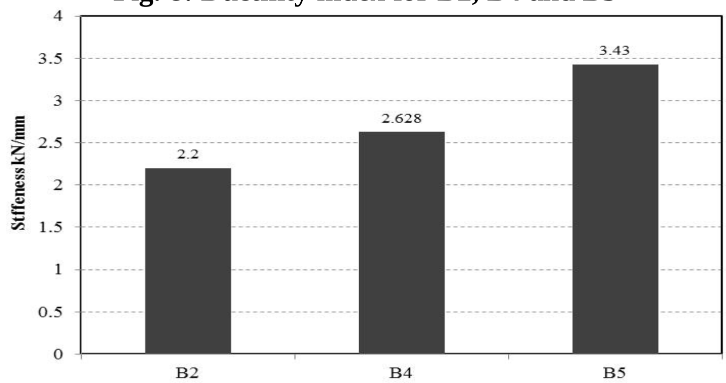

Fig.9: Stiffness and Toughness for B2, B4 and B5

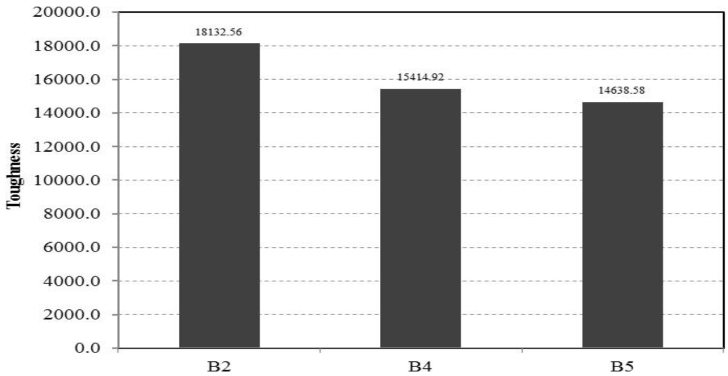

Fig.10: Toughness for B2, B4 and B5

Group 3

This group represents the group of the composite beams; B3, B6 and B7 which had a longitudinal reinforcement ratio of 3.17, 4.03 and 6.13 % respectively. All these beams had the same dimensions, all of them are composite beams with UHSC thickness of 100 mm and NSC thickness of 200 mm, the same compressive strength of the two concrete mixes, stirrups(10 Ø10/m) and the same top reinforcement ratio. The load deflection relationship and ductility index values of the three beams is shown in Figure (8), it was observed that the maximum loads for the UHSC beams increased by increasing the longitudinal steel reinforcement ratio such that the maximum loads were 141.1 KN, 187.7 KN and 257.6 KN for beams B3, B6 and B7 respectively. Consequently by increasing the steel reinforcement ratio the ductility decreased slightly from 1.95 to 1.94 for B3 and B6 respectively with a ratio about 0.5 % and decreased also from 1.94 to 1.1 for B6 and B7 respectively with a ratio 43%. Figure (9) also express the stiffness and toughness for each of B3, B6 and B7 and it was denoted that by increasing the longitudinal steel reinforcement ratio the stiffness increase from 2.369 to 2.66 by a ratio of 11% for B3 and B6 respectively and from 2.66 to 3.232 by a ratio of 18 % for B6 and B7 respectively in contrast the toughness value that increase from 11871.60 to 14986.58 by a ratio of 20% for B3 and B6 respectively and then decrease from 14986.58 to 11862.38 by a ratio of 20 % for B6 and B7 respectively.

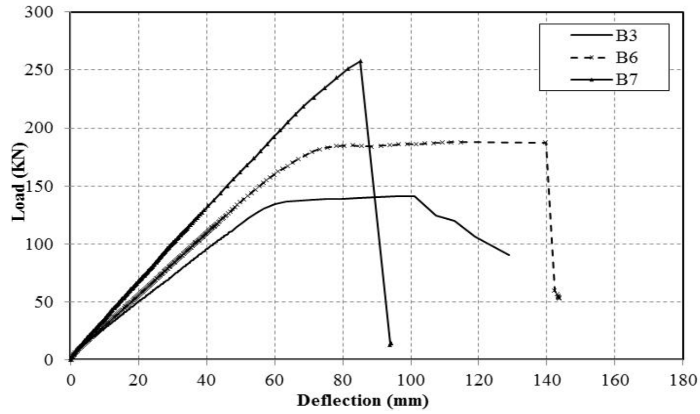

Fig. 11: Load-Deflection Relationship and Ductility index for B3, B6 and B7

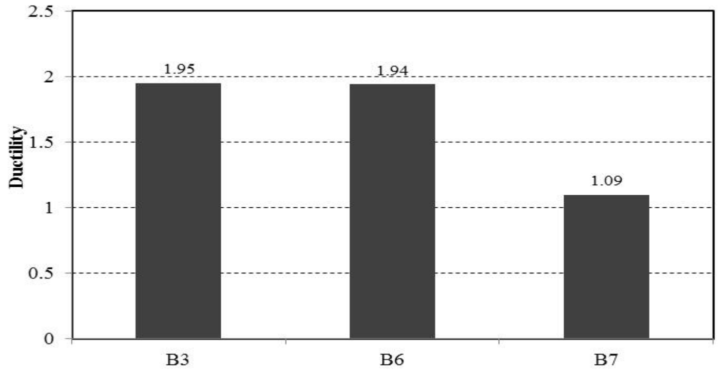

Fig. 12: Ductility index for B3, B6 and B7

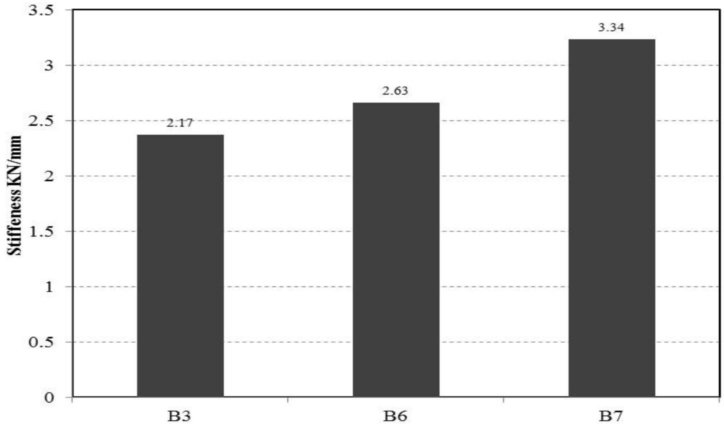

Fig.13: Stiffness and Toughness B3, B6 and B7

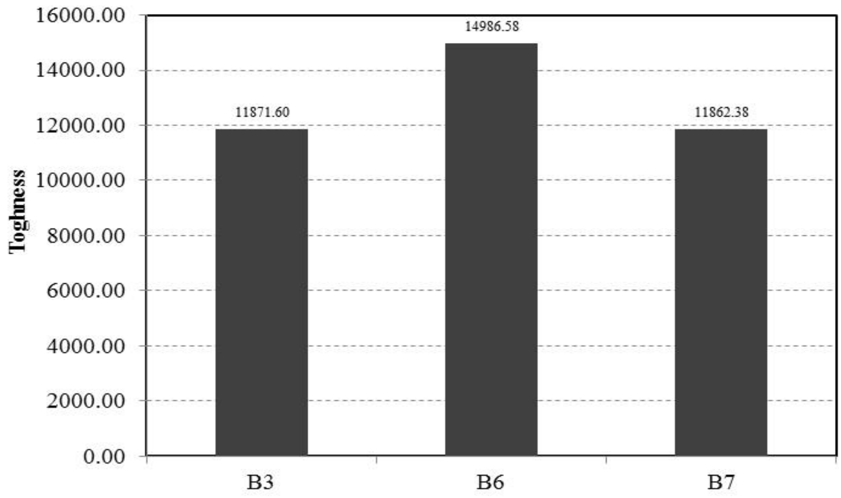

Fig.14: Toughness B3, B6 and B7

Effect of Concrete Type and Thickness:
Group 4:

These group of beams B1, B2 and B3 have the same longitudinal reinforcement ratio of 3.17% and the same cross section dimensions, but they differ in the type of concrete such that B1 is a NSC beam with a total depth 300mm, B2 is an UHSC beam with depth 300 mm in contrast with B3 which represent a composite beam with a thickness of 100 mm UHSC and 200 mm NSC. Figure (10) show the load deflection relationship and ductility index values of the three beams, in which the resulted maximum loads were 110, 146.1 and 141.1 KN for beams B1, B2 and B3 respectively. So it is well demonstrated that the UHSC beam B2 and the composite beam B3 gave nearly close results and behavior. As it was shown that by decreasing the thickness of UHSC from 300 mm in B2 (UHSC) to 100 mm in B3 (composite) which represent the third of the total depth of the beam, the ductility decrease from 2.2 to 1.94 with a ratio about 11% and the maximum load decreased by only a very slight difference by about 3.5 %. While by decreasing the UHSC thickness from 100 mm in B3 (composite) to zero mm as in B1(NSC beam) the ductility decrease from 1.94 to 1.82 by a ratio about 6.2 % and the maximum load decreased by about 22 %. This attributes to the steel reinforcement ratio 3.17% which is considered a maximum ratio for NSC beam while it considered a minimum ratio for both UHSC and composite concrete beams which make the ductility values of UHSC and composite greater than the NSC beams. The same trend for the stiffness and toughness values which were represented by Figure (11) for each of B1, B2 and B3 as by decreasing the thickness of UHSC from 300 mm in B2 (UHSC) to 100 mm in B3 (composite) which represent the third of the total depth of the beam the stiffness and toughness decreased by 1.4% and 15.7% for B2 and B3 respectively. While by decreasing the UHSC thickness from 100 mm in B3 (composite) to zero mm as in B1(NSC beam) the stiffness and toughness decreased by 14% and 10.5% for B3 and B1 respectively.

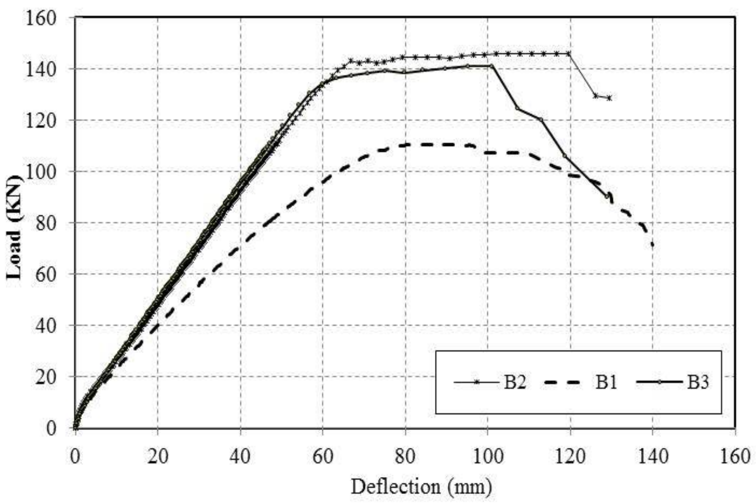

Fig. 15: Load-Deflection Relationship for B1, B2 and B3

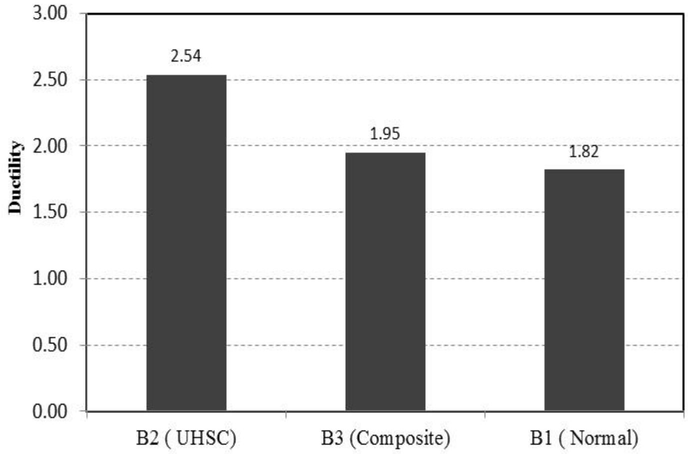

Fig. 16: Ductility index for B1, B2 and B3

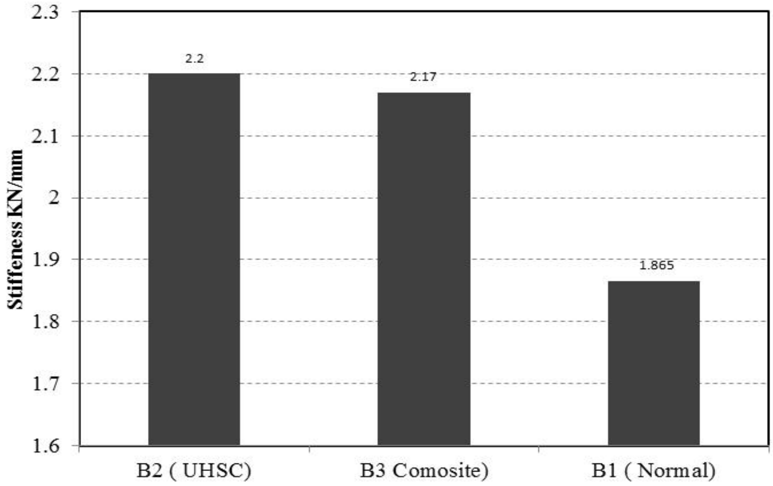

Fig.17: Stiffness and Toughness for B1, B2 and B3

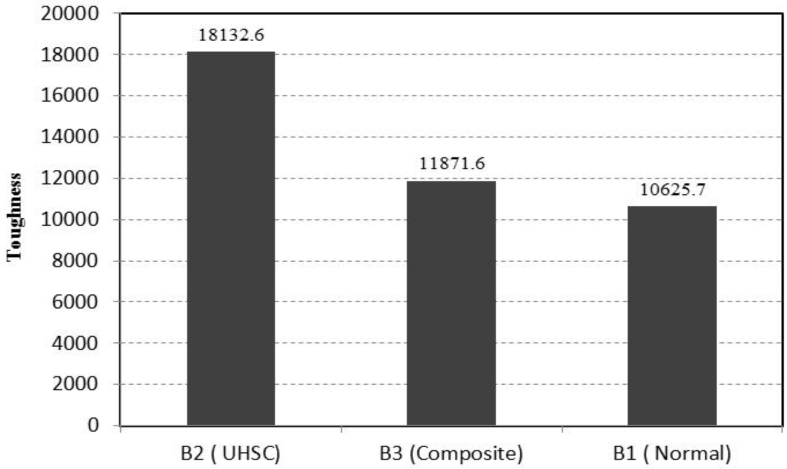

Fig.18: Stiffness and Toughness for B1, B2 and B3

Group 5:

The load deflection relationship and ductility index values of an UHSC beam (B4) and a composite beam with an UHSC thickness of 100 mm (B6) is expressed by Figure (12). The two beams have the same longitudinal reinforcement ratio which is 4.03%. The maximum loads were 165.4 and 187.7 KN for beams B4 and B6 respectively. It was conclude that decreasing the UHSC layer thickness from 300 mm (the total cross section depth) to 100 mm (the third of the total depth) give a very slight difference in the cross section capacity as the maximum load increase only by 11% and also have nearly the same ductility values with only difference about 1.8%. These beams behave by the same trend as they give the same values for stiffness and the toughness values decrease by a slight difference by about 2.8% as shown in Figures (13).

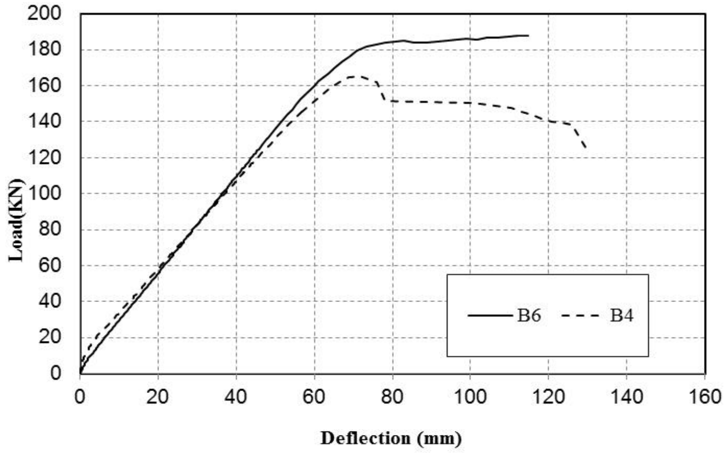

Fig. 19: Load-Deflection Relationship for B4 and B6

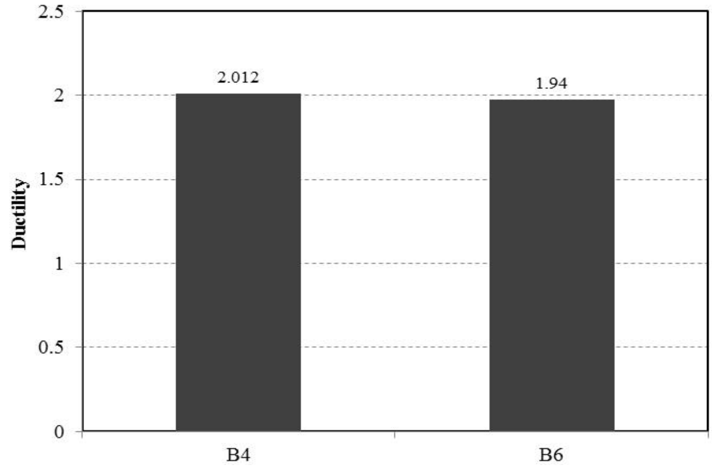

Fig. 20: Ductility index for B4 and B6

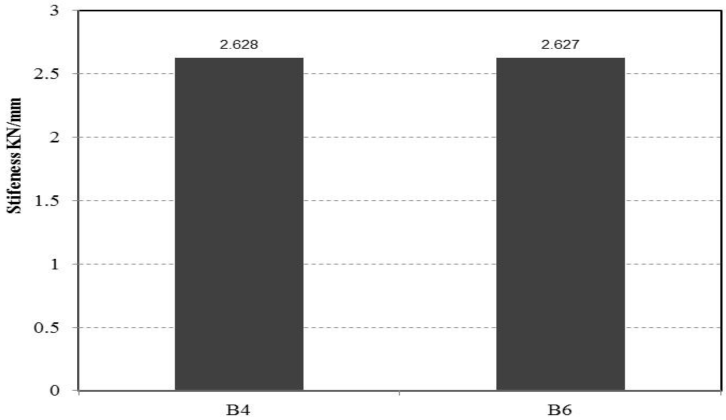

Fig.21: Stiffness for B4 and B6

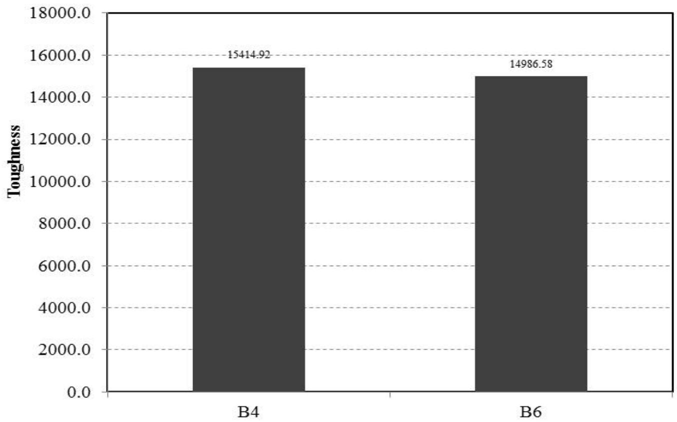

Fig.22: Toughness for B4 and B6

Group 6:

This group consist of four beams one UHSC beam B5 and three composite beams with different UHSC thicknesses which are 100mm, 70mm and 50mm for B7, B8 and B9 respectively. In addition they have the same longitudinal reinforcement ratio which is 6.13%. The load deflection relationship and ductility index values of these beams are shown in Figure (14). Such that the maximum loads were 266.6, 257.6, 218.8 and 188.2 KN for beams B5, B7, B8 and B9 respectively. It was conclude that decreasing the UHSC layer thickness from 300 mm in B5 (the total cross section depth) to 100 mm, 70 mm and 50 mm the maximum load decrease only 3.4%,17.9% and 29.4% for B7, B8 and B9 respectively. So it is obvious that the UHSC beam B5 and beam B7 with UHSC thickness 100 mm give Convergent results. Also it was concluded that by decreasing the UHSC thickness from 300mm to 100mm, 70mm and 50 mm respectively the ductility values decrease by 2.7%, 7.1% and 8.9 % for B7, B8 and B9 respectively. The same trend for the stiffness and toughness values which were represented by Figures (15) for each of B7, B8 and B9 as by decreasing the thickness of UHSC from 300 mm in B5 (UHSC) to 100 mm, 70mm, 50 mm the stiffness decreased by 2.6 %, 3.2% and 19.5% and the toughness decreased by 18%, 42% and 51% for B7, B8 and B9. From these results It can be denoted that Beams B5 (UHSC) and B7 (Composite beam with UHSC thickness 100mm) have the same behavior which allow us for high reinforcement steel ratios to use the UHSC layer with depth about the third of the cross section depth, decreasing of UHSC more than the third cross section depth causes large decreases for values of flexural load, ductility, stiffness and toughness.

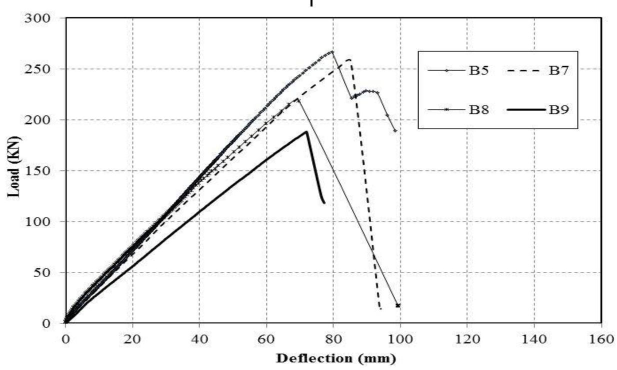

Fig. 23: Load-Deflection Relationship for B5, B7, B8 and B9

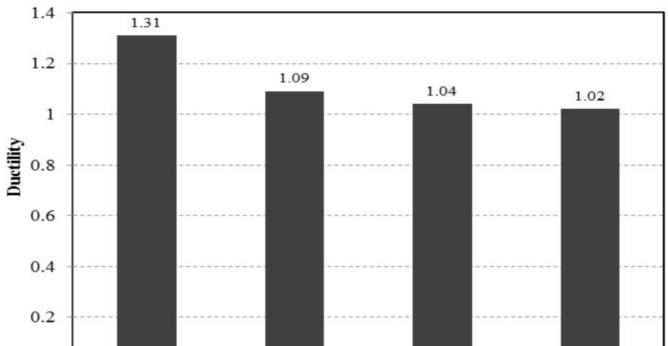

Fig. 24: Ductility index for B5, B7, B8 and B9

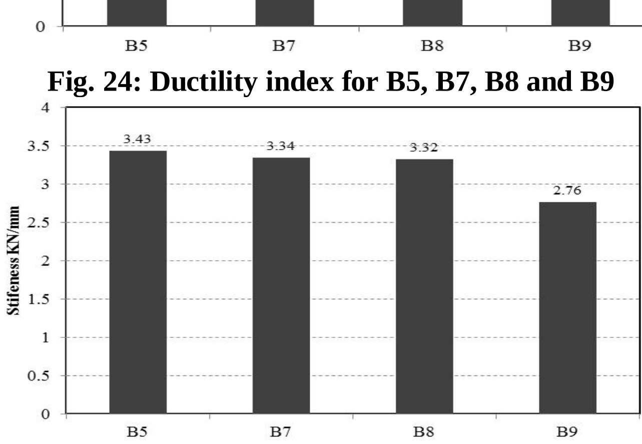

Fig.25: Stiffness and Toughness for B5, B7, B8 and B9

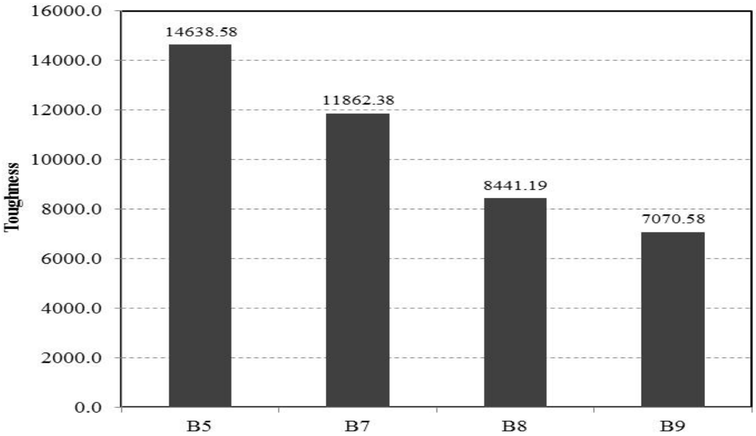

Fig.26: Toughness for B5, B7, B8 and B9

CONCLUSIONS

From the analysis and discussion of the test results obtained from this research, the following conclusions can be drawn.

1. For UHSC beams increasing the longitudinal steel ratio from 3.17% to 4.03% and 6.13% improve the beam ultimate capacity by 13.6% and 46.32% respectively, accompanied with a decreasing in the ductility value by 20.8% and 48.5%. The toughness values also decrease by 15 and 19.2 % respectively while an increasing in the initial stiffness appears by about by 16.3% and 25.4 % respectively.
2. For Composite beams increasing the longitudinal steel ratio from 3.17% to 4.03% and 6.13% improve the beam ultimate capacity by 24.8% and 45% respectively, accompanied with a decreasing in the ductility value by 0.5% and 43.5%. The toughness values also increase by 20.7% by increasing the longitudinal steel ratio from 3.17% to 4.03% and decrease by 19.2 % by increasing the longitudinal steel ratio from 3.17% to 6.13%. While an increasing in the initial stiffness appear by about by 11% and 26.7 % respectively.
3. For beams with longitudinal reinforcement ratio of 3.17 % by increasing the UHSC layer from zero mm (NSC beam) to 100mm (composite beam), the ultimate capacity improved by 28.27% accompanied with an increase of each of ductility, stiffness and toughness values by a ratios of 6.5%, 16.4% and 11.7 % respectively. Also by increasing the UHSC layer from 100 mm (composite beam) to 300mm (UHSC beam) the ultimate capacity improved by only 3.54 % accompanied with an increasing of each of ductility, stiffness and toughness values by a ratios of 13%, 1.4% and 18 % respectively. it is obvious that using both the UHSC or composite concrete improve the ultimate capacity when compared to the NSC beams and there is a very slight difference between the ultimate capacity resulted from using UHSC and composite concrete beams by only about 3.54% .
4. For beams with longitudinal reinforcement ratio of 4.03 % it was concluded that each of composite (100mm UHSC thickness layer) and UHSC beams gives a very slight difference in their results values. Thus by increasing the UHSC layer from 100 mm (composite beam) to 300mm (UHSC beam) give slight increases in the value of the ultimate capacity only by 11.8%. Also the ductility, stiffness and toughness values increase only by 1.8%, 0.03% and 2.8 % respectively .
5. For beams with longitudinal reinforcement ratio of 6.13% by decreasing the UHSC layer from 300 mm (UHSC beam) to 100mm (composite beam) a very slight decrease in the ultimate capacity value by only 3.4% was observed. Also a little decrease appeared in the ductility, stiffness and toughness values by 2.7%, 2.6% and 18% respectively. While by decreasing the UHSC layer from 300 mm (UHSC beam) to70mm (composite beam) and 50mm (composite beam) respectively decreases the ultimate capacity value by 17.9% and 29.4%. The ductility, stiffness and toughness values also decreases by 7.1%, 3.2% and 42% by using the composite concrete beams with UHSC thickness 70 mm, and decreases by 8.9%, 19.5% and 51% by using the composite concrete beams with UHSC thickness 50 mm. It is obvious that the composite concrete beams with UHSC thickness 100 mm which represents third the beam depth give almost the same results of UHSC beams which include the Ultimate capacity, ductility, stiffness and toughness. In

contrast by using the composite concrete beams with UHSC thickness 70 mm and 50mm which gives big differences in their results analysis which may not be acceptable

6. Finally it was deduced that for high reinforcement steel ratios the thickness of UHSC layers that can be used in reinforcement concrete beams cannot be decreased more than the third of cross section depth due to appearing of crushing in the top of NSC layer before it appears in UHSC layer and before the reinforcement steel reaching the yield.
7. By decreasing the reinforcement steel ratio, the UHSC layers thickness may be decreased and that can be confirmed by a future theoretical analysis.

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