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Ductility of Concrete Beams Reinforced with (FRP) Bars

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ملخص البحث :-

في الآونة الأخيرة ، كان هناك اهتمام متزايد بين العديد من الجمعيات الهندسية في جميع أنحاء العالم باستخدام أسياخ وشرائح البوليمرات المقواه بالألياف لتعزيز وإصلاح المنشأت الخرسانية. تم التحقيق في استبدال أسياخ الصلب التقليدية بأسياخ البوليمرات المقواة بالألياف للتغلب على مشكلة التآكل وصدأ حديد التسليح في أسطح الكباري و الجسور ، ومواقف السيارات ، ومنشأت معالجة المياه والمنشأت البحرية.

وقد أظهرت البوليمرات المقواه بالألياف بالفعل مستقبل واعد للتغلب على مشكلة التآكل والصدأ فى العديد من المشروعات. تم تكريس الجهود العلمية والموارد لتقييم الحالة وإعادة تأهيل وإصلاح البنية التحتية المتدهورة. لان السبب الرئيسي لتدهور المنشأت الخرسانة المسلحة الحالية هو تآكل و صدأ حديد التسليح. لمعالجة هذه المشكلة يتم استخدام أسياخ البوليمرات المقواه بالألياف كبديل مناسب بسبب مزايا وعيوب هذه الأسياخ.

وبما ان اشهر عيوب هذه الالياف هوه انخفاض مؤشر المرونة لها بسبب انخفاض معامل يونغ للبوليمرات المقاواه بالالياف مما يعرضها لانهيار قصف قد يمنعنا من الاستفادة القصوي من هذه الكمرات, لذا فمن المهم جدا دراسة سلوك الانحناء لهذه الكمرات المسلحة بالالياف البوليمر ومحاولة تحسين سلوك الانحناء و الممطولية لها.

<u>* في هذا البحث</u>

تم اختبار عدد 6 كمرات خرسانية مسلحة باسياخ البوليمرات المقواه بالالياف و بصلب تسليح تم اختبارها معمليا واخراج النتائج و دراسة تأثير المتغيرات المختلفة علي مقاومة و سلوك وممطولية الكمرات الخرسانية باستخدام معدات واجهزة المعمل المجهزه للاختبارات .

- جميع هذه الكمرات تم اختباراها حتي حمل الانهيار, و تم تسجيل القراءات والنتائج و الملاحظات ورصد الحمل الأقصي و مستوي الترخيم الكلي ورسم المنحنيات الخاصة بها .

Abstract :

Recently, there have been increased attention and interest among many engineering communities all over the world in using of fiber reinforced polymer (FRP) bars and laminates for reinforcing and repairing and maintenance concrete structures.

The replacement of traditional steel bars with FRP bars has been investigated to control and defeat the corrosion problem in bridge decks and slabs, parking garages, water and waste water treatment facilities and naval structures. These FRP bars have already shown a promising future to dominate the corrosion problem in many projects.

Also, the uses of FRP because its advantages which these bars are Light weight, High tensile strength, Corrosion resistance, Electro-magnetic resistance, High performance and durability, Good fatigue properties and endurance.

<u>In this research:</u>

A total of six concrete beams reinforced with FRP and steel bars were tested experimentally and get the results. All these specimens were tested until the ultimate load up to failure and get the ultimate deflections and calculated many parameters ultimate strength, deflections, initial stiffness, ductility and energy absorption and drawing the curves for these specimens.

(1) Introduction:

In this study there was used GFRP bars as a reinforcement and also steel bars and casting specimens

And tested them with different parameters like adding steel fibers to concrete mix with different ratios.

The main objective of this investigation in this search is to study the flexural behavior and the ductility of concrete beams reinforced with Fiber reinforced polymer bars and steel fiber.

In this chapter we used Glass fiber bars and one of the objectives was to manufacture the GFRP Reinforcing bars and evaluate the mechanical properties of those bars. Utilizing locally available materials and sing simple Manufacturing equipment presented by safaan, M.(2004)[3].

Many researches were studied the using of FRP in reinforcement of RC beams have been published. Summary of the most test results found in the literature using FRP bars and EBR for reinforcing and strengthening RC beams are presented in **the following:**

Safaan.M.,2004,[3] The main objective of this study is to achieve significant ductility, while the tensile strength and modulus are reduced moderately. The study describes the process of manufacturing the glass bars using locally available glass fiber roving, and polyester. The mechanical properties of the bars including bond strength were experimentally evaluated by conducting the previous tests using new testing approaches.

The results showed that the produced bars were much cheaper and yielded improved mechanical properties, which make them an attractive alternative as concrete reinforcement.

Almusallam TH.[4] predicting the development of moments and deflections so as to get a good flexural design, the strip method was used in the force analysis. The ultimate strength theory, the equilibrium and compatibility conditions were adopted, and the moment-curvature and load-deflection relationship were solved using a numerical method, and the computation codes as well as a GUI program were proposed for the solutions. The comparison between theoretical results and experimental results shows that the ultimate strength theory is well applicable to the prediction of flexural strength of concrete beams reinforced with FRP bars, for the calculation of short-term deflections of concrete beams reinforced with FRP bars, the result of ACI model is too small compared to experimental results, the Faza & GangaRao model is more suitable under service loads. The numerical method is more suitable under ultimate loads, and the comparison among these methods indicates that the numerical method is more suitable for the solution of short-term deflections of concrete beams reinforced with FRP bars.

S.M. Soliman, E. El-Salakawy, B. Benmokrane. [5] Fiber reinforced polymer (FRP) composite materials have been used as internal and external reinforcement for concrete structures. Flexural strengthening of concrete elements using near surface mounted (NSM)–FRP materials are a promising technology. This research is designed to investigate the behavior of reinforced concrete beams strengthened in flexure with NSM–FRP bars. A total of 20 reinforced concrete beams were tested. Different parameters including internal steel reinforcement ratio, type of NSM–FRP bars, FRP bar diameter, bonded length, and groove size were investigated in this research. Test results showed that the use of NSM–FRP bars is effective in increasing the flexural capacity of concrete beams. In addition, a nonlinear 3D finite element (FE) analysis was used to numerically simulate the behavior of the test beams. Comparisons between the FE predictions and experimental results showed very good agreement in terms of the load−deflection and load−strain relationships, ultimate capacities, and modes of failure for the tested beams.

Muhammad N. S. Hadi, F.ASCE; and Jim Youssef,[10] presents the results of an experimental study on the axial and flexural behavior of square concrete members reinforced with glass fiber-reinforced polymer (GFRP) bars and embedded with GFRP structural sections under different loading conditions. The main parameters investigated in this study were the influence of the type of internal reinforcement (steel bars, GFRP bars and GFRP structural I-sections and C-sections) and magnitude of load eccentricity on the flexural and compressive behavior of square concrete members. The experimental results have shown that the steel-reinforced specimens have a higher load-carrying capacity than specimens reinforced with GFRP bars for all loading conditions. In addition, for concentrically loaded specimens, steel-reinforced specimens have a better ductile performance than specimens reinforced with GFRP bars. In terms of eccentric loading, specimens reinforced with GFRP bars experienced similar ductility as compared to the corresponding steel-reinforced specimens. However, the eventual failure mode of specimens reinforced with GFRP bars was sudden and brittle in nature. However, specimens encased with GFRP structural sections have a higher load-carrying capacity but considerably lower ductility than the steel-reinforced and GFRP bar–reinforced specimens.
Chris G. Karayannis, Parthena-Maria K. Kosmidou, [11] in this study the reinforcement used as fiber-reinforced polymer (FRP) bars has been proposed as Alternative for the substitution of the traditional steel bars in reinforced concrete (RC) structures. Although the advantages of this polymer reinforcement have long been recognized, the predominantly elastic response, the reduced bond capacity under repeated load and the low ductility of RC members with FRP bars restricted its wide application in construction so far. In this work, the behavior of seven slender concrete beams reinforced with carbon-FRP bars under increasing static loading is experimentally investigated. Load capacities, deflections, pre-cracking and after-cracking stiffness, sudden local drops of strength, failure modes, and cracking propagation have been presented and commented. Special attention has been given in the bond conditions of the anchorage lengths of the tensile carbon-FRP bars.

(2) Experimental program:

A total of six reinforced concrete beams were prepared and tested in this research with two concrete mixes (N.C) Normal concrete and (F.C) Fiber concrete with different ratios of steel fibers. To study and compare the ductility and the flexure behavior between studied specimens. And to investigate the effect of adding two different Ratio of hooked end steel fiber on the flexure behavior of concrete beams reinforced with GFRP & Steel bars.

Concrete dimensions of all beams (150 x 250 x 2000) mm as shown in fig. (1).

The major parameters included in this research were: -

- The type of reinforced bars. (Steel bars - GFRP bars).
- The volume fraction of the steel fiber. (V_f) = (0% - 1 % - 1.5 %).

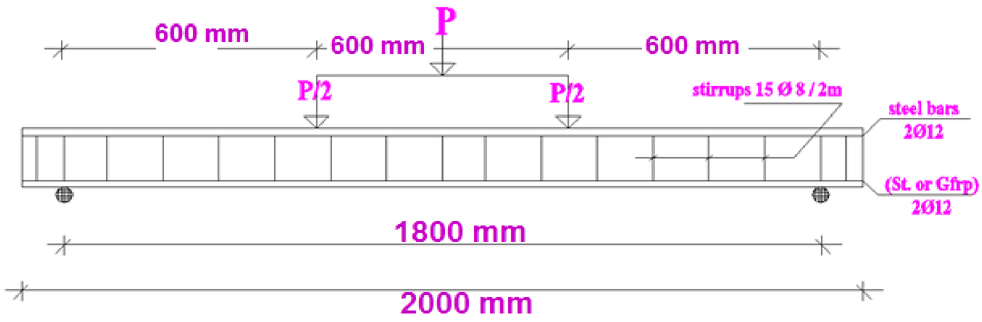


Fig. (1) Dimensions and reinforcement details of tested beams

All the beams were 2000 mm long and were tested under four point loading over an effective simply supported span of 1800 mm, with the loads applied at 100 mm on either side of the mid span. Applied loads, FRP and steel bar strains, vertical deflection at the beam centerline and the concrete compressive strains were monitored over the full range of loading using a data acquisition system.

2.1 <u>Locally Manufacturing of GFRP Bars:</u>

In this study Glass fiber bars were used and one of the objectives was to manufacture the GFRP reinforcing bars by utilizing locally available materials and using simple manufacturing equipment .The length of bar was 2000 mm and the diameter of GFRP bars was 12 mm was chosen to reinforce the tested beams . The bar was made of glass fiber roving and poly resin, where the bar consisted of 70% E-glass fiber and 30% a poly resin. By trials to produce this bar with a nominal diameter of 12 mm. A number of 40 roving bundles of the glass roving were needed, the glass roving with across sectional area of 0.954 mm.

Tools used in the Fabrication of the GFRP bars as shown in fig. (2). these tools represented in one fixed hook, Movable Hook connected to a handle, glass fiber roving and poly resin.

In the First, the thread of continuous fibers is tensioned between the two hooks that are initially 2.30 m long .as showing in fig. (2).The movable arm is pushed in and the sagging glass fibers are wholly laid in 2.1m long. In the Second, the process of Resining glass fiber with half tube basin containing 500 gm of poly resin with peroxide dose of 0.5% by weight works as a hardener causes a sufficient strength within twenty minutes. The third stage, after resining the movable is pull out and rotated to twist the fibers and squeeze out the excessive amount of resin. Then the movable arm is locked using bolt closure to prevent sagging of the bar under its own weight. After about 12 hours the bar was cut at the two ends by using a saw.

Fig. (2) Stages of locally manufacturing of GFRP bars.

2.1.1 Fiber Reinforced Polymer (roving):-

A glass fiber roving formed from continuous UN twisted strands that are bonded together with a polyester-compatible size used. According to the manufacturer, the fiber combines the mechanical properties of traditional e-glass and the acid corrosion resistance. The glass fiber has a specific gravity of 2.54, a TAX of 2400 (TAX =weight in grams of 1 km length of roving), tensile strength of 3250 MPa, tensile modulus of 69 GPA and tensile elongation of 4.5% according to manufacturer, as shown in fig. (3).

2.1.2 Poly Resin :-

The poly resin is suitable for various fabrication processes of corrosion resistance applications. Poly resin used to make a bond between filaments of glass fiber roving. The mechanical properties of the resin are tensile strength (86 Mpa) , tensile modulus (3.4 Gpa) and tensile elongation 4 % and a specific gravity of 1.12 It was be package weighted twenty Kilograms as shown in fig. (3).

Fig. (3) Glass fiber roving and the poly resin.

2.2 Steel Fiber :-

Hooked end steel fiber with length 50mm is used in this study. Table (1) shows the properties of steel fiber and fig. (4) Shows the shape of hooked end steel fiber used in the experimental work.

Fig. (4) Shape of steel fiber

Table (1) properties of S.F

Property	Value
Specific gravity	7.84
Tensile strength(N/mm2)	800 – 1500 (1100)
Crimped height (mm)	2 - 3
Diameter (mm)	0.75
Length (mm)	50
Young's modulus (Mpa)	2×10^5
Aspect ratio (Approx.)	67

2.3 <u>Concrete Mix Design :-</u>

Three concrete mix was used according to the different ratios of steel fibers. Twelve batches were used to cast the test specimens. The mix proportions (by weight) Each 4 batches was scaled to cast two test specimen and 9 Cubic specimens (150 ×150×150 mm) to determine the concrete compressive strength, So there was three concrete mixes.

Table (2) Mix properties.

Materials	Weight by (K.g/m^3)
Cement	360
Fine aggregate (sand)	640
Dolomite size No.1	600
Dolomite size No.2	600
water	190
Steel fibers	(0 – 1 – 1.5) %

2.4 <u>Loading Arrangement On Testing Beams :-</u>

The available hydraulic testing machine (MTS machine) at structural laboratory was used, which controlled the concrete dimensions of the tested beams. The beams were rested on two roller supports. The applied load by the testing machine was transmitted to the tested beams through a transitional steel beam (I-sec.) supported on two cylinder bars giving Four point load test in order to obtain a zone of constant bending moment and to avoid shear failure, shows in fig. (5). It was observed that the use of S.F in concrete occurred more deflection before failure and rupture in addition to increasing in load capability and increasing stiffness of the beams in the beginning (Ki) and deformed capacity**.**

Fig. (5) Test setup.

(3) <u>Results of Experimental program:</u>

3.1 <u>GFRP BARS Tension Test:-</u>

The GFRP bars locally manufacturing testing phase was carried out on the MTS machine of 200 KN capacity. The tension test of GFRP bars are shown in fig. (6) .The mechanical properties of the produced bars were experimentally evaluated by conducting the testing approaches of ACI-440 committee [1].

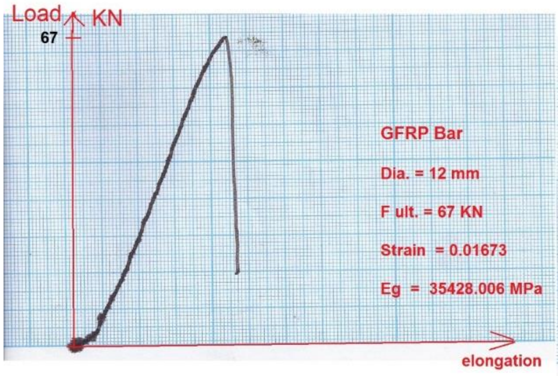


Fig. (6) Tension test for GFRP bar

Fig. (7) Load-elongation curve.

Tensile test was carried out on three specimens of locally manufactures GFRP bars. The test results represent "ultimate load, the corresponding strain and modulus of elasticity "were listed in table (3). To estimate the production process , the average of elastic modulus of GFRP (E.g.) was founded to be about 0.177 of the elastic modulus of steel (E.s.) , where the young's modulus of steel bar was found equal 200000 MPa .The load – elongation curve generated by the MTS machine is shown in Fig. (7).

Table (3) properties of tested specimens.

NO.	diameter (mm)	(Pu) KN	Stress (MPa)	Strain (Ɛ u)	Eg (MPa)	Eg / Es
1	12	65	575.017	0.0157	36625.28	0.183
2	12	67	592.71	0.01673	35428	0.177
3	12	70	619.249	0.0171	36213.39	0.181

3.2 Crack patterns And Modes of Rupture of Tested Beams:-

Modes of rupture of tested specimens, were spotted during stages of the test as shown in fig. (8). the modes of rupture observed for the specimens can be split into two denominations. The first one was the flexural rupture named ductile failure and the second was compression rapture named brittle failure (concrete rupture).

All the tested specimens have three phases responses up to fracture in the first phase, linear phase (un cracked concrete) cracks were not appearance when the load cell rises load linearly at the beginning of the linear stage. The second phase, the appearance of the first micro crack was appeared in the second phase of linear stage, concrete made some cracking to tensile steel previous yield point for steel reinforcement beams specimens and for GFRP bars there is no yield point up to failure. The first crack appeared at the lower surface of the beam between the loading Placements where the beam specimen was incurred to pure flexural bending. Most of cracks go on to increase toward the upper surface and the cracks did not appeared expanded. The third phase in steel reinforcement beams, tension steel made yielding phase to rupture. Cracks shown in fig. (8). Flexural failure at concrete beams with steel fibers mostly occurs when the steel fiber begins to pull out and withdrawal of the concrete mix when the load carried by a single piece of fiber rides the ability and the capacity of concrete to handful the fibers.

As the load cell rise the load on the tested beam, more signs of cracks created and the entanglement of steel fibers bridging the existing cracks more stress. And at the ultimate load, the fibers at one specific cross section began to pull out. This crack width became significantly increased wider than any other cracks in the other beams.

Fig. (8) Crack patterns And Modes of Failure

The specimens of tested beams were tested under four point up to failure. The deflection was measured at the bottom of middle span of the tested beam .Data logger obtained data from load cell & L.V.D.T can produce Load-deflection curves from these data, as shown in fig. (9)..that shows in fig. (10). It was observed that the use of GFRP, crack load come earlier than steel reinforcement. However, in ultimate load they are closed to each other and there is no yielding up to failure. Table (4) shows the values of deflections, ductility index, initial stiffness and energy absorption index for each beam at different stages of loading.

Table. (4) The test results.

NO.	Pu	Pcr	Py	Δu	Δcr	Δy	Δu/ Δu-c	Ki	E.A.I	μΔ
B 1	94	20	75	55	3	25	1	6.66	3.704	2.2
B 2	96	14	-	50	4	-	0.9	3.5	1.48	1.04
B 3	104	30	79	84	4	21	1.52	7.5	7.94	4
B 4	113	22	-	80	5	-	1.45	4.4	2.71	1.41
B 5	110	35	82	85	4	17	1.54	8.75	10.36	4.8
B 6	114	24	-	86	5	-	1.56	4.8	3.53	1.62

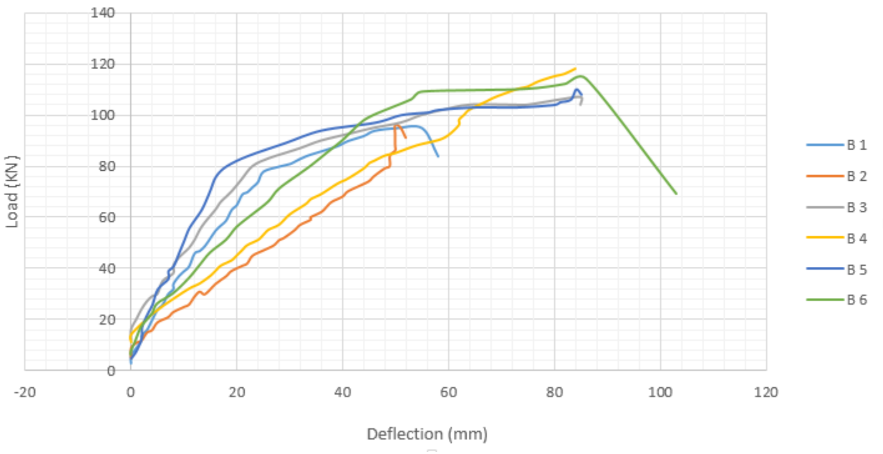


Fig. (9) Load-deflection curves

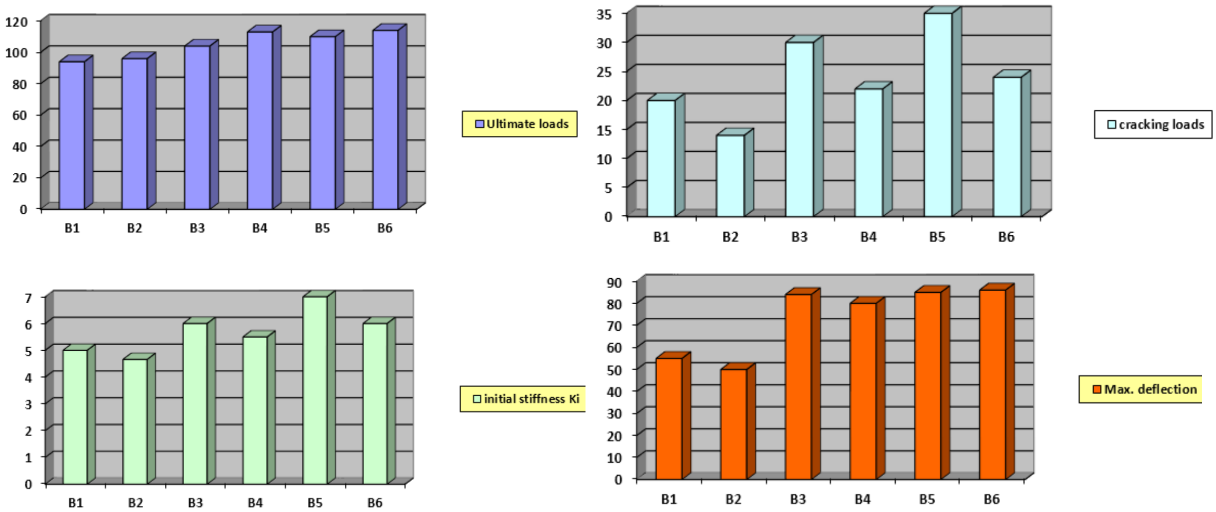


Fig. (10) Bar charts of (ultimate loads-cracking loads-initial stiffness-max. deflections).

3.3 <u>Ultimate Load</u> :-

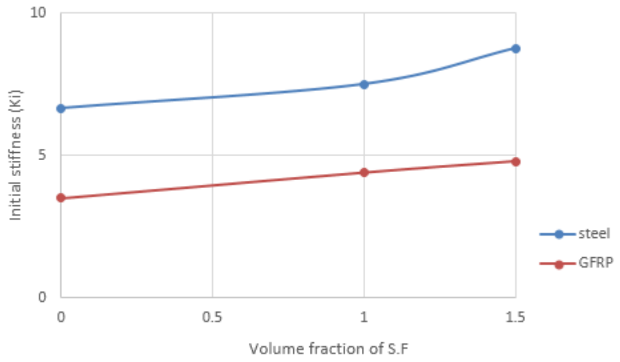
The values of ultimate loads in tested beams at the end of loading were increased by the different parameters were used in this test, the addition of steel fibers ratio in concrete mix and the type of reinforcement bars reinforced the tested beams. Table (4) gives the values of increasing percentages of ultimate loads to the variation of volume fraction of steel fiber from 0% to 1.5% and to the type of reinforcement bars.

In experimental program two types of reinforcement were used in this test as the parameters, steel bars for control beam and locally manufacture of glass fiber bars. The results shows that the ultimate load in GFRP tested beams was increase little than control beams with steel bars by 10.6%, 20.2%, and 21.2% for beams with internal S.F ratio from 0%, 1% and 1.5%.

3.4 <u>Initial stiffness (Ki)</u> :-

The results show that the initial stiffness for GFRP tested beams were less than tested beams reinforced with steel bar. It was observed that use of GFRP bars makes crack load come earlier than steel reinforcement. The ultimate loads were closed to each other and there was no yielding up to failure .The crack load of steel beams was more than GFRP beams with 40% of cracking load and by using steel fiber volume ratio from

1% to 1.5% the cracking load of GFRP increased with 50% of cracking load with 0% steel fiber. Fig. (11) shows the effect of type reinforcement on the cracking load.
The initial stiffness was increased with addition of volume fraction of steel fiber from 0% to 1.5% for the different types of bars used in test. Fig. (12) shows the effect of type reinforcement on the initial stiffness.



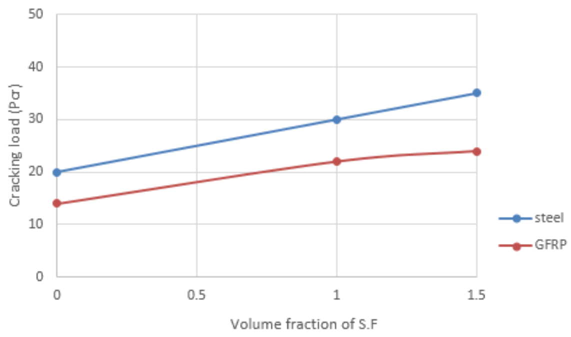


Fig. (11) Crack load

Fig. (12) Initial stiffness

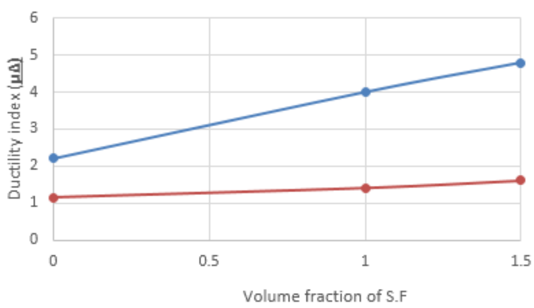
3.5 **Ductility of Tested Beams:-**

Ductility is a structural property of concrete beams that was very important because it was redistribution allowable stresses and provides warnings before failure.
The ductility of reinforced concrete beams can determined by load –deflection curve of concrete beams which can obtain from it the ductility index (**μΔ**) that was the ratio between the ultimate deflections and the yielding deflection or point of distortion at the middle span of the tested beams.
Table (4) Deflection values at different stages of tested beams.

The results show that the ductility index of GFRP tested beams were less than tested beams reinforced with steel bar. The ductility index of GFRP beams can be improved by the additions of steel fiber volume ratio from 1%, 1.5% by 35%, 55% respectively than the GFRP beam without steel fiber. Fig. (13) Shows the effect of type reinforcement on the ductility index.

3.6 **Energy Absorption Index (E.A.I) :-**

The energy absorption index (E.A.I) was defined as the ratio of the total area under load-deflection curve to the area under yield part at the same curve. Fig. (14) shows the effect of type reinforcement on energy absorption index. The values of E.A.I were calculated and listed in table (4).



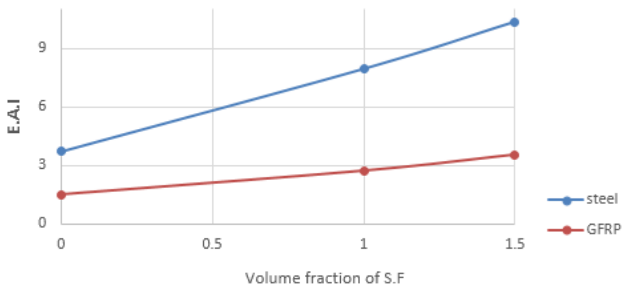


Fig. (13) Ductility index

Fig. (14) E.A.I

(4) Conclusions:-

1- The GFRP tested beams were closed and similar to the steel reinforcement beams specimens in ultimate loads but were less than them in initial stiffness (Ki), ductility (**μΔ**) and Energy absorption index (E.A.I).

2- Increasing of the ratio of Steel fibers from 0% to 1.5% volume fractions could be improve the ductility and the shape of load-deflection curves and increase the ultimate deflections with increasing of ultimate loads.

3- The Ductility of GFRP beams can be improved by the additions of steel fiber volume ratio from 1%, 1.5% by 35% and 55%, respectively than the GFRP beam without steel fibers.

4- Ultimate loads in GFRP tested beams was increased little than control beams with steel bars by 10.6%, 20.2%, and 21.2% for beams with internal S.F ratio from 0%, 1% and 1.5% respectively.

5- The initial stiffness for GFRP tested beams were less than tested beams reinforced with steel bar. It was observed that use of GFRP, crack load comes earlier than steel reinforcement but in the ultimate load they are close to each other and there is no yielding up to failure.

6-The crack load of steel beams was more than GFRP beams with 40% of cracking load and by using steel fiber volume ratio from 1% and 1.5% the cracking load of GFRP increased with 50% of cracking load with 0% steel fiber.

7-Energy absorption index in GFRP tested beams was increased by 75% and 85% for beams with 1% and 1.5% steel fiber than the GFRP without steel fibers.

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