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Strengthening of Lightweight Concrete Beams Using Carbon and Glass Fibers

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ملخص البحث
يحتوي هذا البحث علي دراسة معملية لتدعيم الكمرات الخرسانية خفيفة الوزن بإستخدام ألياف الكربون والزجاج. وقد تم التوصل الي الخرسانة خفيفة الوزن لصب الكمرات المراد تدعيمها عن طريق الاستبدال الجزئي للركام بفوم البوليسترين ، وذلك بهدف خفض وزن الخرسانة من 23كن/م^3 الى 18 كن/م^3. وقد تم إجراء دراسة معمليه علي عدد 7 كمرات منهم كمره بدون تدعيم وعدد 6 كمرات مدعمه بإستخدام الياف الزجاج والكربون وقد شمل البحث المتغيرات الأتية: نوع الألياف المدعمه ،وعرض الشرائح المستخدمه في التدعيم ، وقد شمل البحث أيضا خصائص المواد المستخدمة وادوات القياس المستخدمة.

ABSTRACT
In order to study the strengthening of light weight concrete beams using carbon and glass fibers. An experimental program has been conducted. The test program included seven reinforced concrete simply supported beams. The main parameter examined were type of fiber, width of layers used in strengthening. The details of specimens, material properties, instrumentation, tests apparatuses and the testing procedure are presented in this paper. The effect of the studied variable is presented and discussed.
KEYWORDS :Concrete, Lightweight, strengthening, fiber reinforced polymer (FRP)

Introduction
Deterioration of concrete structure is one of the construction industry problems today. Moreover, a large number of structures constructed in the past using the older design codes in the different parts of the world are structurally unsafe according today's design codes. Since replacement of such deficient structures requires a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service life's. In order to avoid the problems created by the corrosion of steel reinforcement in light weight concrete structures, research has demonstrated that one could replace the steel reinforcement by fiber reinforced polymer (FRP) reinforcement. The strength of corroding steel reinforcing bar is reduced because of a reduction in the cross-sectional area of the steel bar. While the steel reinforcing bars are corroding, the concrete integrity is impaired because of cracking of the concrete cover caused by the expansion of the corrosion products.

The rehabilitation of infra-structure is not new and various projects have been carried out around the world over the past two decades. Historically, steel has been the primary used to strengthen concrete bridges and buildings. Bonded steel plates or stirrups have been applied externally to successfully repair concrete girder that are deficient in bending or in shear. However, using steel as a strengthening element adds additional dead load to the structure and normally requires corrosion protection.

Only a few years ago, the construction market started to use FRP for structural reinforcement, generally in combination with other construction materials such as wood,

steel and concrete. FRP exhibit several attractive properties, such as low weight to strength ratio, non-corrosiveness high fatigue strength, and case of application.
The use of FRP sheets or plates bonded to concrete beams has been studied by several researchers. Strengthening with adhesive bonded fiber reinforced polymers has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs and walls. Because FRP materials are non-corrosive, non-magnetic, and resistance to various types of chemicals, they are increasingly being for external reinforcement of existing concrete structures.

1 Experimental program

The performed experimental work consisted of seven simply supported beams are listed in table (1). The table gives information about beam label, type of fiber, width of wrapped fiber and type of strengthening. All beams have dimensions10*30*325cm. all beams with reinforcement of 4Ø18 at bottom, 2Ø12 at top and vertical stirrup Ø6 every 14cm as shown in fig (1).

Table (1) Details of tested beams

Group label	*Beam label*	*Type of fiber*	*Width of wrapped fiber*	*Type of strengthening*
	CBS	-	-	-
Group No(1)	BGS1	GFRP	3cm	SHEAR
	BGS2		5cm	
	BGS3		10cm	
Group No(2)	BCS1	CFRP	3cm	
	BCS2		5cm	
	BCS3		10cm	

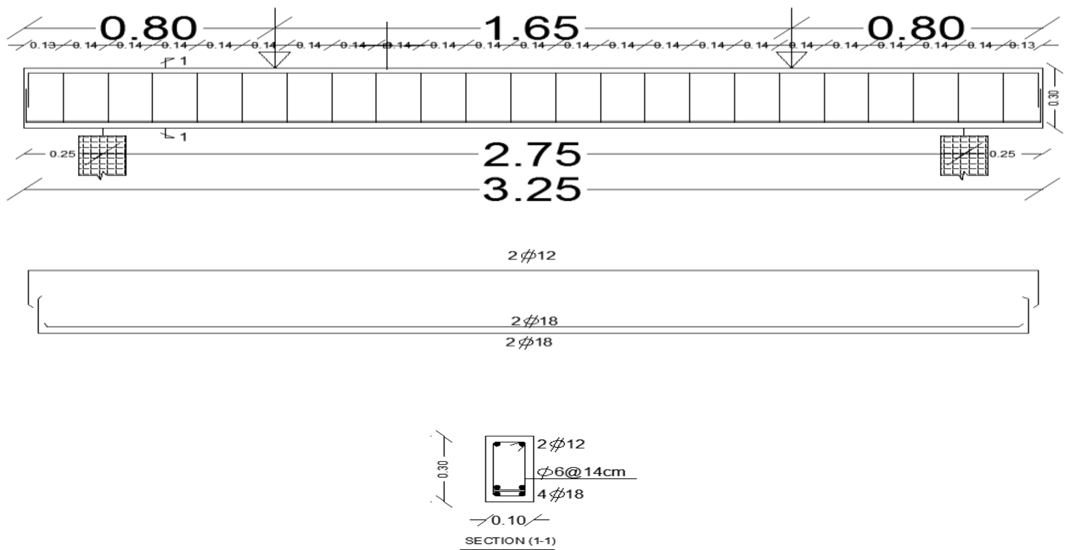


Fig. (1) Shows tested beam details in shear

1.1 Concrete Mixtures Evaluated

The quantities required by weight for one cubic meter of fresh concrete for the L.W.C specimens are as given in table (2).

Table 2 Material Quantities in Kg/m3 for The LWC Specimens.

Materials	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	w/c ratio	Super-Plasticizer $(liter/m^3)$	Silica fume (kg/m^3)	Polystyrenes Foam $(liter/m^3)$
Quantity	450	630	630	0.308	13.5	40	330

1.2 Fabrication of beams

The beam formwork was designed from 25mm thick wood plates. The inner sides of the beam formwork were coated by a layer of oil before casting of concrete to facilitate removal of formwork and concrete surface cleaning. The steel of specimens were prepared as shown in fig (2) and placed in formwork as shown in fig (3).The beams were cast at the concrete laboratory of Housing and Building National Research Center (HBRC) at 25c$^{\circ}$ temperature. Concrete was compacted after casting using electrical vibrator for 3minutes. The beam surface was leveled to give a smooth surface.

Fig (2) shows steel reinforcement of specimens

Fig (3) shows steel reinforcement of specimens in the plywood form

1.3 Beams Strengthening

The GFRP and CFRP sheets were attached after the concrete had reached an age of 28 days. The main steps for preparation of tested beams are given as follows:-

1- Roughness of concrete surface using electrical hand and blower to remove the weak parts on the concrete cover.
2- Filling the irrigation on the surface by applied of epoxy paste (sikadure - 31cf) on the beam surface.

3- Rounding the corners of the beams with radius of 15mm.
4- Smoothing the epoxy paste surface.
5- For shear specimens wrapping U- wrap shape of GFRP or CFRP sheets using epoxy resin (sikadure 330) shown in fig (4).
6- Rolling the FRP sheets by special laminating roller to ensure that FRP is saturated in epoxy and there is no air voids between fiber and concrete surface as shown in fig (5).

Fig. (4) shows U- wrapping shape of FRP

Fig. (5) shows rolling the FRP sheets

1.4 Test procedure

The specimens were tested by using a hydraulic jack. At the beginning of each test, the specimen was installed on the two supports as a simple beam. The reading of the hydraulic jacks and the steel strain gauges were taken by special instruments as shown in figure (6).

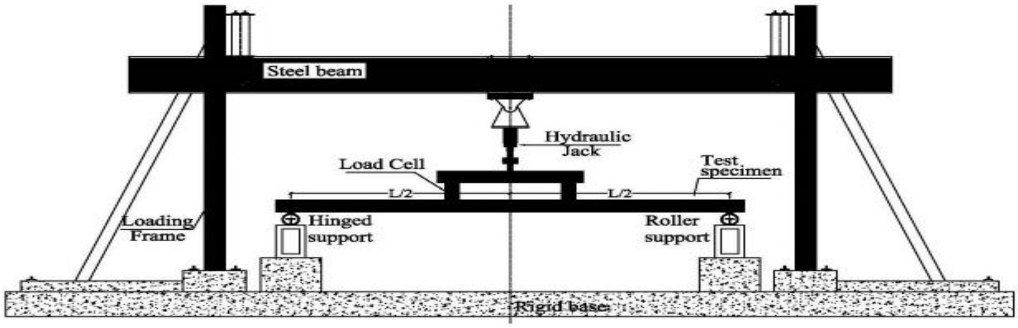


Fig. (6) Shows test setup

2 Experimental Results and Discussion

2.1 Cracking and Failure Load

A total of seven beam specimens were tested to failure. All beams were failed in shear before flexural capacity is reached. No slip of the flexural capacity is reached. No slip of flexural reinforcement was observed during any of the beam tests, A summary of the test results for each tested beam specimens is presented in Table (3) includes the failure load, shear cracking load and flexural cracking load. The following remarks could be concluded.

Table (3) shows values of failure, shear cracking and flexural cracking loads.

Group	*Specimen*	*Failure load (KN)*	*Shear cracking load (KN)*	*Flexural cracking load (KN)*
control	**CBS**	173	70	50
Group No(1)	**BGS1**	196.7	170	160
	BGS2	217.4	132	120
	BGS3	237.3	121	88
Group No(2)	**BCS1**	207	127	126
	BCS2	223.2	160	86
	BCS3	259.6	170	60

After the peak of each loading, the crack pattern was marked to provide the necessary information required for defining the failure mechanism of each specimen. Figure (7) show the failure mode of all the tested specimens. From these figures, the following remark could be concluded:

• For all specimens, the flexural cracks initiated on the tension side in the middle of the beam span, the cracks propagated upward with the increase of load. For solid beam, the first diagonal crack suddenly developed at mid-depth within the shear span. Diagonal cracks were observed parallel to the compression strut and propagated towards the loading region and supports.

Fig. (7) shows crack pattern of beam specimens

2.2 Load Deflection Response

As mentioned before, the vertical deformations were measured using linear variable displacement transducers (LVDTs) of three points on each beam to predict the deflection shape of the tested beams two points under two loads and the third point in the mid span of each beam. From the test we observed the following:

* The load - deflection curves for the tested beams were nearly linear at high percentage of the stages of loading from zero up to the failure cracking of the concrete. The great decrease in stiffness due to excessive cracking had resulted in relatively great increase in the deflection values, approaching the failure load, the deflection continued to increase even with the applied load being maintained constant.
* Comparing the deflections of beams at the same load the deflections decreased due to increasing the percentages of strengthening. This is shown in figures (8). For beam specimens BGS1,BGS2 and BGS3 which strengthened by U shape glass fiber reinforced polymers GFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the vertical deflection decreased by about 11%, 18% and 28% respectively from CBS which have rectangular section without strengthening at the same load. For beam specimens BCS1,BCS2 and BCS3 which strengthened by U shape carbon fiber reinforced polymers CFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the vertical deflection decreased by about 18%, 35% and 40% respectively from CBS which have rectangular section without strengthening at the same load.

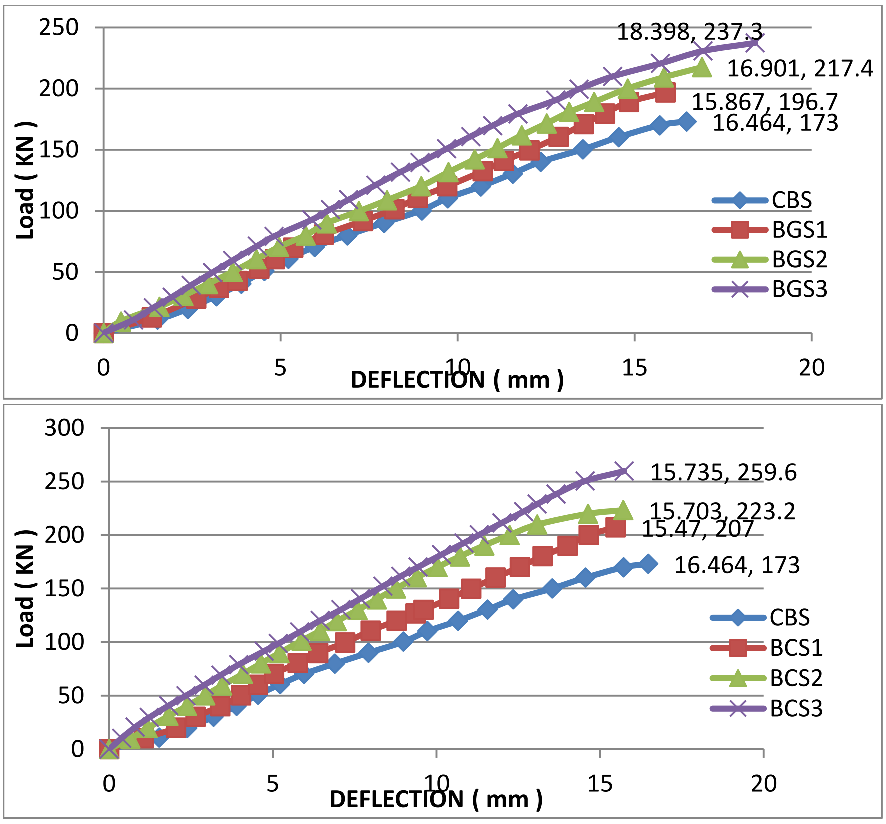
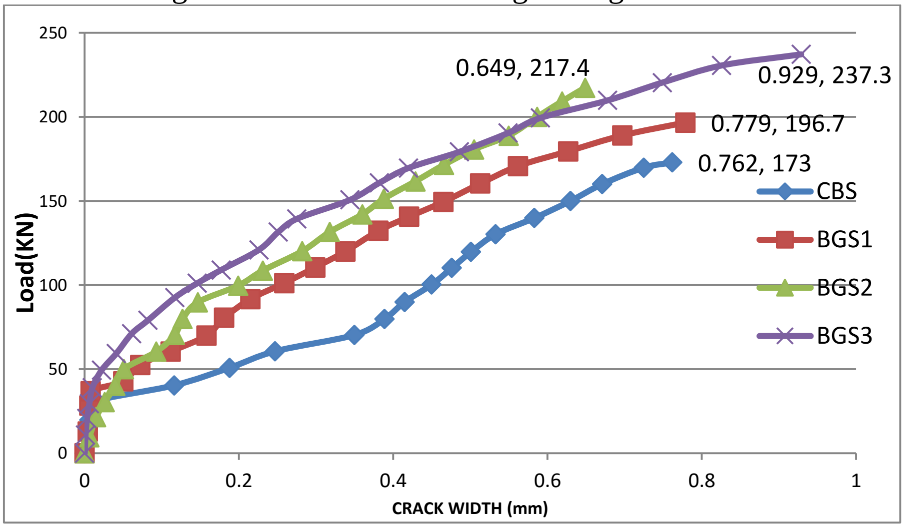


Fig. (8) shows Load- deflection curves for beam specimens

2.3 CRACK WIDTH

The crack width was measured using linear variable displacement transducers (LVDTs) to determine the maximum crack width through the span of each tested beam from zero up to the failure load. From the test we observed the following:
* Comparing the crack width of beams at the same load the crack width decreased due to increasing the percentages of strengthening. This is shown in figure (9). For beam specimens BGS1,BGS2 and BGS3 which strengthened by U shape glass fiber reinforced polymers GFRP sheets which attached on the surface of specimens with

width 30mm, 50mm, 100mm respectively, it was found the crack width decreased by about 26%, 38% and 45% respectively from CBS which have rectangular section without strengthening at the same load. For beam specimens BCS1,BCS2 and BCS3 which strengthened by U shape carbon fiber reinforced polymers CFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the crack width decreased by about 32%, 51% and 58% respectively from CBS which have rectangular section without strengthening at the same load.



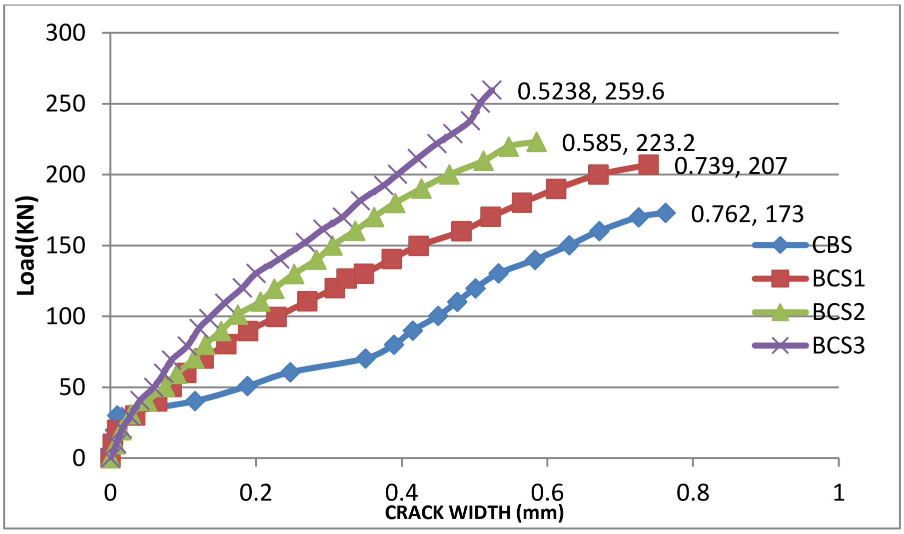


Fig. (9) shows Load- crack width curves for beam specimens

2.4 STEEL STRAIN

The steel strain measured during testing by using electric strain gauges mounted on the beam longitudinal reinforcement, upper reinforcement and on the stirrups.

2.4.1 LONGITUDINAL STEEL STRAIN

Comparing the longitudinal steel strain of beams at the same load the longitudinal steel strain decreased due to increasing the percentages of strengthening. This is shown in figure (10). For beam specimens BGS1,BGS2 and BGS3 which strengthened by U shape glass fiber reinforced polymers GFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the longitudinal steel strain decreased by about 7%, 13% and 21% respectively from CBS which have rectangular section without strengthening at the same load. For beam specimens

BCS1,BCS2 and BCS3 which strengthened by U shape carbon fiber reinforced polymers CFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the longitudinal steel strain decreased by about 17%, 23% and 28% respectively from CBS which have rectangular section without strengthening at the same load.

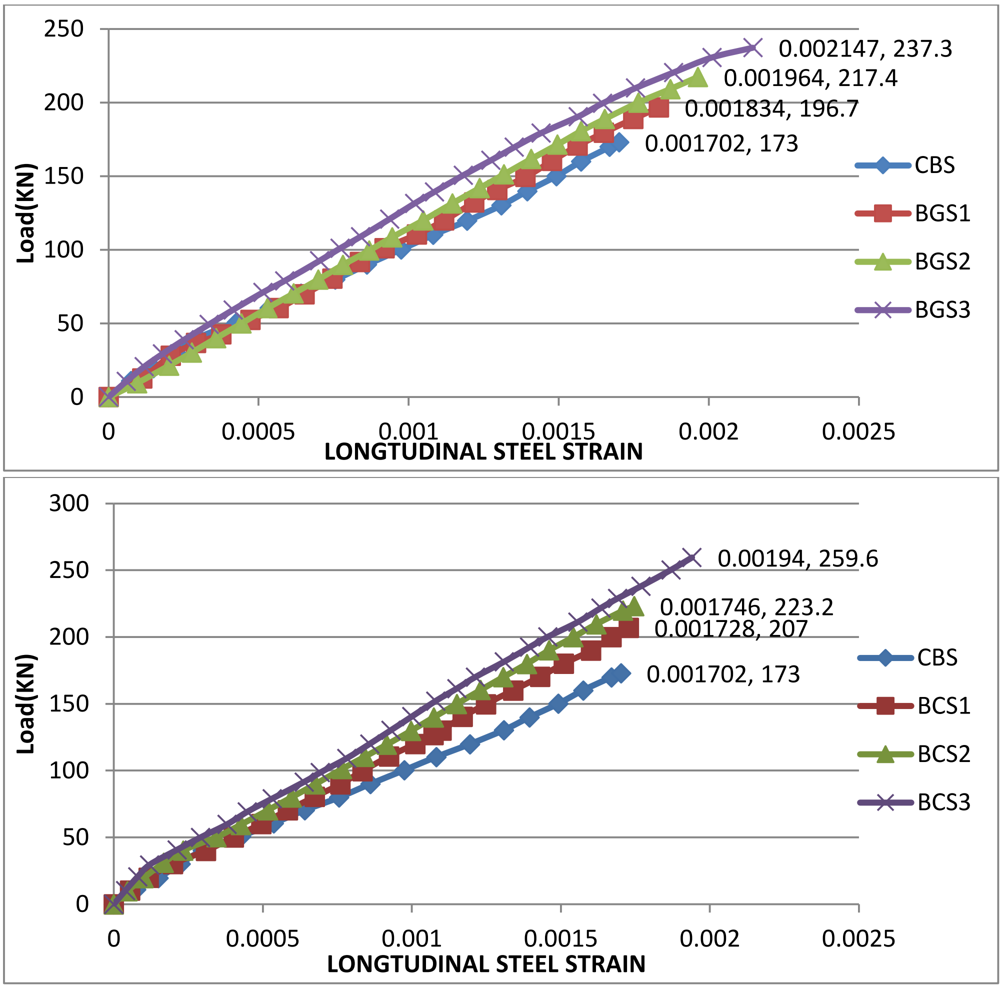


Fig. (10) shows Load- longitudinal steel strain curves for beam specimens

2.4.2 STIRRUP STEEL STRAIN

Comparing the stirrup steel strain of beams at the same load the stirrup steel strain decreased due to increasing the percentages of strengthening. This is shown in figure (11). For beam specimens BGS1,BGS2 and BGS3 which strengthened by U shape glass fiber reinforced polymers GFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the stirrup steel strain decreased by about 7%, 11% and 18% respectively from CBS which have rectangular section without strengthening at the same load. For beam specimens BCS1,BCS2 and BCS3 which strengthened by U shape carbon fiber reinforced polymers CFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the stirrup steel strain decreased by about 46%, 65% and 71% respectively from CBS which have rectangular section without strengthening at the same load.

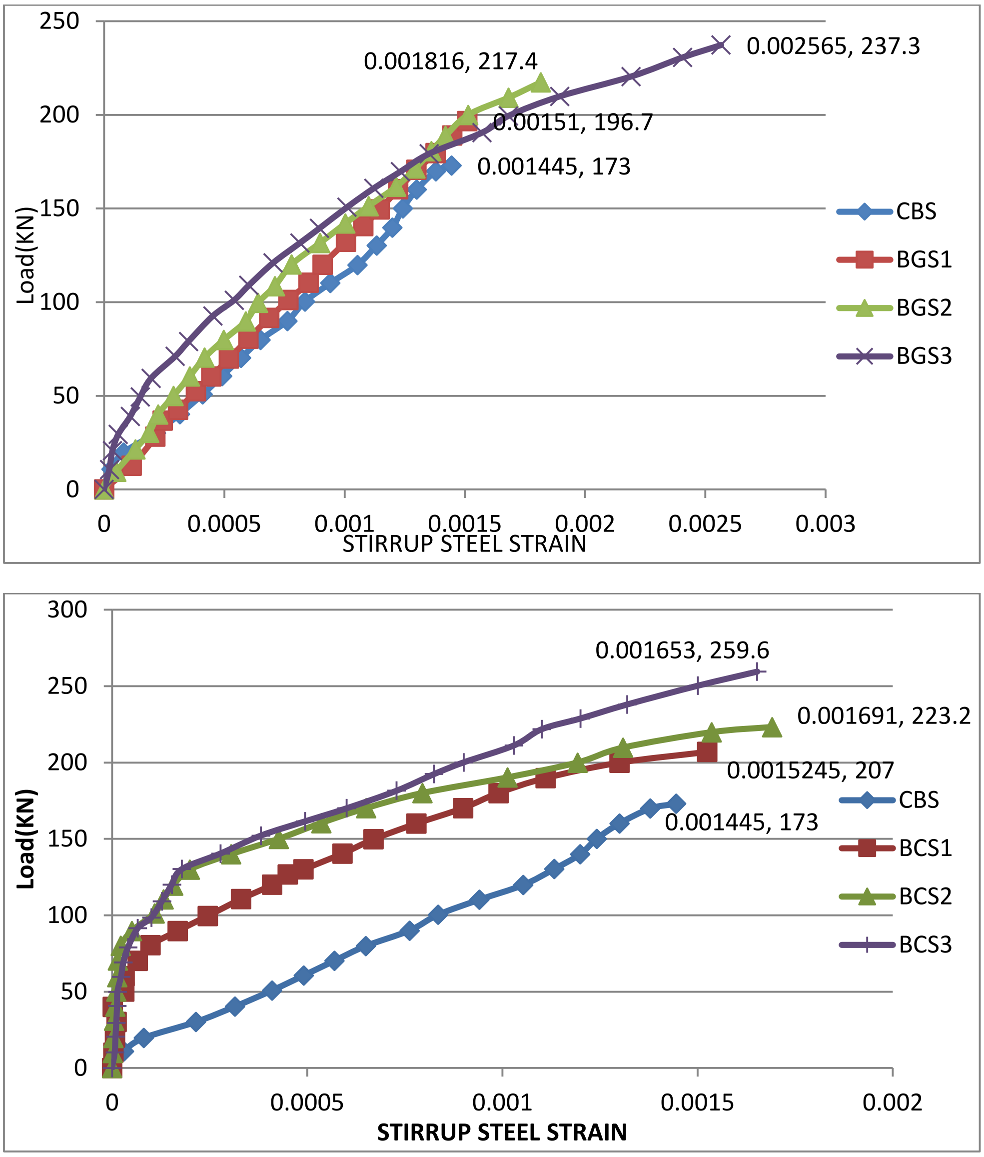


Fig. (11) Shows Load- stirrup steel strain curves for beam specimens

2.4.3 UPPER STEEL STRAIN

Comparing the upper steel strain of beams at the same load the upper steel strain decreased due to increasing the percentages of strengthening. This is shown in figure (12). For beam specimens BGS1,BGS2 and BGS3 which strengthened by U shape glass fiber reinforced polymers GFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the upper steel strain decreased by about 18%, 20% and 24% respectively from CBS which have rectangular section without strengthening at the same load. For beam specimens BCS1,BCS2 and BCS3 which strengthened by U shape carbon fiber reinforced polymers CFRP sheets which attached on the surface of specimens with width 30mm, 50mm, 100mm respectively, it was found the upper steel strain decreased by about 42%, 44% and 47% respectively from CBS which have rectangular section without strengthening at the same load.

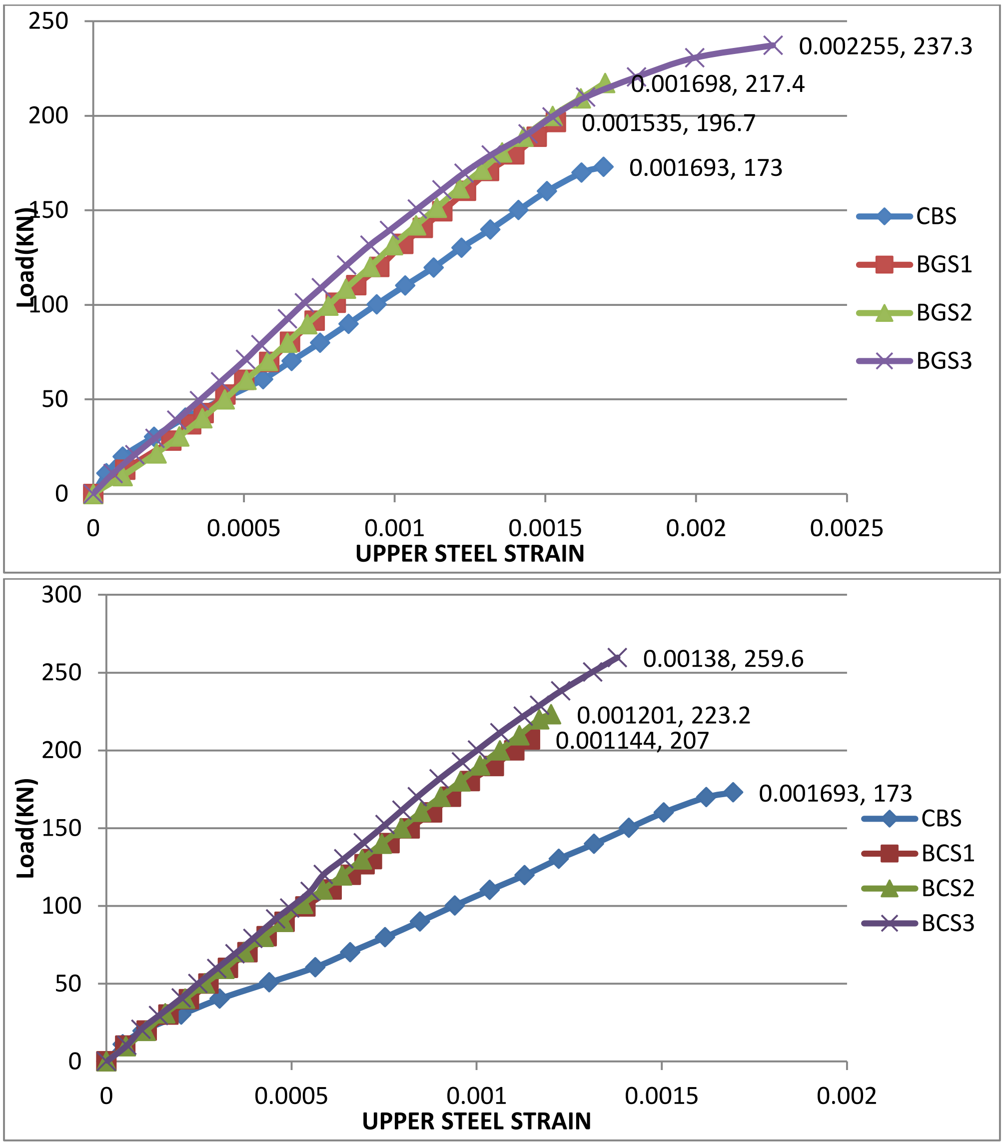


Fig. (12) Shows Load- upper steel strain curves for beam specimens

3 CONCLUSIONS

1- Strengthening of light weight concrete beams using carbon and glass fibers sheets (CFRP& GFRP) increased failure load compared to unstrengthened beams.
2- At the same load Reinforcement steel strain decreased due to using carbon and glass fibers (CFRP&GFRP) in strengthening of light weight concrete beams.
3- Using CFRP in strengthening in shear increase shear failure loads about 20% in 30mm U wrapped sheet and ratio up to 29% in 50mm U wrapped sheet while ratio up to 50% in 100mm U wrapped sheet.
4- Using GFRP in strengthening in shear increase shear failure loads about 13.9% in 30mm U wrapped sheet and ratio up to 26% in 50mm U wrapped sheet while ratio up to 37% in 100mm U wrapped sheet.
5- Failure of beams strengthened in shear by carbon and glass fibers exhibited diagonal cracks in shear zones and failure of concrete with rupture of fiber sheets.

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