Journal of Engineering and Sustainable Development

www.jeasd.org
Vol. 20, No.06, November 2016
ISSN 2520-0917

BEHAVIOUR AND STRENGTH OF SUSTAINABLE RUBBERIZED REINFORCED CONCRETE BEAMS STRENGTHENED BY CFRP

Amer Mohamed Ibrahim [1], Ahmed Abdullah Mansor [2], Suhad Mohammed Abd [3]

1) Prof., Civil Engineering Department, Diyala University, Baquba, Iraq.
2) Lecturer, Civil Engineering Department, Diyala University, Baquba, Iraq.
3) Lecturer, Civil Engineering Department, Diyala University, Baquba, Iraq.

Abstract: The current study is interested for investigating the effect of replacing 50% of sand by textured rubber (Crumb Rubber) that reduced 10% from specimen's weight, then using the CFRP to strengthening the flexural efficiency of beams. Five specimens with 200x300x2000mm dimensions are investigated. The variables are studied in instillation of CFRP. Three situation of fixing the CFRP, the first is in area exposed to flatten, the second in both regions of tension and compression and the last one covered all faces by CFRP. Laboratory results showed that when replacing 50% of sand by crumb rubber the weight of beams decreased by 9% and increased the ductility by 74% also the crack width is reduced by 9% and 38% at yield and ultimate loads respectively. Strengthening by CFRP strips is increase the yield and ultimate load by 40% and 35% on average respectively, but by covering all faces the ratios was increased by 60% and 63%. Using the crumb rubber decreased the deflection by 27% on average and by using CFRP the defection was decreased by 36%, 19% on average at yield and ultimate load respectively. CFRP is increase the strain in compression face of concrete and the value was greater than maximum strain of concrete (0.003). Also the crack width was decreased by 45% , 23% on average at yield and ultimate loads respectively.

Keywords: *Reinforced Concrete; Beams, Crumb Rubber, CFRP, Strengthening.*

تصرف ومقاومة العتبات الخرسانية المسلحة والمستدامة المصنوعة باستخدام مخلفات المطاط والمقواة بألياف الكاربون البولمرية

الخلاصة: اهتمت الدراسة الحالية في تحري تأثير استبدال ٥٠% من الرمل بمادة مخلفات المطاط الذي ساهم بتقليل ١٠% من وزن النماذج وكذلك استعمال الياف الكاربون لتقوية كفاءة الانثناء في العتبات. اشتملت الدراسة على صب خمسة نماذج بابعاد 200x300x2000 ملم. تم دراسة تاثير تثبيت صفائح الكاربون. هناك ثلاث حالات لتثبيت صفائح الكاربون، الاولى في المنطقة المعرضة للشد والثانية في المناطق المعرضة للشد والانضغاط والثالثة بتغليف النموذج بالكامل. النتائج المختبرية أظهرت ان استبدال ٥٠% من الرمل بمادة مخلفات المطاط قلل وزن العتبات بنسبة ٩% وزاد من المطيلية بنسبة ٧٤% اضافة الى تقليل عرض التشقق بمقدار ٩% و٣٨% من حملي الخضوع والفشل على التوالي. وعند تعزيز النماذج باشرطة الياف الكاربون يزداد حمل الخضوع والفشل بمعدل ٤٠%و ٣٥% على التوالي، اما في حالة بتغطية كامل النموذج فتكون الزيادة بنسبة ٦٠% و٦٣% على التوالي. ان استخدام مخلفات المطاط ، يقلل الهطول بمعدل ٢٧% في مرحلة الخضوع ، وباستخدام الياف الكاربون يقل الهطول بنسبة ٣٦% و١٩% عند حملي الخضوع والفشل على التوالي. ان استخام الياف الكاربون يزيد من انفعال الخرسانة الى قيم تتجاوز اعلى قيمة لانفعال الخرسانة (٠,٠٠٣). بالاضافة الى تقليل عرض التشققات بمعدل ٤٥% و٢٣% عند حملى الخضوع والفشل على التوالي.

1. Introduction

A wide variability of concrete approaches and produces give the techniques to generate both beauty and function in ways that develop the impact of constructions on the environment. The sustainable improvement is round complementary humanoid requirements with the earth's capability to meet them. The concrete proposals an extensive range of capacity to help achieve this balance. One of challenges for the civil engineering public in the close future will be to recognize projects in agreement with the perception of sustainable growth, and this includes the use of great performance materials made at sensible cost with the lowermost likely environmental influence. Each of the sustainability explanations should afford an impression of the environmental challenges or subjects and how concrete can help statement it; they afford links to more detail on the exact concrete uses that can help meet this challenge.

The use of CFRP in strengthening reinforced concrete (RC) constructions by developed a gradually communal retrofit system. The system of strengthening RC constructions by externally bonded CFRP fabric was began in 1980s and has since concerned investigators around the world(1).

Application of manufacturing waste produces in concrete has concerned consideration around the world due to the growth of environmental awareness. Tyre pile fires have been larger environmental complications. Accretions of stocks of Tyres are risky because they carriage a possible environmental considerations, fire risks and supply refinement lands for parasites that may carry sickness.

Crumb rubber is a term regularly useful to reused rubber from automotive and truck scrap tyres. By using the crumb rubber can reduction the dangerous influence on environment and providing a sustainable concrete (2).

Crumb rubber is industrial from two main feeds tocks, tire buffing's, a consequence of tire retread and scrap of tire rubber. Indeed, a classic scrap tire consists of (by weight): 70 % recoverable rubber, 15 % steel, 3 % fiber and12 % minor material (e.g. inert fillers). Scrap tire rubber derives from three kinds of tires: first: passenger car tires, which mean about 84% of units or around 65% of the total weight of U.S. second: scrap tires; truck tires, which establish 15% of units, or 20% of the total weight of U.S. scrap tires; and third: off-the-road tires, which account for 1% of units, or 15 % of the total weight of U.S. scrap tires. Finale production for each of tire styles are affected by the tire's creation, strength and unite weight.

2. Related Studies

2.1. Strengthening and Retrofitting Using Cfrp

Moreover, in recent years, (FRP) Fiber Reinforced Polymers is used to develop the ability of reinforced concrete structural members. FRP is usually included of great strength fibers (e.g. aramid, carbon, glass) filled with an epoxy, polyester, or vinyl ester resin (often termed the matrix).

Many researches Spadea et al. 1998; Matthys 2000; ACI Committee 440 2002; Tamuzs and Tepfers 2004 (3, 4, 5 and 6) have pointed out that concrete renovation using FRPs is more effective at increasing the strength of concrete elements.

During latest years also, FRP sheets represent excessive capacity as a substitute the steel plates for concrete construction renovation or used for strengthening. As well as Swiss investigators founded work on the use of FRP as a alternative for steel in plate bonding applications (Meier and Kaiser, 1991)(7) and many investigators presented that the concrete renovation using FRP is high effective application to develop the strength of reinforced concrete members (El-Badry, 1996; Tamuzs and Tepfers, 2004)(8,9) .

For FRP strengthened beams failure may takes place according to shear, flexural, FRP rupture, FRP de-bonding or concrete cover tearing as shown by (Ascione and Feo, 2000)(10), and (Bonacci and Maalej, 2000; Bonacci and Maalej, 2001)(11, 12).

2.2. Crumb Rubber

Many ASTM specifications that relate to crumb rubber, such as ASTM D5644 test methods for rubber compounding materials-determination of particle size distribution of recycled vulcanizate particulate rubber, explains approaches of calculating particle size and particle size distribution for crumb rubber(13) and ASTM D5603 standard classification for rubber compounding materials-recycled vulcanizate particulate (14).

This reduction of fine aggregates by tyre rubber may be recognized to the lesser volume of pores in the mortars and to the fact that these pores cannot be simply got by the water. Oikonomou et al. (2006)(15) presented the adding of tyre rubber to cement mortars as an alternative materials for the fine aggregates (sand) and established that the open absorbency and capillarity by suction is reduced with using tyre rubber.

Benazzouk et al. (2007) (16) presented the water absorption of cement combinations having ragged rubber wastes; tyre rubber has been used as a fractional replacement for cement in order to improve lightweight structure materials. Test results for the hydraulic conveyance properties presented that combination of tyre rubber into such compounds tends to decrease the water absorption of the combinations.

Segre and Joekes 2000; Turatsinze et al., 2005; Oikonomou et al., 2006 (17, 18, 15) pointed out that the bond between rubber elements and matrix can be completed by the use of several means. As much as styrene butadiene rubber (SBR) liquid and anionic bitumen suspension are disturbed, microscopic tests showed that these types of extracts are well bonded to the rubber particle surface, hence strengthening the bonding between cement mortar, aggregates additives and rubber particles.

Siddique and Naik, 2004; Turatsinze et al., 2005; Oikonomou et al., 2006 (19, 18, 15), found that rubber aggregate replacement reduces the strength of cement based products. This decrease differs depending upon the size and the surface texture of the rubber particles and the percentage, in addition to the kind of cement.

Li et al. 2004 (20) resulted that concrete having waste tyre rubber in the form of fibers has greater strength likened with that made with greater rubber particles (chips). To replacement of the fine aggregates by using crumb rubber results in a decrease in concrete strength and this redaction is even greater when crumb rubber has been to replace the coarse aggregates Eldin and Senouci, 1993 (21).

Topçu et al., 1995; Pierce and Williams, 2004; Oikonomou et al., 2006 (22, 23, 15) presented that the flexural and split tensile strengths properties are significantly reduced at a slow rate compared with compressive strength. As predicted, subsequently the strength of cement composites improved with tyre rubber reduction and specified the fact that mechanical strength is close associated to the dynamic modulus of elasticity.

3. Research Significance

The purposes of this study are to:

1. Develop the considering on crumb rubber concrete material properties through laboratory testing.
2. Estimate probable benefits of using crumb rubber in concrete including; resistance against cracking, decreasing of thermal development and contraction, and lightweight concrete through a series of the above-mentioned test sections.
3. Improve the knowledge of flexural strengthening by using CFRP.
4. Predict the flexural behavior and modes of failure of RC beams with flexural deficiencies after strengthening with CFRP.
5. To predict the effect of several CFRP installation on the flexural behavior of beam specimens.

4. Details Of Exprimental Test

4.1. Outline Of Program

The experimental program consisted of five beams tested using the mid-span concentrated loading arrangement. All beams were 200 mm wide, 300 mm deep, 2000mm long. The longitudinal steel reinforcement in tension and compression was 3 ϕ 12mm and using 2 ϕ 10mm with 410MPa and 400MPa yield strength respectively as shown in Figure 1 and cross section in Figure 2.

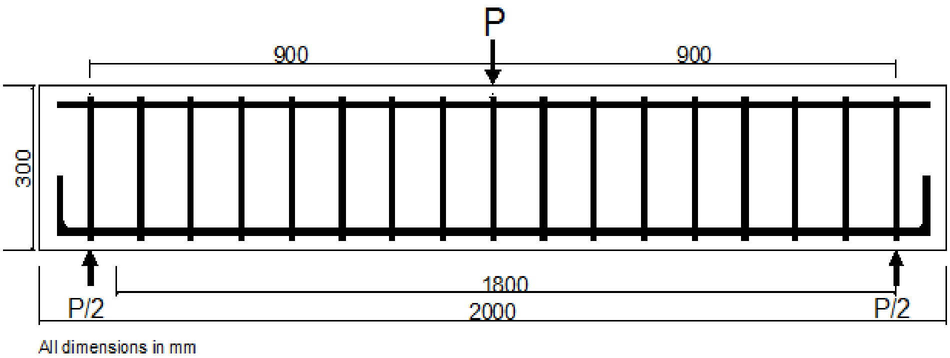


Fig. 1 Elevation and specimens details

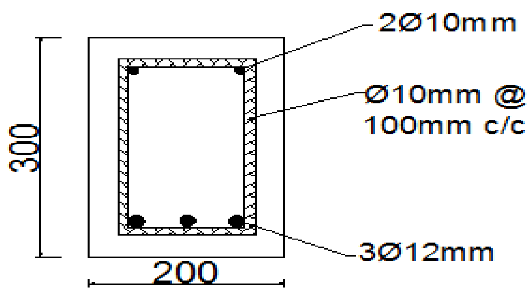


Fig. (2) Cross section of specimens

The variables of this study are corresponding to compressive strength of concrete and strengthening by CFRP strips. The reference specimens beam (C1) has compressive strength of 35.9MPa, and the others (C2, C3, C4 and C5) have 17.3-20.95MPa as shown in Table 1. The mix proportions of concrete are shown in Table 2.

Table (1) Specimens specifications

Beams	f'_c *MPa*	f_t *MPa*	*Flexural reinforcement*	*Shear reinforcement*	*CFRP*
C1	35.90	2.732	3 ϕ 12mm	ϕ 10mm @100mm	-----
C2	17.30	1.390	3 ϕ 12mm	ϕ 10mm @100mm	-----
C3	17.95	1.420	3 ϕ 12mm	ϕ 10mm @100mm	Two strips 10cm an area exposed to flatten
C4	20.92	1.870	3 ϕ 12mm	ϕ 10mm @100mm	10cm strips in tension and comp. zones in both sides
C5	20.60	1.816	3 ϕ 12mm	ϕ 10mm @100mm	10cm covered all faces of the beam

Table (2) Mixes proportions

Material	Kg/m^3
Cement	465
Gravel	903
Sand	371
Water	260
Meta kaolin	24
Chrome rubber	50% volume of sand for specimens C2, C3, C4 and C5
Super plasticizer	1.9L/m^3

The specimens C1 and C2 were tested without using CFRP strips, the specimen C3 has been strengthened with CFRP in an area exposed to flatten .The C4 specimen has been strengthened with CFRP in both regions of tensile and compression .The fifth specimen C5 has covered by CFRP at all faces. The mold used to cast the specimens is shown in Plates 1 and 2.

The CFRP strips used in the strengthening application was Sika CarboDurS512 unidirectional flexible strip. The structural adhesive paste used for bonding the Sika CarboDur strips to the concrete substrate was (Sikadur-30) which is high modulus high-strength two component (A and B) product. CFRP strips width was 100mm. Uniaxial CFRP strips are placed as a single layer for strengthening and two component epoxy adhesive is used for bonding. The application of the CFRP strips material was a simple and rapid operation. (See Plate 3 and 4).

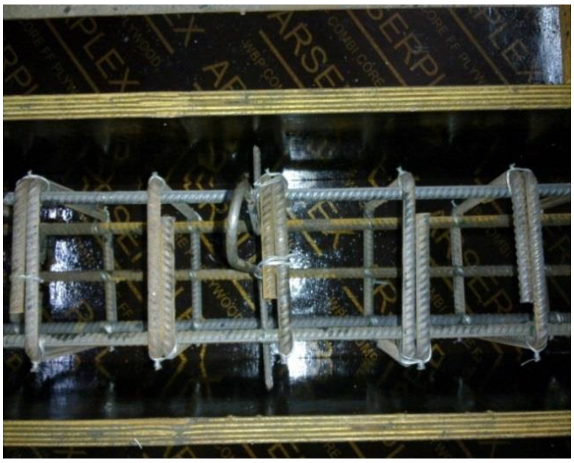


Plate (1) Side view of mold and reinforcement

Plate (2) Top view of mold and reinforcement

Plate (3) steps in a row for packing

Plate (4) Carbon profile situation

4.2. Tested method and measurement

All specimens were simply supported beams tested with single mid-span concentrated point load by a hydraulic machine with a 600 kN capacity with effective span of (1800mm). The load was applied in sequential increases up to failure. Observations and measurements have been documented corresponding to mid span deflection, concrete strain and crack width.

Measurement of strain at concrete surface was done by three sets of dimec point which was fixed at the side surface of concrete in the compression zone .The dimec points were used at the mid span of beam and designated as (S1, S2, S3 and S4 for C4, C5) respectively from top to bottom and the Plate (5) below show the tool which is used for measured the strain

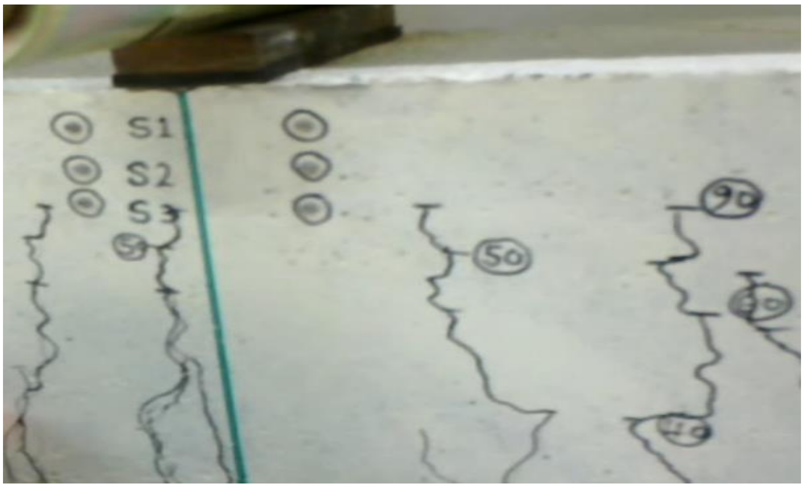


Plate (5) Location of the strain reading on the beam surface

5. Test results

The cracking, yield, and ultimate loads as well as the deflection and ductility values are arranged in Table (3) and all specimens fail under flexural.

5.1 . Cracking load

Table (3) reveals that the experimental crack loads are increased by 16% on average for beams have chrome rubber (C2, C3, C4 and C5). It can be seen that the crack loads was increased as a result of strengthening by inclined and coated CFRP especially for specimens C3, C4, and C5.

5.2. Yield load

Table (3) shows that the experimental yield load is decreased by 10% for specimen C2 compared with C1 as a result of using the chore rubber as expected. By using the CFRP strips, the yield load is increased by 20% and 60% for C4 and C5 respectively, but there is no significant effect for using the CFRP an area exposed to flatten of specimen C3 compared with C1.

5.3 .Ultimate load

Table (3) reveals that the experimental ultimate load was reduced by 9% for beam C2 compared with C1 as a result of using the chore rubber. By using the CFRP the ultimate load was increased by 20%, 17% and 63% for C3, C4 and C5 respectively.

5.4 . Ductility index

Ductility is usually defined as the energy absorbed by the material until complete failure occurs. It can be seen from Table (3) that the ductility index for reference specimen (C1) was 2.03 and the flexural failure was done. By using the chrome rubber as shown for specimens C1 and C2 the ductility increased by 74%. By using the CFRP, the ductility was improved and increased by 53% and 1% for C3 and C4 respectively compared with C1, but it is decreased by 37% for C5.

Table (3) Strength characteristics of tested specimen

* Reference Beam f'_c : Compressive strength of concrete at 28 days.

Beam Spe.	f'_c MPa	P_c (kN)	$\frac{P_c}{P_{cr}}$	P_y (kN)	$\frac{P_y}{P_{yr}}$	P_u (kN)	$\frac{P_u}{P_{ur}}$	Δ_y	$\frac{\Delta_y}{\Delta_{yr}}$	Δ_u	$\frac{\Delta_u}{\Delta_{ur}}$	Ductility $\frac{\Delta_u}{\Delta_y}$	$\frac{W}{W_r}$
C1*	35.90	26	1.00	100	1.00	109	1.00	11.1	1.00	22.55	1.00	2.03	1.000
C2	17.30	30	1.15	90	0.90	100	0.91	6.97	0.63	24.65	1.09	3.54	0.904
C3	17.95	31	1.19	100	1.00	131	1.2	7.20	0.65	22.28	0.99	3.10	0.912
C4	20.92	30	1.15	120	1.20	128	1.17	6.90	0.62	14.16	0.63	2.05	0.915
C5	20.60	Cannot be measured		160	1.60	178	1.63	14.90	1.34	18.95	0.84	1.27	0.916

(P_{cr}, P_{yr} P_{ur}) : Cracking, yielding and ultimate load for reference beam P_c, P_y, P_u: cracking , yielding and ultimate load

Δ_y , Δ_u : Deflection at yield and ultimate load W/W_r: ratio of beams weight

5.5 .Weight

It can be seen from Table (3) that by using the chrome rubber, the weight of specimens (C2, C3, C4 and C5) was decreased by 9% on average compared with C1.

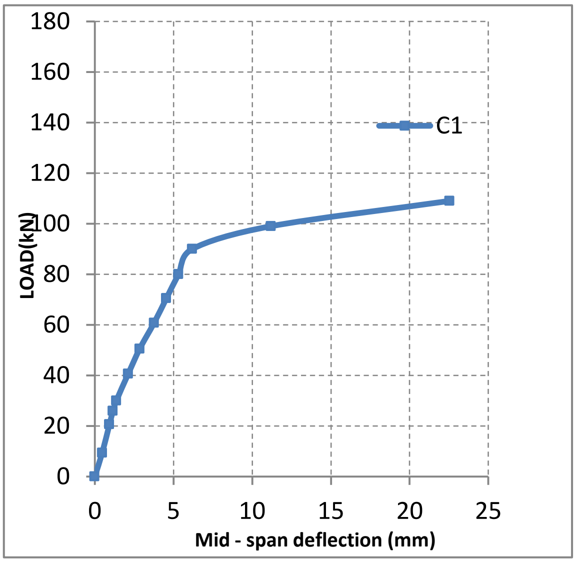
5.6 .Load- deflection relationship

Table (3) presented the deflection values at yield load and ultimate loads which are found from load-deflection figures. The deflection value at yield load is decreased by 27% for specimens C2 compared with C1 as a result of yield load decreasing. By using the CFRP for specimens C3 and C4, the defection is decreased by 35% and 38% when compared with C1 (at yield load) and by 1% and 37% (at ultimate). For specimen C5 the deflection is decreased by 16% as compared with specimen C1.

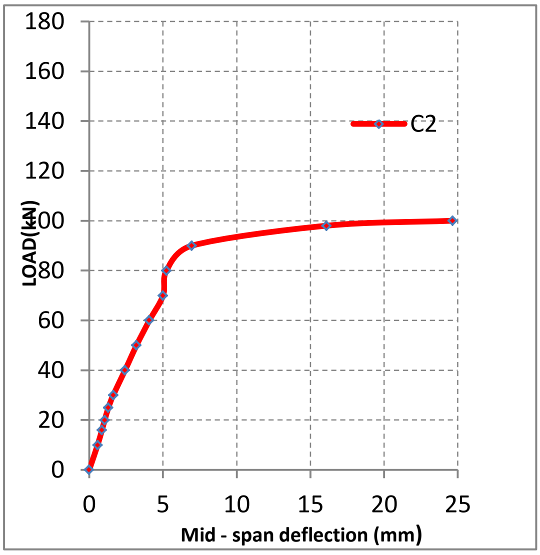
Figures (3) to (8), exhibit the load- deflection curves for the specimens. All specimens were failing in flexural mode. The role of CFRP is clear by improving the flexural strength of the beams.

5.7. Load- concrete stain curves of tested beams

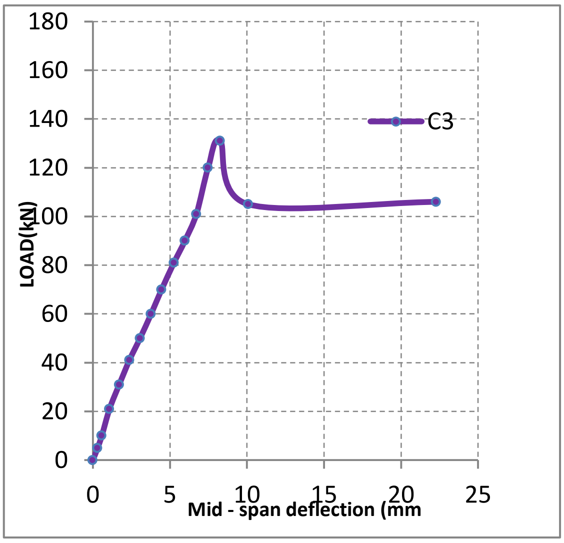
Load concrete strain curves explain the behavior of beams and the magnitude of strain at face of concrete. Three sets of demic were installed at side face of compression face of specimens. The values of strain were recorded as S1, S2, S3 and S4. The value of S1 was the actual value of strain in compression fiber of concrete because it was the nearest one to the top surface. For C1specimen the strain at



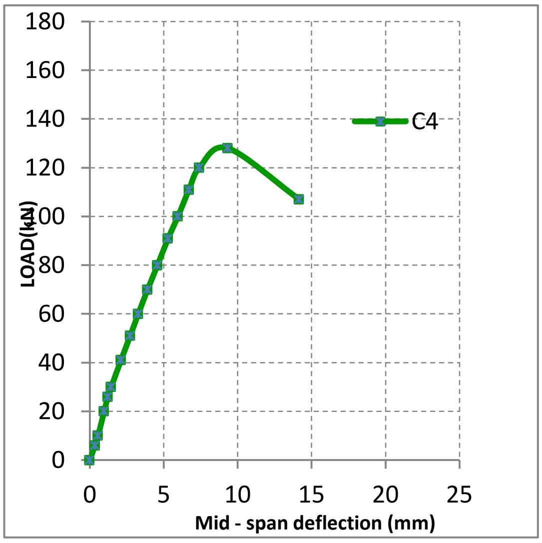
Figure(3) Load-deflection response of C1 specimen



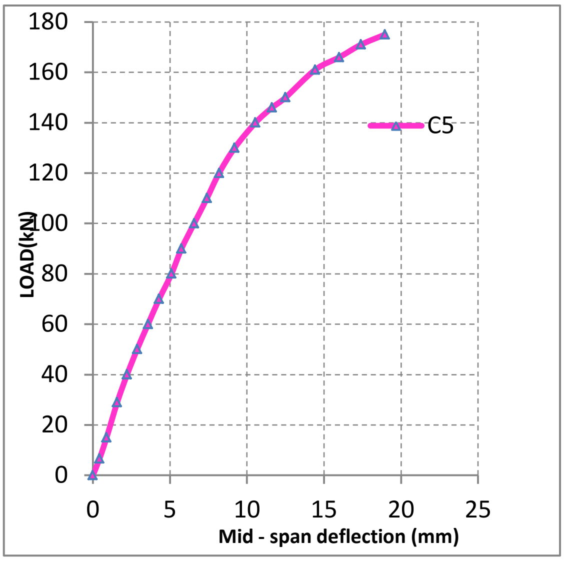
Figure(4) Load-deflection response of C2 specimen



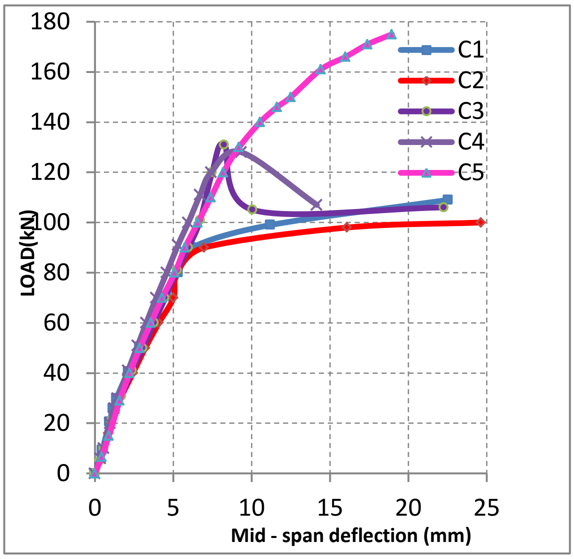
Figure(5) Load-deflection response of C3 specimen



Figure(6) Load-deflection response of C4 specimen



Figure(7) Load-deflection response of C5 specimen



Figure(8) Load-deflection response of all specimens

ultimate load reaches to 0.0025, 0.00085 and 0.00037 for S1, S2 and S3 respectively, which indicates that the failure is flexural as shown in Figure (9). For specimen C2 the strain at ultimate reaches to 0.00486, 0.00048 and 0.00042 for S1, S2 and S3 respectively, which indicates that the strain in concrete is greater than (0.003) as shown in Figure (10)

The result of strain of C3 specimen was 0.0049, 0.00409 and 0.00265 for gauges S1, S2 and S3 respectively as shown in Figure (11), and for C4 specimen it was 0.00282, 0.00265, 0.00217 and 0.00181 for gaugesS1, S2, S3 and S4 respectively as shown in Figure (12), and for C5 specimen was 0.00858, 0.00681, 0.0053 and 0.00293 for S1, S2, S3 and S4 respectively as shown in Figure (13). This good results show the capacity of CFRP in developing and increasing flexural strength so it causes increasing in compression zone as mentioned in specimens C3, C4 and C5.

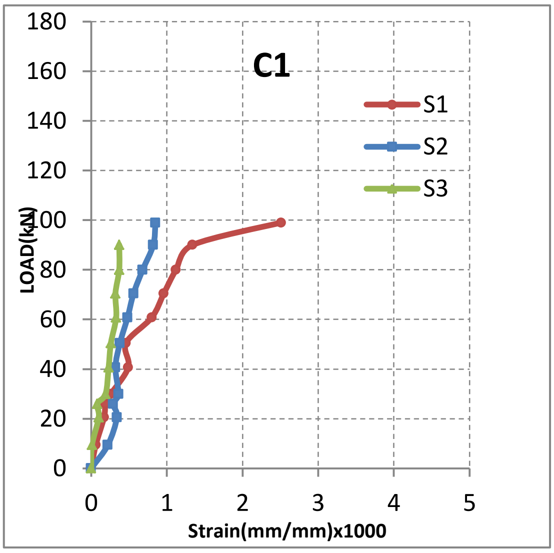


Figure (9) Load- compression strain of specimen C1

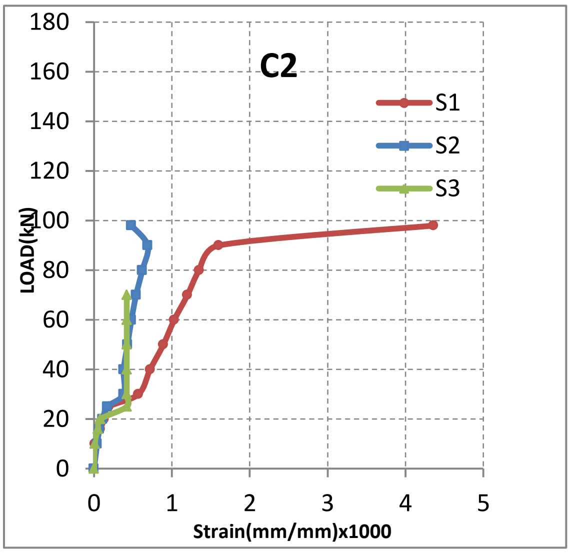


Figure (10) Load-compression strain of specimenC2

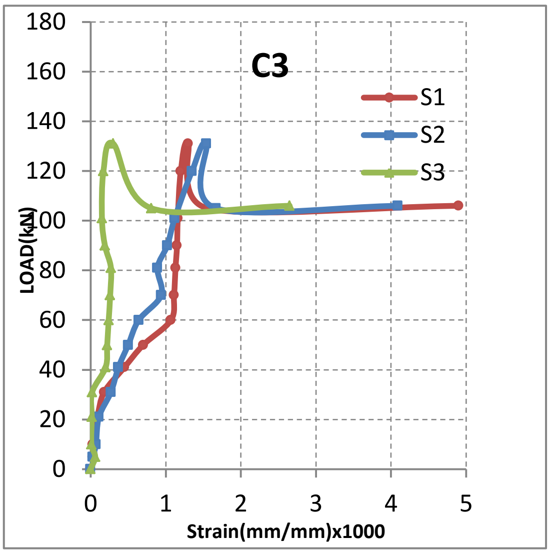


Figure (11) Load- compression strain of specimen C3

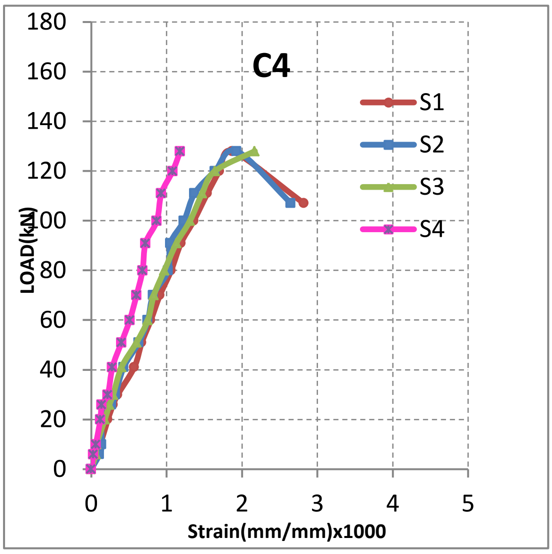


Figure (12) Load-compression strainof specimenC4

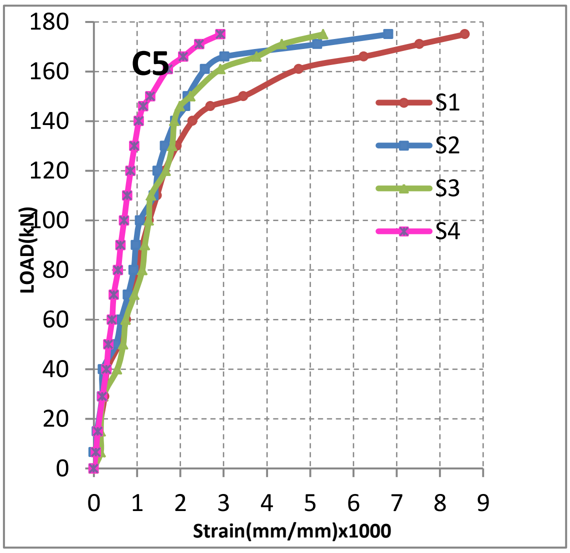


Figure (13) Load- compression strain of C5

5.8. Crack Pattern

The crack patterns of tested beams are shown in Plates (6) to (9). The cracks at the central zone of the beams were propagated upward with increasing the applied load as a result of high moment. The first crack usually appeared within the middle zone due to the high moment applied at this zone. The formation of cracks was haphazard and created within the center zone of the beams are frequently vertical due to the high moment applied on this region of the beam. For the other regions the cracks became inclined due to the presence of shearing forces in addition to the moment.

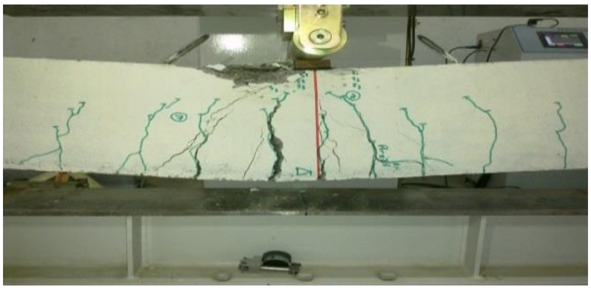


Plate (6) Crack pattern of C1 specimen

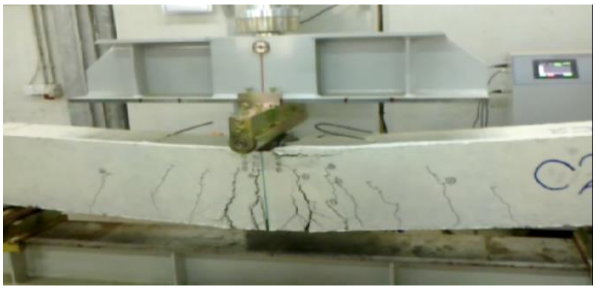


Plate (7) Crack pattern of C2 specimen

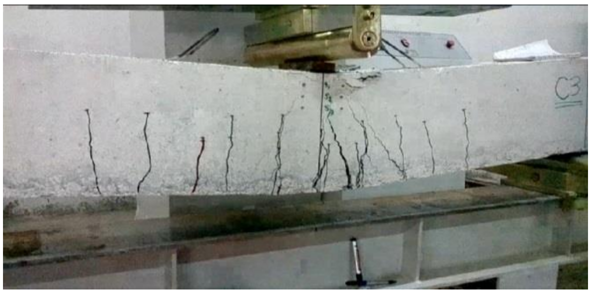


Plate (8) Crack pattern of C3 specimen

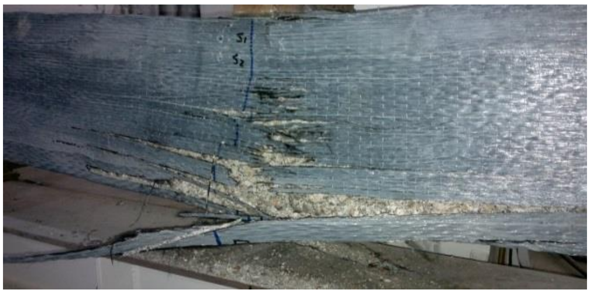


Plate (9) Crack pattern of C5 specimen

5.9. Load crack width curve

It can be seen from Figures (14) to (18), that the load crack width relationship for specimens C1, C2, C3 and C4 and the crack width of specimen C5 cannot be measured because it was covered by CFRP strips. The values of crack width at crack, yield and ultimate loads (before failure) is tabulated in Table (4). For specimen C1 the failure was flexural one, and the stress in longitudinal bars was increased after yield load, so the crack width was increased to reach 3.7mm. In C2 the crack width is less than of specimen C1 at yield and ultimate load by 9% and 38% respectively as a result of using the chrome rubber. For specimens C3 and C5, the crack width was decreased by 40% and 50% (at yield) and by 9% and 38% (at ultimate). This reduction in crack width is due to the strengthening the two specimens by CFRP strips.

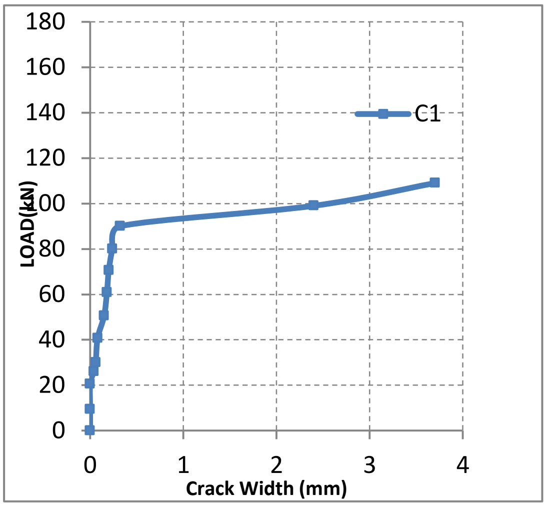


Figure (14) Load-crack width of C1 specimen

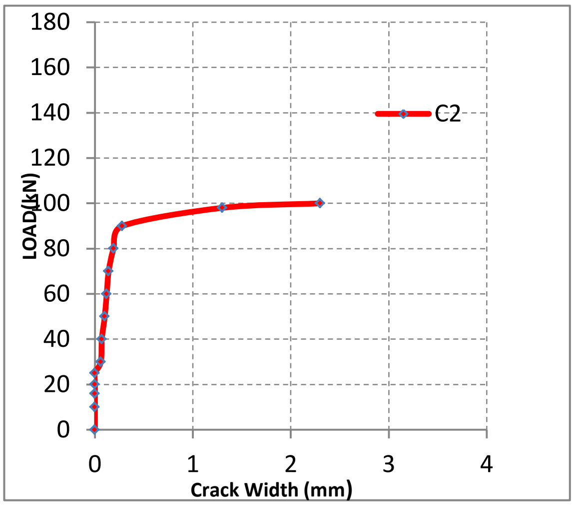


Figure (15) Load-crack width of C2 specimen

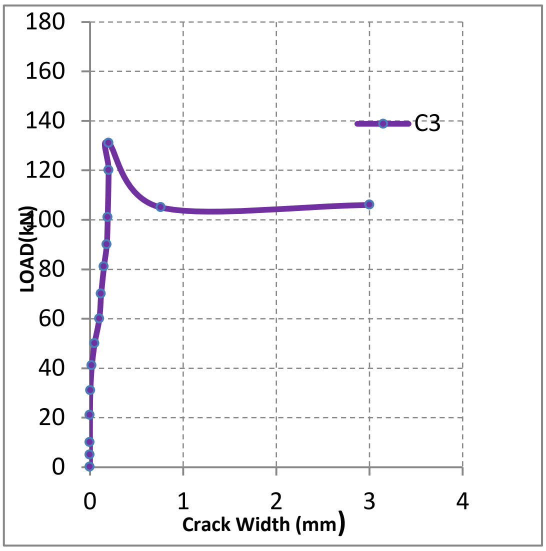


Figure (16) Load-crack width of C3 specimen

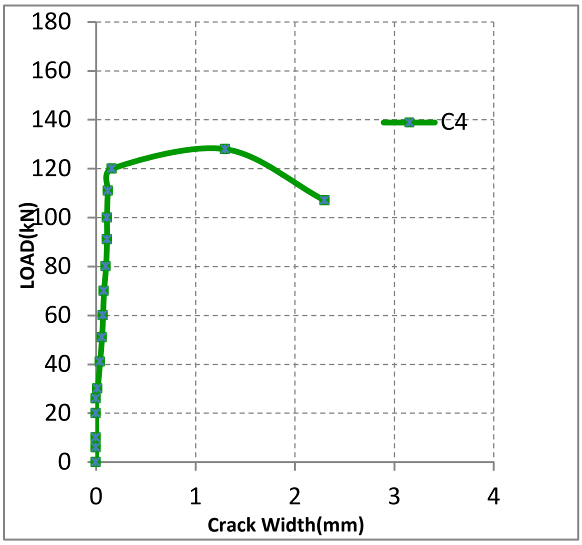


Figure (17) Load-crack width of C4 specimen

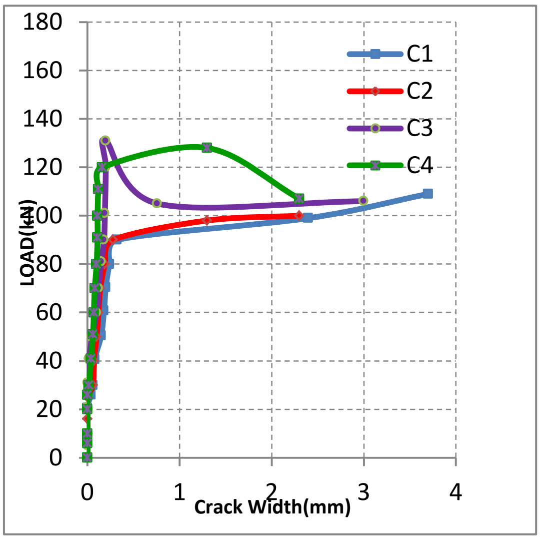


Figure (18) Load-crack width of all specimens

Table (4) Maximum crack width of tested specimens

Specimens	*Max. Crack Width (mm)*		
	At crack load	At yield load	At Ultimate load (before failure)
C1	0.04	0.32	3.7
C2	0.06	0.28	2.3
C3	0.004	0.19	3.0
C4	0.016	0.16	2.3
C5		Cannot be measured	

6. Conclusions

1) Replacing the chrome rubber with 50% of sand, the compressive strength of concrete reduced by 46%, but the weight was decreased by 9% on average.
2) The strengthening by CFRP strips increases the yield and ultimate load by 40% and 35% respectively.
3) Strengthening all faces of specimen with CFRP strips, the yield and ultimate load increased by 60% and 63%.
4) By using the chrome rubber the ductility increased by 74%. While using the CFRP, the ductility was improved and increased by 27% on average.
5) Using the chrome rubber, the deflection at yield load was decreased by 27%. By using the CFRP the deflection was decreased by 36% on average (at yield load) and by 19% (at ultimate load).
6) The response of CFRP increase the strain at compression face of concrete and the value at ultimate stage was greater than (0.003).
7) By using the chrome rubber, crack width is reduced by 9% and 38% at yield and ultimate loads respectively. Also by using CFRP, the crack width was decreased by 45% on average (at yield) and by 23% on average (at ultimate).

6. References

1. U. Meier, M. Deuring, H. Meier, and G. Schwegler, “Srtengthening of structures with CFRP strips: research and applications in Switzerland”, Adv. Comp. Mat. Bridges Struct. Can. Soc. Civil Eng., Montreal and Canada., vol. 1, June 1992, pp. 243-251,.
2. N. Oikonomou, S. Mavridou, The use of waste tyre rubber in civil engineering works, In Sustainability of construction materials Ed. J., Khatib, ISBN 978-1-84569-349-7, WoodHead Publishing Limited, Abington Hall, Cambridge, UK, 2009.
3. Spadea, G., Bencardino, F., and Swamy, R. 1998, “Structural behavior of composite RC beams with externally bonded CFRP.” J. Compos. Constr., 2 3, pp.132–137.
4. Matthys, S. 2000, “Structural behavior and design of concrete members strengthened with externally bonded FRP reinforcement.” Ph.D. dissertation, Dept. of Structural Engineering, Faculty of Applied Science, Ghent Univ., Belgium.
5. ACI Committee 440. 2002, “Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures.” ACI 440.2R-02, American Concrete Institute, Farmington Hills, Mich.
6. Tamuzs, V., and Tepfers, R. 2004, “Strengthening of concrete structures with advanced composite materials: Prospects and problems.” J. Mater. Civ. Eng., 16 5 , pp.391–397.
7. Meier, U., Kaiser, H (1991), “Strengthening of structures with CFRP laminates”, advanced composites materials in civil engineering structures, ASCE, New York, pp. 224–232.
8. El-Badry, M (1996), “Advanced composite materials in bridges and structures”, Canadian Society for Civil Engineering, Montreal.

9. Tamuzs, V., and Tepfers, R (2004), "Strengthening of concrete structures with advanced composite materials: Prospects and problems", J. Mater. Civ. Eng, 16(5), pp. 391–397.
10. Bonacci, J.F., Maalej, M (2001), "Behavioral trends of RC beams strengthened with externally bonded FRP", Journal of Composite for Construction, 5(2), pp. 102–113.
11. Bonacci, J.F., Maalej, M (2000), "Externally bonded fiber-reinforced polymer for rehabilitation of corrosion damaged concrete beams", ACI Structural Journal, 97(5), pp 703–711.
12. Teng, J.G. Smith, S.T., Yao, J. Chen, J.F (2003), "Intermediate crack-induced de-bonding in RC beams and slabs", Construction and Building Materials, 17, pp. 447–462.
13. ASTM D5644 Test Methods for Rubber Compounding Materials-Determination of Particle Size Distribution of Recycled Vulcanizate Particulate Rubber
14. ASTM D5603 Standard Classification for Rubber Compounding Materials-Recycled Vulcanizate Particulate.
15. Khaloo A.R., Dehestani M. and Rahmatabadi P. (2008), "Mechanical properties of concrete containing a high volume of tire-rubber particles", Waste Management, available online26 March 2008.
16. Benazzouk A., Douzane O, Langlet T., Mezreb K., Roucoult J.M. and Quéneudec M., (2007), "Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes", Cement and Concrete Composites, 29, pp.732–740.
17. Segre N. and Joekes I. (2000), "Use of tire rubber particles in addition to cement paste", Cement and Concrete Research 30(9), pp.1421–1425.
18. Turatsinze A., Bonnet S. and Granju J.-L. (2005), "Mechanical characterization of cement- based mortar incorporating rubber aggregates from recycled worn tyres", Building and Environment, 40, pp.221–226.
19. Siddique R. and Naik R.T. (2004), "Properties of concrete containing scrap-tire rubber – an overview", Waste Management, 24, 563–569.
20. Li G., Stubblefield M.A., Garrick G., Eggers J., Abadie Ch. and Huang B. (2004), "Development of waste tire modified concrete", Cement and Concrete Research, 34, pp.2283–2289.
21. Eldin N.N. and Senouci A.B. (1993), "Rubber-tire particles as concrete aggregates", ASCE Journal of Materials in Civil Engineering, 5(4), pp.478–496.
22. Topçu I.B. (1995), "The properties of rubberized concrete", Cement and Concrete Research, 25(2), pp.304–310.
23. Pierce C.E. and Williams R.J. (2004), "Scrap tire rubber modified concrete: Past, present and future", in Proceedings of the International Conference Organized by the Concrete and Masonry Research Group, Kingston University-London, Eds M.C. Limbachiya and J.J. Roberts, Sustainable Waste Management and Recycling: Used-Post-Consumer Tyres, Thomas Telford, pp. 1–16.