SHEAR BEHAVIOR OF HYBRID REINFORCED CONCRETE BEAMS

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ABSTRACT

This study present experimental investigation on shear behavior of hybrid rectangular cross section reinforced concrete beams strengthened with high strength concrete on compression zone of beams.

The experimental work contain six specimens, three with normal strength concrete at all section and others contain high strength concrete in compression zone.

The effect of inclusion layer of high strength concrete on shear strength, ductility, deflection and cracking load are studied in this investigation.

Experimental results showed that the ultimate shear strength, ductility deflection and cracking load are increased when used high strength concrete in compression zone.

Key words : shear, hybrid, high strength concrete

سلوك القص للعتبات الخرسانية الهجينة

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الخلاصة

تقدم هذه الدراسة بحثاً عملياً لسلوك القص للعتبات الخرسانية المسلحة ذات مقطع مستطيل المقواة بالخرسانة عالية المقاومة في منطقة الانضغاط.

يتضمن الجزء المختبري ستة نماذج, ثلاثة منها تحوي خرسانة عادية المقاومة في كل المقطع والثلاثة الاخرى تحوي خرسانة عالية المقاومة في منطقة الانضغاط.

تأثير استخدام طبقة من الخرسانة عالية المقاومة على مقاومة القص, المطيلية, التشوهات وحمل التشقق تمت دراسته في هذا البحث.

اظهرت النتائج المختبرية بان هناك زيادة في مقاومة القص والمطيلية والهطول وكذلك حمل التشقق عندما استخدمت الخرسانة عالية المقاومة في منطقة الانضغاط.

INTRODUCTION

To increase the load carrying requirement of steel sections, a hybrid section is used. The concept of hybrid section in steel structures is not a new idea. Salmon and Johnson [1] defined a hybrid girder as one that has either the tension flange or both flanges of steel section made with a higher strength grade of steel than used for the web.

For steel fiber reinforced concrete sections, Kawamata et al**.**[2] defined a hybrid fiber reinforced concrete as a composite material which contains two different types of fiber together. The hybrid matrix (concrete) containing the steel fibers becomes more ductile and the tensile strength due to crack arrest mechanisms of steel fibers is much improved.

Ali[3] make an experimental and theoretical investigation of flexural and shear behavior of hybrid I-shaped cross section reinforced concrete beams strengthened with steel fibers and/or high strength concrete (HSC), and cast with or without construction joints. Also sahib[4] make an experimental study on beam which contain high strength concrete and normal strength concrete in one beam and study effect the layer of high strength concrete on flexural behavior, strain and ductility.

In order to repair or strengthen structural elements, layers of new concrete are often applied to an old structure. Hence, Bernard, et al**.**[5] defined hybrid concrete structures as structural elements consisting of new and old concrete layers.

When extending the hybrid concept to composite concrete members and due to advances in concrete technology, it is relatively easy to produce composite sections which possess high compressive strength, high ductility, high energy absorption and high tensile strength at the same time.

These characteristics can be achieved by placing two or more different types or strengths of concrete layers together so that each layer is used to its best advantage and as a result, the concrete section becomes a "hybrid" section.

In the present study, the hybrid rectangular shape cross section beam is defined as one that has either the compression zone made with high strength concrete different from that used for the tension zone.

High Strength Concrete

The relatively recent development in concrete technology has led to produce high compressive strength concrete of (50 to 150 MPa). High strength concrete can be produced by adding high range water-reducing admixtures (superplasticizers) and/or other admixtures (silica fume or fly ash) to Portland cement concrete. Superplasticizer compounds sharply reduce the amount of water required to produce a workable mix so that concretes with water cement ratios on the order of (0.25) or less flow easily without excessive bleeding and segregation.

The use of high strength concrete in construction leads to the design of smaller sections; reduction of dead weight, and allowance of longer spans and more usable area of buildings.

Although high strength concrete offers advantages in terms of performance and economy of construction, the brittle behavior of the material remains a major drawback in some structural applications especially in earthquake resistant structures. Since strength and ductility of concrete are inversely proportional, high strength concrete is significantly more brittle than the normal strength concrete(6).

Shear In Reinforced Concrete Beams

Shear failure in reinforced concrete members are sudden and catastrophic in nature and should be avoided in the design process. That is why reinforced concrete members are first dimensioned in flexure and then checked out for shear. The effect of shear is to induce tensile stresses on inclined plans oriented at approximately 45^o to the plane on which the shear stresses act. Failure occurs when these stresses, along with horizontal stresses due to bending, exceed the diagonal tensile strength of the material. Therefore, shear failures in concrete members are diagonal tension phenomena; the failures occur in an inclined plane due to the combined effect of shear and flexural stresses. However, it is difficult to determine the value of the diagonal tension stresses in reinforced concrete beam because the distribution of shear and flexural stresses over a cross section is not known with certainty (reinforced concrete is a composite, non homogeneous and nonisotropic material that cracks significantly under relatively low loads). Accordingly, shear strength prediction in reinforced concrete members is an empirical problem based on the assumption that a shear failure at the critical section occurs on a vertical plane when the fictitious shear stresses at that section, $\frac{V}{bd}$, exceed the concrete fictitious vertical shear strength (also called nominal shear strength). That are basically two definitions for the nominal shear strength: the ultimate shear strength , $\frac{Vu}{bd}$, and the cracking shear strength, $\frac{Vc}{bd}$. the cracking shear strength is defined as the shear strength at the occurrence of a first major diagonal crack; the ultimate shear strength is defined as the shear strength when complete and total failure occurs(7).

According to ACI 318-2008(8) design procedure, it is useful to know the shear carrying capacity of beams reinforced in bending only before the addition of web reinforcement. If the shear at the critical shear is greater than one-half the nominal shear resistance, then stirrups are added to carry the difference. Therefore, the shear strength prediction of reinforced concrete members without web reinforcement is an important piece of information in the design process of concrete beams and frames. Furthermore, there are many concrete structural members such as slabs, walls and foundations that do not use stirrups, and consequently, a good knowledge of the shear strength of reinforced concrete members without web reinforcement is also necessary in these cases.

There are several factors effect shear strength of beams:

Beam size: The shear strength increase with increasing beam dimension(9).

Longitudinal Reinforcement: As the longitudinal reinforcement decrease there is reduction in beam shear strength(9).

Shear span to depth ratio: the shear strength decreases dramatically as the shear span to depth ration increase in case of short beam[10].

Concrete compressive strength: there increase in shear strength when increasing the compressive strength of concrete.

EXPERIMENTAL INVESTIGATION

Six beams were tested in an experimental investigation conducted at Al-Mustansiriya University the primary variable influencing the specimen design was layer of high strength concrete which added to the upper side of beam in compression zone. The experimental program was divided in to three separate test series.

Series (1) was comprised of two beams designed flexural reinforcement over ρmin and 3Ø5 in each side as a shear reinforcement and the dimension of these beams (100x200x1000mm).

Series (2) was comprised of two beams designed flexural reinforcement over ρmin and 5Ø5 in each side as a shear reinforcement and the dimension of these beams (100x200x1000mm).

Series (3) was comprised of two beams designed flexural reinforcement over ρmin and 7Ø5 in each side as a shear reinforcement and the dimension of these beams (100x200x1000mm). See **Figures (1,2,3)** and **Table (1)**.

MATERIALS

Cement

The type of cement used in this study is ordinary Portland cement (Type I).

Fine Aggregate

Fine aggregate used in this study, has a maximum size less than (5 mm).

Coarse Aggregate

The ideal coarse aggregate should be clean. With large amount of crushed aggregate and a minimum of flat and elongated particles is used.

Steel Reinforcement

The reinforcing steel is deformed .The average yield strength is (435MPa), the average ultimate strength is (601 MPa), and the reinforcing steel bar is (10 and 12 mm) in diameter for compression and tension respectively. This test is made in the materials laboratory, College of Engineering, Al-Mustansiriya University.

MIX PROPORTIONS

Table (2) show the mix proportions is used in tested beams.

Compressive Strength

Cylindrical (150x300) and cubical (150x150) specimens were used to test the compressive strength of concrete. The compressive test was done according to ASTM C39 and B.S 1881 by using a computerized machine in the materials laboratory, College of Engineering, Al-Mustansiriya University, with a capacity of (1000 kN). The cylindrical and cubical compressive strength is shown in **Table (3)**.

Testing Machine

The machine which was used in the tests is a universal hydraulic machine with (300 ton) capacity . The loading arrangement is shown in **Figure (4)** and **Figure (5).**

Cracks Pattern And General Behavior

The mode of failure as expected was typical shear failure in all tested beams. See **Figure (6)** to **Figure (11)**.

Cracking of each specimen progressed as follow; Flexural cracks at mid-span developed during the early stages of loading. Additional flexural cracks along the shear span as load increased. These cracks gradually became inclined as the propagated along the longitudinal reinforcement continue to the support.

In general, the type of concrete in compression zone greatly affects the observed cracking pattern. In beams HS3, HS5 and HS7 with high strength concrete in compression zone have shear cracks wider than the shear cracks in NS3, NS5 and NS7 with no high strength concrete in compression zone this may be due to the high compressive strength in HS3, HS5 and HS7 beams.

Ultimate Shear Strength

The ultimate shear strength of the tested beams are compared with the reference beams (NS3, NS5 and NS7) and reported in the **Table (4)** in terms of shear force at failure (Vu).

The strength of beams (HS3, HS5 and HS7) with high strength concrete in compression zone was increased (10.8, 13.7 and 11.1)% this due to increase in compressive strength, beam stiffness and improved the resistance to the tensile cracking in the compression zone and as a result, the overall strength of the beam was increased.

LOAD-DEFLECTION BEHAVIOR

In general, there are three stages in load-deflection curve, these stages are cracking load, yielding load and ultimate load capacity.

At first stage, beams cracks in flexure under small load, first crack is observed at load ranging from (10-18)% of the ultimate load.

In precracking stage, deflection increase linearly in all beams with loading this means that the materials in compression and tension zone are in elastic manner.

In postcracking stage there is also linear relationship between load and deflection but with different slope up to yielding of longitudinal reinforcement after that there is a curvature in load-deflection curve up to failure by shear.

In general the deflection of beams (HS3, HS5 and HS7) (which contain high strength concrete in compression zone) more than the reference specimens (NS3, NS5 and NS7) at same loading values, and the maximum deflection at failure in specimens which contain high strength concrete in compression zone is more than the maximum deflection in beams had not high strength concrete in compression zone. See **Figure (12) to Figure (14).**

Ductility

Ductility is defined as the energy absorbed by the material until complete failure occurs and equal to the deflection at ultimate load to the deflection at yielding. As shown in **Table (5)**, at beams (HS3, HS5 and HS7) the ductility was increased (47.9, 97,3 and 46.85)% respectively in comparison with beams (NS3, NS5 and NS7) which had not high strength concrete in compression zone, this is because slight increase in ultimate load capacity, which produce higher ultimate deflection, also this is may be due to the construction joint between high and normal strength concrete which decreased the beam stiffness then increased ultimate deflection and ductility.

In general, all tested beams exhibited good ductility due to presence high strength concrete in compression zone and presence of construction joint.

First Cracking Load

The first cracking loads are shown in **Table (4)**. For all beams, the first cracking were distributed in the moment region, the visible first cracking loads of the beams are between (10.25%) and (18.3%) with respect to the ultimate loads.

For beams cast with high strength concrete in compression zone (HS3, HS5 and HS7) the cracking load that produced first cracking about (15.38%, 20.46%, 12.3%) in comparison with beams without high strength concrete in compression zone (NS3, NS5 and NS7) respectively. This increase may be due to the resistance remaining in the tension zone.

The experimental values of cracking loads are obtained from measuring the load-deflection diagram. **Table (6)** shows a comparison between measured and predicted values of cracking load according to ACI 318-02 code.

$$M_{cr} = \frac{f_r . I_g}{y_t} \quad \dots (1)$$

$$Pcr = \frac{M_{cr} * 6}{L} \quad \dots (2)$$

Where:-

Mcr = cracking moment, N.mm

Pcr = cracking Load; N

fr = modulus of rupture of concrete, N/mm2.

Ig = moment of inertia of gross concrete section about centroidal axis, mm4

yt = distance from centroidal axis of gross-section to extreme fiber in tension L = distance between two supports; mm

Comparing the experimentally measured values and those calculated according to Eq. (2), it can be seen, that all the estimated values are within an accuracy of about (33%, 34%, 33%, 34.8%, 27.5%, 24.3) for NS3, HS3, NS5, HS5, NS7 and HS7 respectively.

CONCLUSIONS

1. The beams with high strength concrete in compression zone have shear cracks wider than the shear cracks in beams with no high strength concrete in compression zone.
2. The beams with high strength concrete in compression zone have ultimate shear strength higher than the beams which have no high strength concrete in compression zone.
3. The deflection in beams with high strength concrete in compression zone is more than the deflection in beams with no high strength concrete in compression zone.
4. The maximum deflection at failure in beams with high strength concrete in compression zone is more than the maximum deflection in beams with no high strength concrete in compression zone.
5. There is good improvement in ductility in beams with high strength concrete in compression zone.
6. The cracking load in beams with high strength concrete in compression zone is greater than the cracking load in beams with no high strength concrete in compression zone.

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Table (1) Specimens Specifications

Group No.	Specimens	Type of section		Flexural Reinforcement	Shear Reinforcement	Compressive strength	
		Normal reinforced concrete	Hybrid reinforced concrete			Normal concrete	High strength concrete
G1	NS3	/		2Ø12 down 2 Ø10 up	3Ø5	36	
	HS3		/	2Ø12 down 2 Ø10 up	3Ø5	36	51.3
G2	NS5	/		2Ø12 down 2 Ø10 up	5Ø5	33.15	
	HS5		/	2Ø12 down 2 Ø10 up	5Ø5	33.15	49.3
G3	NS7	/		2Ø12 down 2 Ø10 up	7Ø5	31.8	
	HS7		/	2Ø12 down 2 Ø10 up	7Ø5	31.8	54

Table (2) Mix Proportions

Concrete strength MPa	Cement Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	Water Kg/m^3	w/c ratio	SP Ltr/m^3
27	415	535	1250	183	0.44	-
80	541	774	984	151	0.28	7

Table (3) Compressive Strength Of Tested Beams

Specimens		Cube Strength f_{cu} (MPa)	Cylinder Strength f'_c (MPa)
NS3		36	27.13
HS3	Normal strength	36	27.13
	High strength	51.3	40.3
NS5		33.15	24.93
HS5	Normal strength	33.15	24.93
	High strength	49.3	38.65
NS7		31.8	23.1
HS7	Normal strength	31.8	23.1
	High strength	54	42.82

Table (4) Ultimate Shear Strength Of Tested Beams

Specimens	Ultimate Shear Strength	Percent of Increase in Ultimate Load
NS3	74	—
HS3	82	10.8
NS5	102	—
HS5	116	13.7
NS7	117	—
HS7	130	11.1

Table (5) Ductility Index Of Tested Beams

Beam No.	Ultimate Deflection(Δu) (mm)	Yielding Deflection(Δy) (mm)	Ductility Index($\frac{\Delta u}{\Delta y}$)	% Increase in Ductility
NS3	3.3	1.98	1.67	———
HS3	3.52	1.42	2.47	47.9
NS5	4.3	2.82	1.52	———
HS5	5.1	1.7	3	97.3
NS7	3.05	2.13	1.43	———
HS7	5.45	2.6	2.1	46.85

Table (6) cracking load

Beam No.	Experimental Cracking Loads (kN)	Theoretical Cracking Loads (kN)	%increase in experimental cracking load	% $\frac{\text{(exprtimental} - \text{theoritical)}}{\text{experimental cracking Loads}}$
NS3	13	8.7	———	33
HS3	15	9.9	15.38	34
NS5	13	8.7	———	33
HS5	15.66	10.2	20.46	34.8
NS7	12	8.7	———	27.5
HS7	14.75	11.16	22.9	24.3

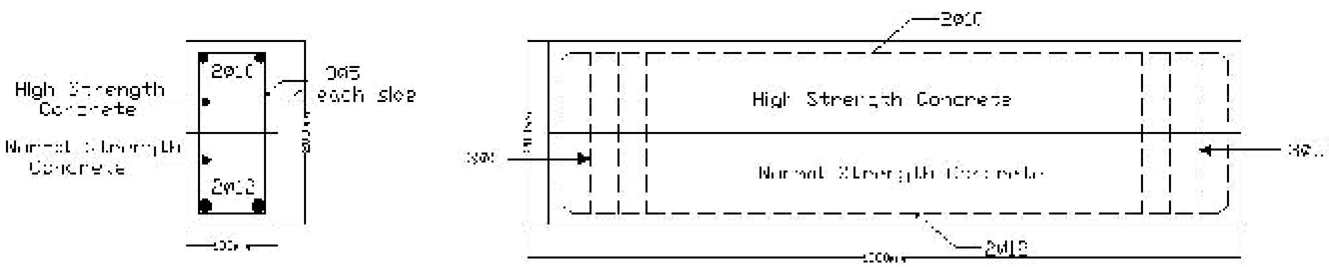

Figure (1) series (1)

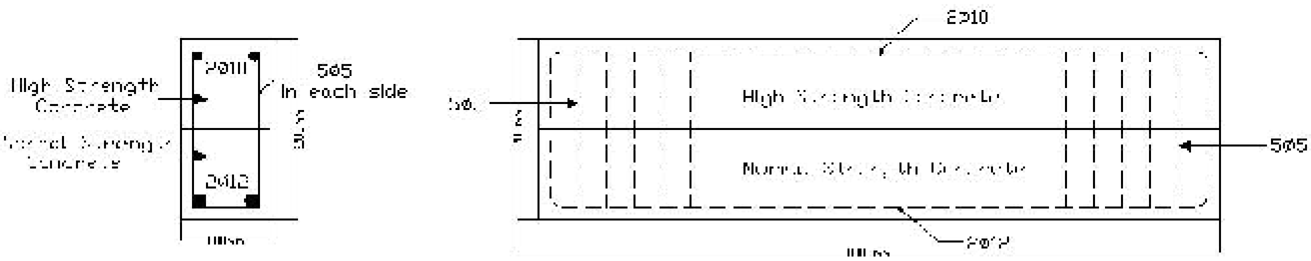

Figure (2) series (2)

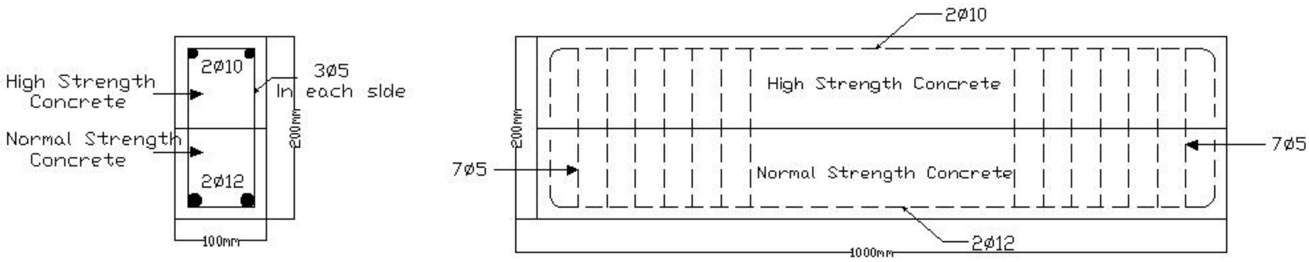

Figure (3) series (3)

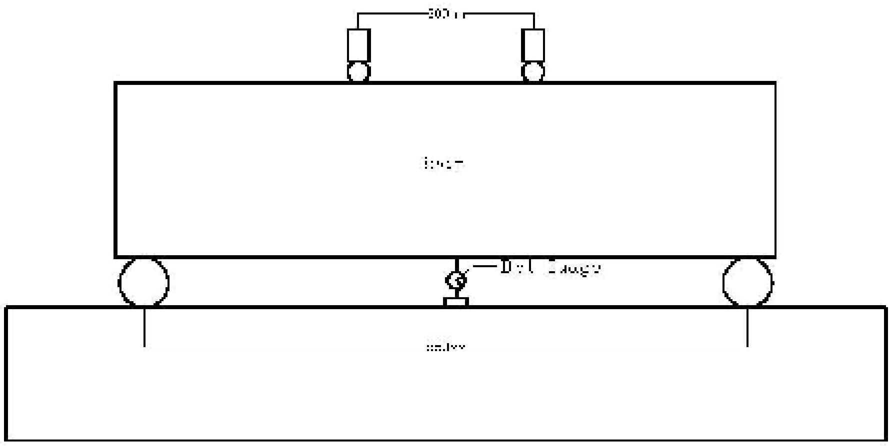

Figure (4) test set-up

Figure (5) testing machine

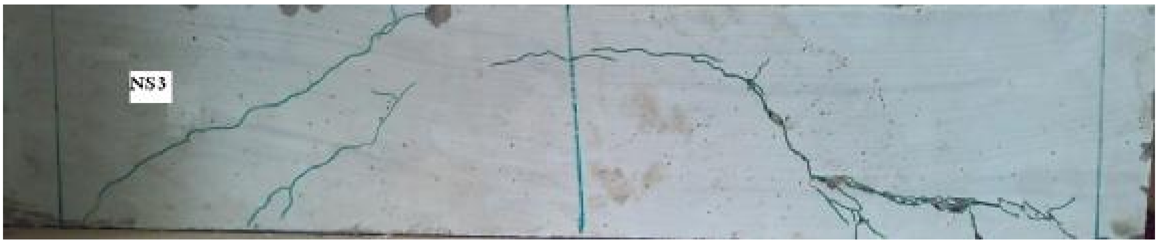

Figure (6) crack pattern and failure mode of beam NS3

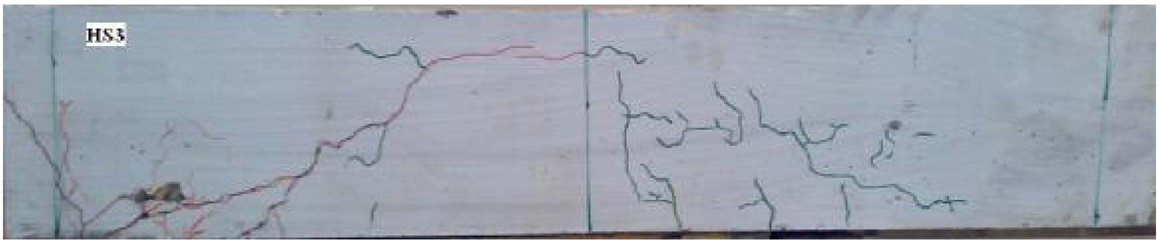

Figure (7) crack pattern and failure mode of beam HS3

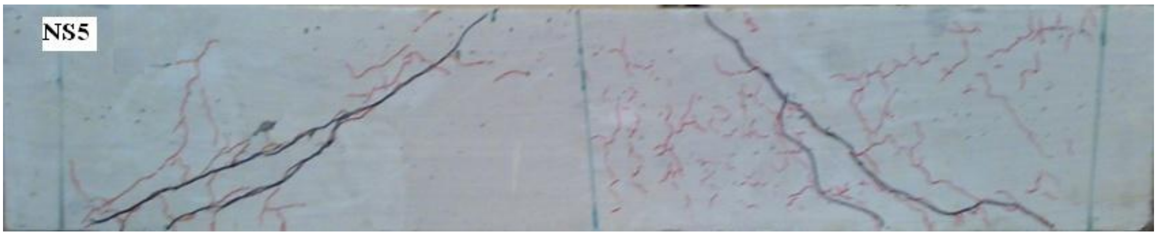

Figure (8) crack pattern and failure mode of beam NS5

Figure (9) crack pattern and failure mode of beam HS5

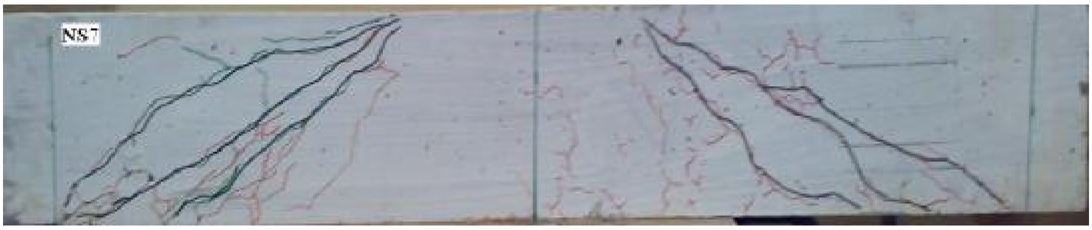

Figure (10) crack pattern and failure mode of beam NS7

Figure (11) crack pattern and failure mode of beam NS7

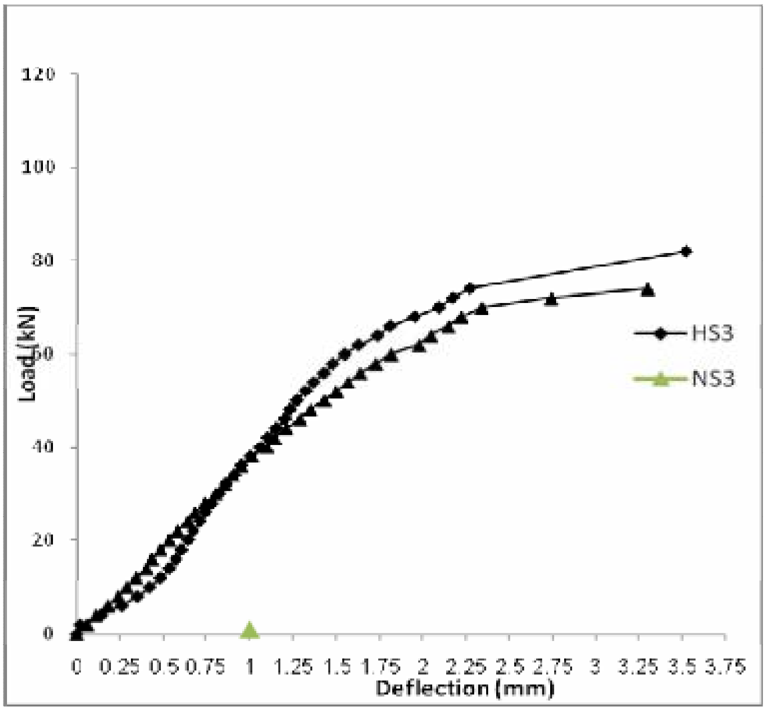

Figure (12) load-deflection curve of specimens (NS3 and HS3)

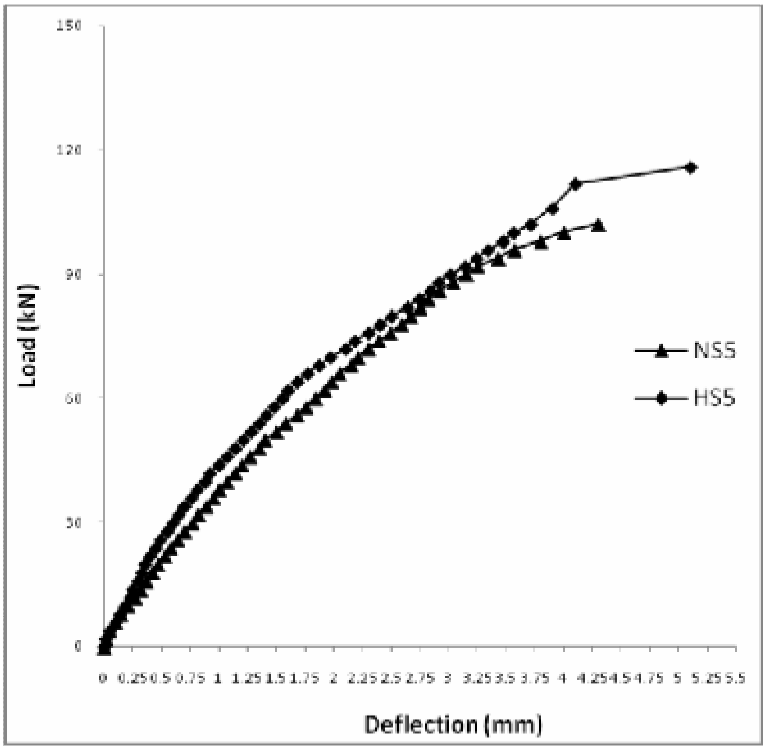

Figure (13) load-deflection curve of specimens (NS5 and HS5)

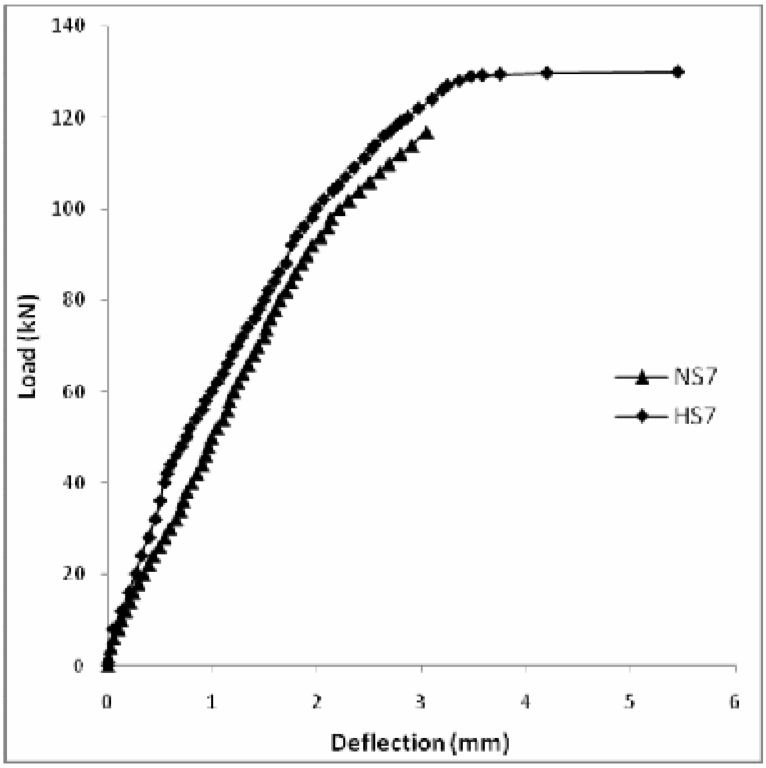

Figure (14) load-deflection curve of specimens (NS7 and HS7)