Mansoura Engineering Journal

Volume 42 | Issue 4 Article 6

6-24-2020

Effect of Confinement Techniques on Mechanical Behavior of Over-Reinforced HSC Beams.

Seleem Ahmad
Professor,Mat.Dept., Faculty of Engineering Zagazig University, Egypt, seleemahmad62@yahoo.com

Mohamed El-Shikh
Professor, Str.Dept., Faculty of engineering, El mansura,University,Egypt, mohamed_elshikh@yahoo.com

Mohamed Elmahdy
Assistant Lecturer, Misr Higher Institute of Eng.&Tech,Elmansura,Egypt, engmohamed_elmahdy@yahoo.com

Recommended Citation

Ahmad, Seleem; El-Shikh, Mohamed; and Elmahdy, Mohamed (2020) "Effect of Confinement Techniques on Mechanical Behavior of Over-Reinforced HSC Beams.," *Mansoura Engineering Journal*: Vol. 42 : Iss. 4 , Article 6.
Available at: https://doi.org/10.21608/bfemu.2020.97680

Mansoura University
Faculty of Engineering
Mansoura Engineering Journal

Effect of Confinement Techniques on Mechanical Behavior of Over- Reinforced HSC Beams

تأثير تقنيات تدعيم الكمرات الخرسانية عالية التسليح والمقاومة على سلوكها الميكانيكي

S.S.E. Ahmad, El-Shikh M. Yousry and Mohamed.A.R. Elmahdy

KEYWORDS:
High strength concrete, Confinement method, Fiber reinforcement concrete, Fiber reinforced epoxy, Stirrups pitch, Strength and ductility

الملخص العربي :-
تظهر الخرسانة عالية المقاومة العديد من المشاكل في السلوك الميكانيكي لها والذي يتحول إلي سلوك مادة شديد القصافة مما يؤدى إلي نقص في متانة الكسر بشكل كبير ولذلك هناك حاجة ماسة للتغلب علي نقص متانة الكسر .
ويهدف هذا البحث الي تقييم عدة طرق مقترحة لتغيير نمط الإنهيار للكمرات الخرسانية المسلحة من الخرسانة عالية المقاومة ذات مقاومة للضغط حوالي 80 ميجا باسكال أستخدم فى صبها نسب تسليح مختلفة. كما استخدمت ثلاث طرق مختلفة للتدعيم (زيادة عدد الكانات في منطقة الضغط - استخدام خرسانة الألياف في منطقة الضغط - و بإستخدام شرائح الإيبوكسي المسلح بألياف الكربون فى منطقة الضغط.
وقد أعطت الطريقة الأولي والطريقة الثالثة نتائج متماثلة في زيادة مقاومة الكمرة وزيادة في قيمة الترخيم الناتج مقارنة بنتائج الكمرة المرجعية.

Abstract— **Over-reinforced high strength concrete, HSC, sections are restricted in most design codes to avoid the brittle compression failure of concrete which occurs suddenly without warnings. Recently, there have been significant improvements in construction industry that needs to use over-reinforced sections in huge projects such as, high-rise buildings and bridges. Limited trials have been carried out to strengthen the over-reinforced section by using proper confinement in the compression zone. This confinement restrains the lateral expansion and failure of concrete in the compression zone. HSC provides high strength but lower ductility than normal strength concrete. This low ductility limits the benefit of using HSC in building safe structures.**

This study investigates experimentally the effect of installing different configurations of confinement techniques in the compression zone of over reinforcement high concrete beams. These configurations contain confined by square ties, wrapping fiber reinforced epoxy sheet, and fiber reinforced concrete in compression zone. Four groups of beams made of HSC were cast and tested under three-point loading, with emphasis placed on the mid span deflection. The first group served as a reference beam. Results of testing the four groups proved that the suggested techniques of confinement for HS reinforced concrete beams gave highest values for first crack and ultimate loading and maximum beam deflection. Moreover, the crack pattern and mode of failures were changed from sudden compression-shear failure for control beam to multiple tensions cracking for confinement beams.

Received: (23 April, 2017) - revised: (7 September, 2017) - accepted: (18 October, 2017)

S.S.E. Ahmad, Professor,Mat.Dept., Faculty of Engineering Zagazig University, Egypt, 01062189843, (e-mail: seleemahmad62@yahoo.com)

El-Shikh M. Yousry,Professor, Str.Dept., Faculty of engineering, El mansura,University,Egypt,01124010042,(e-mail: Mohamed_elshikh@yahoo.com)

Mohamed.A.R. Elmahdy, Assistant Lecturer, Misr Higher Institute of Eng.&Tech,Elmansura,Egypt,01229474010,(e-mail: Engmohamed_elmahdy@yahoo.com.)

I. INTRODUCTION

THE availability of high strength materials such as high strength steel and high strength concrete enhances the strength of reinforced concrete columns as well as beams, but increasing strength decreases beam ductility. Installing confining reinforcement in the compression zone of a reinforced concrete beam enhances its ductility and compressive strength. This confined concrete compressive strength cannot be predicted using models for columns, because columns behave differently. The position of helices in beams affects confinement, the spalling off phenomena, and the confined strain developed from resisting the concrete expansion. Extensive experimental data and worthy observation are required to understand and develop a model to predict the behavior of over-reinforced high strength concrete beams [1].

Beam is a structural element that carries load primarily in bending. Bending causes the beam to go into compression and tension zones. The compression zone designed to resist buckling and crushing, while the tension zone must be able to resist the tension. When designing reinforced concrete beams, designers have to limit the amount of tensile reinforcement to prevent the brittle failure of concrete. Therefore, the full potential of the use of steel reinforcement cannot be achieved. At over reinforced-concrete sections, the longitudinal reinforcement ratio should allow to exceed the maximum value specified in design codes by using the confining stirrups in compression zone [2].

The preference for ductility is partly to try to obviate brittle and semi-brittle structural failure, which because of its usual sudden nature tends to have very negative consequences. Ductility also has high-energy dissipation capability for withstanding dynamic loads, such as those caused by earthquakes. There are a few ways of improving the ductility of concrete in compression, providing longitudinal compression reinforcement, using randomly oriented steel fiber, or installing a helical or tie confinement in the compression zone [1, 3, and 4].

The use of fiber-reinforced polymer (FRP) composites started about 15 years ago with the pioneering research performed at the Swiss Federal Laboratories for Materials Testing and Research, or EMPA. Superior strength or stiffness to weight ratio, ductile form in design, and sustained chemical inertness in most civil environments. The Fiber Reinforced Polymer (FRP) or Fiber Reinforced Plastics have been widely utilized in civil infrastructures due to their unique properties. The advantages of FRP composites include current design of FRP confined concrete retrofit jacketing system is still limited to the experimental results of transversely reinforced steel in concrete confinement [5, 6].

Yulita Arni, et al. explains the behavior of both reinforced concrete beams with and without confinement in compression zone to evaluate the influence of confinement in compression zone to the increasing of beam ductility. Four beams with reinforcement ratio $\rho = 1.9$ % and 2.5 % have been tested with monotonic loading. The results showed that an increase up to 300 % in concrete strain for beams with confinement on the compression zone than beams without confinement [7].

Self-compacting concrete is very sensitive to changes in aggregate characteristics (shape, texture, maximum size, grading and morphology), so the aggregate should be chosen carefully. The optimum coarse aggregate for SCC depends on two parameters. The first parameter is the maximum size, where lower values of maximum size lead to increased coarse aggregate content. The second parameter is the shape of the coarse aggregate, whether it's crushed or rounded, where a higher content of rounded shape leads to increased coarse aggregate content increased in maximum size leads to decreased passing ability(8).

The use of confinement in over-reinforced concrete beams was discusses by R.G. Delalibera, etal. This reinforcement consists of square stirrups, placed in the compression zone of the beam cross-section, in order to improve its ductility. The experimental results show that the post-peak ductility factor is proportional to the confining reinforcement ratio, however the same is not observed for the pre-peak ductility factor, which varied randomly with changes in the confining reinforcement ratio. It was also observed from the experiments that the confinement effect tends to be smaller close to the beam neutral axis [8, 9, and 10].

This study investigates experimentally the effect of installing different configurations of confinement techniques in the compression zone of over reinforcement high concrete beams. These configurations contain confinement by square ties, wrapping fiber reinforced epoxy sheet, and fiber reinforced concrete in compression zone.

II. EXPERIMENTAL PLAN

The used materials in the current research were chosen from the available materials in Egypt. The experimental program includes preparation, tests of materials, mixing, casting, curing, testing setup and test plan.

2.1 Materials Properties

Ordinary Portland Cement (OPC) (CEM I 52.5 N) produced by Bani Sweif cement factory was used in this study. The different laboratory tests were conducted on cement conforms to Egyptian Standards (ES 4756-1/2009) [11]. The physical and mechanical properties of cement are shown in table (I).

TABLE I
PHYSICAL AND MECHANICAL PROPERTIES OF THE CEMENT

Test		Test result	(ES 4756-1/2009) limits
specific gravity		3.15	-----
Specific surface area (cm^2/gm)		3600	≥2750
Setting time (Vicat apparatus) (min)	Initial	75	≥45 min
	Final	190	≤10 hours
Compressive strength 2 days (MPa)		23.5	≥20 MPa
Compressive strength 28days (MPa)		54.4	≥52.5 MPa
Consistency of standard cement paste		W/C= 28 %	26% - 33%

All aggregates used in this research are locally available; it consisted of basalt, quartz and Siliceous Sand. Coarse aggregate washed 7 days before using and left dry to avoid the effect of fine materials in aggregate. The coarse aggregates used in the experimental work is Basalt from Beni sweif with a maximum nominal size 10 mm. Testing of the used coarse aggregate was complied with the Egyptian Standards ES 1109-2008 [12].

Table (II) show the grading of the used coarse aggregate. The physical properties of the used coarse aggregate given in table (III).

TABLE II
GRADING OF THE COARSE AGGREGATE

Sieve size (mm)	37.5	20	10	5	2.36	1.18
Passing %),Basalt	100	99	96.5	11.4	1.6	0.25

TABLE III
THE PHYSICAL PROPERTIES OF THE COARSE AGGREGATE

Property	**Basalt**	**Limits***
Specific weight	2.5	-
Bulk density (t/m3)	1.47	-
Coefficient of abrasion (Loss Angloss) %	16	Less than 30
Coefficient of impact %	12	Less than 30
Crushing value %	22	Less than 30
Absorption %	1.5	Less than 2.5
Clay and fine dust content %	0.8	Less than 3.0

*The limits according to Egyptian Specification No (1109/2008).

Crushed Quartz and Siliceous Sand used as fine aggregate. Testing of the used fine aggregate was complied with the Egyptian Standards ES 1109-2008 [12]. The physical properties of used fine given in table (IV).

TABLE IV
THE PHYSICAL PROPERTIES OF THE FINE AGGREGATE

Property	**Crushed Quartz**	**Siliceous Sand**	**Limits***
Specific weight	2.5	2.3	-
Bulk density (t/m3)	1.52	1.52	-
Fineness modulus	3	2.9	-
Material finer than No 200 sieve %	2.62	2.6	Less than 3%

*The limits according to Egyptian Specification No (1109/2008).

The silica fume used in this research as a mineral admixture was brought from sika company in Egypt.Table (V) show the physical composition of the used silica fume obtained from the manufacture data sheet.

TABLE V
THE PHYSICAL PROPERTIES OF THE SILICA FUME

Property	**Result***
Specific surface area (m2/kg)	17×10^3
Particle size (t/m3)	8.00
Specific gravity	2.20

*By the manufacture data sheet.

A high performance superplasticizer concrete admixture Sika Viscocrete -3425 was used in this work, it is a third generation superplasicizer for homogenous concrete, it meets the requirements for superplasticizers according to ASTM-C-494 types G and F and BS EN 934 part 2:2001. Using this type of superplasticizers obtained extremely powerful water reduction and resulting in high density and strengths, it improves shrinkage, creep behavior and water impermeability. The used dosage of superplasticizers was constant in all mixes equal 4.5 % of the weight of cement, Table (VI) show the properties of superplasticizers used in this work.

TABLE VI
PROPERTIES OF THE USED SUPERPLASTICIZERS

Property	**Result***
Appearance / color	Clear liquid
Density (Kg/lit)	1.08
PH value	4.0
Solid content (% by weight)	40

*By the manufacture data sheet.

Clean tab drinking water was used in mixing. The water to cement ratio W/C was 0.20 in all beams to get ultra-high strength concrete.

Plain steel fibers used were manually prepared by cutting wire galvanized strap with 0.70 mm diameter and a tensile strength 680 Mpa. Steel fibers used had 0.70 mm diameter and (30 mm ± 10 mm) length with aspect ratio (L/D) equal 45.

High tensile deformed steel rebars (nominal diameter 16 mm) were used as tension reinforcement. The rebars had a yield stress of 550 MPa. Mild steel rebars (nominal diameters 6 and 8 mm) were used for stirrups and compression reinforcement with yield strength of 350 MPa

A high strength carbon fiber fabric for structural strengthening, X- Wrap C300 manufactured by X- CALIBUR Company was used. It is a carbon fiber uni-directional sheet designed for the strengthening of structural members against tensile, shear and impact forces. The sheet is used in conjunction with a primer and lamination resin. It is black in color. The laboratory test data are given Table (VII) according to manufacture technical data sheet.

TABLE VII
PROPERTIES OF THE USED CARBON FIBER SHEET

Property	**Result***
Sheet weight	300 g/m2
Carbon content	95%
Nett effective thickness	0.166 mm
Modulus of elasticity	240 GPa
Tensile strength	4000 MPa
Elongation at break	2%

*By the manufacture data sheet.

Lamination resin for X-Wrap Fabrics was used. It is a high performance epoxy resin designed as an impregnate for fabric reinforcement; the resulting laminate offers excellent strengthening properties coupled with long term durability. The properties of product are given in Table (VIII) according to manufacture technical data sheet.

TABLE VIII.
PROPERTIES OF THE USED X-WRAP LAMINATION ADHESIVE

Property		**Result***
Viscosity 20oC	Standard	5000 cps
	Tropical	7000 cps
Pot Life	Standard	40 mins at 25C
	Tropical	40 mins at 35C
Tensile Strength 7d/20o C		45MPa
Flexural Strength 7d/20o C		60MPa
Compressive Modulus 7d/20o C		1.67GPa
Glass Transition Temperature		65C
Theoretical Coverage		0.5 to 0.6 kg/m2

*By the manufacture data sheet.

2.2 Mix Design, casting and curing

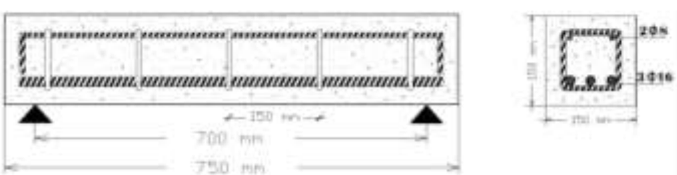
The preliminary mix Proportions which shown in table (IX) were determined and the weight of each component to produce one cubic meter of concrete can be calculated based on absolute volume method. Hence, the content of fine and coarse aggregate can calculated. Mixing of concrete components done by using a horizontal mixer. The aggregates (coarse and fine), cement, silica fume, were added into the mixer in dry state and mixed for 2 minutes. The mixing time necessary was determined by practical trials, and then the mixing water and superplasticizer were added gradually and mixed for another 3+2 minutes to get on uniformity and homogeneous mixes. The fresh concrete taken from the mixer placed in the molds under its own weight without any vibration effort. After the molds had filled of concrete, the specimens kept in the molds for 24 hours in air. After 24 hours, specimens removed from the molds and stored under fresh water until the tests.

TABLE IX
MIX PARAMETERS FOR THE PRESENT EXPERIMENTAL PROGRAM

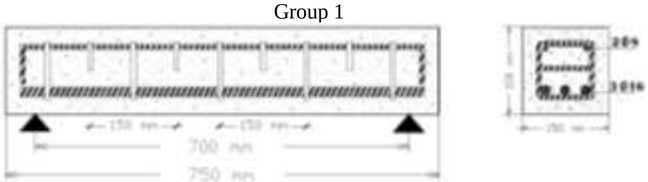
C.C	water	SF	Aggregate Type		Aggregates (100%)	
Kg/m3	Lit/m3	%C	Coarse	Fine	Coarse (%)	Fine(%)
1000	200	15%	Basalt	Quartz + Sand	50%	50%

2.3 Test specimens

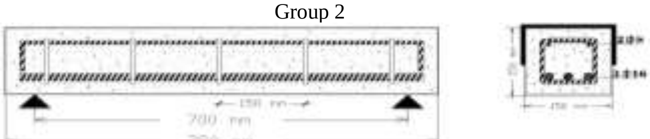
Twelve beams (four models and three beams for every model) were cast with Their cross section was 150×150 mm, they were 750 mm long and had a clear span of 700 mm. Their generic details are shown in Figure (1). The beams categorized as maximum longitudinal reinforcement ratio, stirrups confinement in compression zone, confining compression zone using carbon fiber wrap and confining compression zone using steel fiber as shown in table (X).



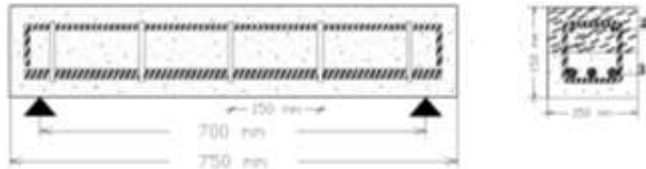
Group 1



Group 2



Group 3



Group 4

Figure (1): from group 1 to 4: Geometrical and reinforcement details of the tested beams.

TABLE (X)
DETAILS OF THE TESTED BEAMS.

Group No.	Description	Stirrups			Steel	
		Diameter	Section	Space	Tension	Compression
1	maximum longitudinal reinforcement ratios	8 mm	100×100 mm	150 mm	3D16mm	2D8mm
2	Stirrups confinement in compression zone	8 mm 8 mm	100×100 mm 100×50 mm	150 mm 150 mm	3D16mm	2D8mm
3	carbon fiber wrap in compression zone	8 mm	100×100 mm	150 mm	3D16mm	2D8mm
4	steel fiber in compression zone	8 mm	100×100 mm	150 mm	3D16mm	2D8mm

2.4 Test setup

LVDT (Linear Variable Displacement Transducer) was put at the beam to measure the deflection. Two strain gauges with 6 mm gauge length were installed on the concrete to measure the strain, one at tension zone and one at compressive zone.

The specimen setup is shown in Figure (2). Specimen testing was carried out, at the age of 28 days with the observed parameter comprised the crack propagation including the load at first crack, maximum bending load, deflection and failure pattern of the beams.

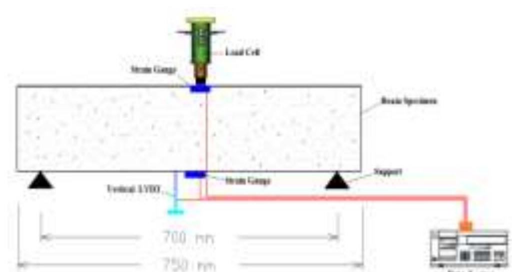


Figure (2): Specimen setup.

III. RESULTS AND DISCUSSION

The behavior of test specimens in terms of load-deflection relationship, stress-stress curve, mode of failure and ductility factor are illustrated and discussed in the following sections.

3.1 Load-deflections behavior

The relationship between the applied mid span load and central deflection for the tested beams is presented in Fig (3).

From this figure, it can be clearly seen that for beams, the relationship between the load and deflection can be divided into three stages. Elastic behavior until the first crack, transition stage and plastic deformation stage started from zero loads until the first crack load which equal to 54 KN. The transition zone and plastic deformation zone take place from load equal to 54 KN up to max load, 80.4 KN. In this regime no remarkable plastic deformation was observed. This behavior was attributed to mode of failure occurred in this specimens. The mode of failure here was a sudden crushing due compression-shear failure of compression zone. The resulting maximum deflection was about 0.70 mm.

In group (2 and 3), elastic regime starting from zero load up to first crack load, which equals to 71 KN. A large plastic deformation stage occurred here as the result of yielding of reinforcing bars. The maximum load was approximately equals 169.4 KN in two groups. Also, from these figures, it can be observed that the maximum deflection was approximately equals to 3.2 mm in two groups. These results were attributed to the used confinement techniques in two groups, where the beams of group 2 were confined in compression zone by using stirrups, while the beams of group 3 were confined in compression zone by using epoxy sheet reinforced by carbon fiber wrap. These techniques changed the mode of failure for group 2 and group 3. The cracking patterns for these groups are shown in Fig (4). From this figure, it can be clearly seen that the observed cracking and mode of failure are flexural cracks and they started in appearing at beam mid-span, then they developed from tension side toward the compression side.

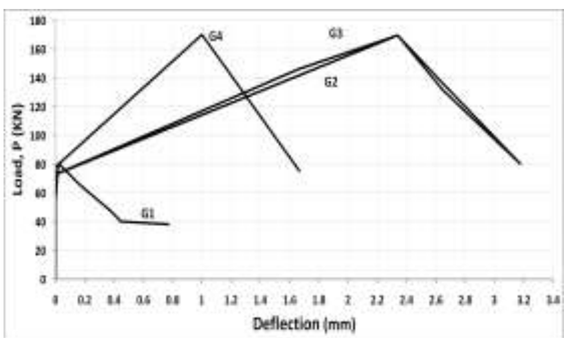


Figure (3) load deflection curves of all tested specimens.

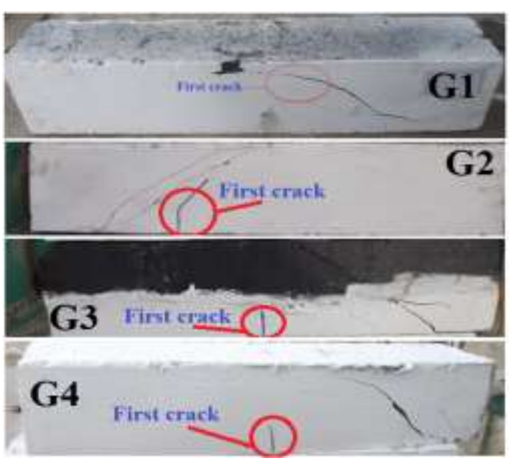


Figure (4) the mode of failure for all tested specimens.

3.2 Stress-strain behavior in compression zone

Figure (5) gives a comparison between stress-strain behaviors in compression zone for all tested groups.

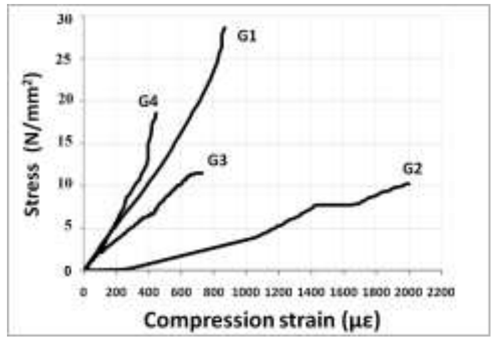


Figure (5) stress-strain curve in compression zone

The compressive strain of beams was measured at mid span of the beam. For all tested beams, the compressive strain increased with the increase of applied stress. At any stress level, it is observed that the compressive strain of group 3 was less than that of all other groups. For G1, It is observed that in compression zone there is a linear behavior between stress and strain from stress equal zero up to stress equal 4.9 N/mm^2. Then nonlinear behavior occurs until failure with an ultimate strain equal 868 με and an ultimate stress equal 28.6 N/mm^2. For G2, It was observed that in compression zone there is a linear proportion between stress and strain from strain equal zero με to strain equal 292 με. Then stress increased with stain none linearly until failure with an ultimate strain equal 2000 με and an ultimate stress equal 1 N/mm^2. For G3, It was observed that in compression zone there is a linear region between stress and strain from strain equal zero με to strain equal 115 με. Then stress and strain exhibit non until failure with an ultimate strain equal 728 με and an ultimate stress equal 1.1 N/mm^2. For G4, It was observed that in was observed that in compression zone there is a linear proportion between stress and strain from strain equal zero με to strain equal 239 με. Then stress increased with stain none linearly until failure with an ultimate strain equal 446 με and an ultimate stress equal 18.5 N/mm^2.

3.3 Stress-strain behavior in tension zone

Figure (6) gives a comparison between e stress-strain behaviors in tension zone for all tested groups.

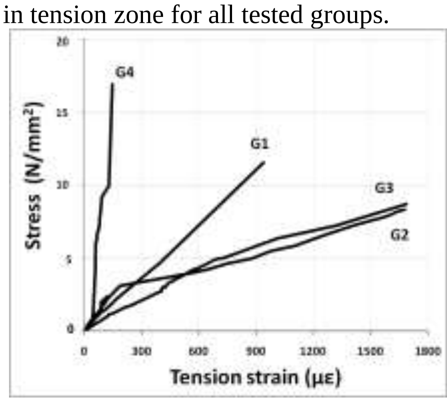


Figure (6) stress-strain curve in tension zone

For G1, It was observed that in tension zone there is a linear behavior between stress and strain from stress equal zero up to stress until failure equal 16.9 N/mm^2. For G2, It was observed that in tension zone there is a linear proportion between stress and strain from strain equal zero με to strain equal 189 με. Then stress increased with stain none linearly until failure with an ultimate strain equal 1678 με and an ultimate stress equal 8.3 N/mm^2. For G3, The data shows that in tension zone there is a linear proportion between stress and strain from strain equal zero με to strain equal 128 με. Then stress increased with stain none linearly until failure with an ultimate strain equal 1686 με and an ultimate stress equal 8.7 KN/mm^2. For G4, in tension zone there is a linear proportion between stress and strain from strain equal zero με to strain equal 47 με. Then stress increased with stain none linearly until failure with an ultimate strain equal 149 με and an ultimate stress equal16.9 N/mm^2.

3.4 Ductility factor

To study the effect of strengthening beams, ductility factor is measured for G1, G2, G3 and G4. Ductility factor (D) may be defined as the ratio of deflection at failure to the deflection at yield or at the first crack, or the ratio of strain at failure to the strain at yield or at the first crack.

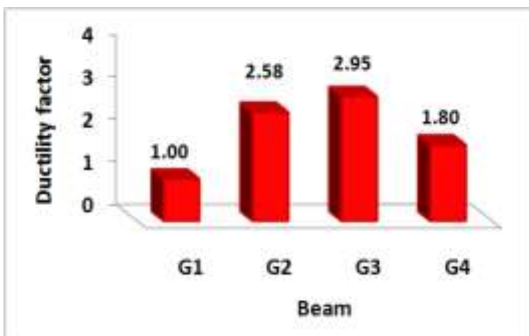


Figure (7) ductility factor (D) for all beams

Figure (7) shows variation of ductility factor for G1, G2, G3 and G4. It's clear that the highest value of ductility factor was 2.95 for G3 and the lowest value was 1 for G1. The result of ductility factor indicated that the ductility factor of G2 increased 158% compared to the ductility factor of G1 from 1.00 to 2.58. The ductility factor of G3 increased 195% compared to the ductility factor of G1 from 1.00 to 2.95. The result of ductility factor indicated that the ductility factor of G4 increased 80% compared to the ductility factor of G1 from 1.00 to 1.80.

IV. CONCLUSIONS

The results in the present investigation reveal several conclusions:

1-The suggested techniques of confinement for HS reinforced concrete beams gave highest values for first crack and ultimate loading and maximum beam deflection.

2-The crack pattern and mode of failures were changed from sudden compression-shear failure for control beam to multiple tensions cracking for confinement beams.

3-The beams which confined in compression zone by using epoxy sheet reinforced by carbon fiber wrap showed less value of compressive strain.

4-The beams which confined in compression zone by using steel fiber showed less value of tensile strain.

5- The beams which confined in compression zone by using epoxy sheet reinforced by carbon fiber wrap and Stirrups confinement in compression zone showed high value of ductility factor.

REFERENCES

[1] Elbasha, Nuri M, Beahviour of over reinforced HSC helically confined beams, Phd thesis, School of Civil, Mining Environmental Engineering, University of Wollongong, 2005
[2] Ahmed M. Ali, Mohamed A. Tarkhan " Experimental investigation of confining the compression zone in over-reinforced beams " Tarkhan, 4(11): November, 2015, ISSN: 2277-9655
[3] Baji, H., H. R. Ronagh, and R. E. Melchers. "Reliability of ductility requirements in concrete design codes." Structural Safety 62 (2016): 76-87.
[4] Pam, H. J., A. K. H. Kwan, and M. S. Islam. "Flexural strength and ductility of reinforced normal-and high-strength concrete beams." Proceedings of the Institution of Civil Engineers: Structures and Buildings (2001).
[5] Hui Wu "Constitutive model of concrete confined by advanced fiber composite materials and applications in seismic retrofitting" A dissertation presented to the faculty of the graduate school university of Southern California, August 2007.
[6] Meier, U, “Bridge Repair with High Performance Composite Materials”, Material und Technik, Vol. 15, pp. 125-128, 1987.
[7] Yulita Arni Priastiwi, Iswandi Imranb, Nuroji, Arif Hidayat " Behavior of ductile beam with addition confinement in compression zone "2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014 (SCESCM 2014), Procedia Engineering 95 (2014) 132–138
[8] R.G. Delalibera, J.S. Giongo, Theorical and numerical analysis of reinforced concrete beams with confinement reinforcement, RevistaIbracon De Estruturas E Materials, Ibracon Structures and Materials Journal, Vol.1, No. 1, 2008, pp:17-30.
[9] Yulita Arni Priastiwi, Iswandi Imranb, Nuroji, Arif Hidayat " Behavior of ductile beam with addition confinement in compression zone "2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014 (SCESCM 2014), Procedia Engineering 95 - 132–138, 2014.
[10] Jeffry, Ross, and Muhammad NS Hadi. "The effect of confinement shapes on over-reinforced HSC beams." (2008): 286.
[11] ES (4756-1) part 1, "Compositing Specifications and Conformity Criteria for common cement “, Egyptian Organization for Standardization and Quality, Cairo, Egypt, 2009.
[12] E.S.S. No. 1109,"Aggregate", Egyptian Standard Specification, Ministry of Industry, Cairo, Egypt, 2008.