Iraqi journal of civil engineering (IJCE)
P-ISSN: 1992-7428 ; E-ISSN: 2706-686X

Vol. 17 , No. 2 (2023) , pp. 34 ~ 44
DOI: 10.37650/ijce.2023.170204

Iraqi Journal of Civil Engineering

Journal homepage: https://ijce.uoanbar.edu.iq/

Behaviour of RC-Deep Beam by GFRP Rubberized Concrete

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PAPER INFO

Paper history
Received: 03 /09 /2023
Revised: 04/ 10 /2023
Accepted: 07/10 /2023

Keywords:
Crumb rubber
Deep beams
Rubberized concrete
GFRP bars

ABSTRACT

In this study, the structural behaviour of RC-deep beams of glass fibre-reinforced polymer (GFRP) rubberized concrete is investigated. Rubberized concrete is manufactured by replacing fine sand aggregate with rubber crumbs in volumetric replacement ratios. The main variables were the crumb rubber content (0%, 10%, and 20%) and the main reinforcement ratio. Tested Six samples of deep beams with different dimensions (b = 150, h = 300 mm, L = 1400 mm) were under a four-point load until failure. The parameters under investigation were the mechanical properties of mixtures, load-midspan deflection curves, toughness, and the load-strain relationship. The results indicate that the increment in crumb rubber content led to a decrement in the mechanical properties of rubberized concrete mixtures. It was found that the behaviour of all samples of rubberized concrete affected the deflection load curve, the ultimate load, and the increase in deflection. The sample R2-10% Rub showed the highest toughness among the tested samples, with an increase of 301.6% compared to the reference.

1. Introduction

Concrete is the most commonly used construction material worldwide, and a significant quantity of natural resources is required to produce it, which demonstrates that natural resources must be available permanently. On the other hand, the build-up of solid trash, particularly tires from old cars that are dumped in landfills on a massive scale every year in different areas of the world, has become a catastrophe for the environment(Phale, 2005). According to the previous study(Najim & Hall, 2010), it dampens tires on the ground, which leads to numerous major environmental difficulties as well as anticipated economic problems. Harmful pollutants could be released into the air by accidental fires caused by dampening issues. Since tires are highly flammable, it is therefore difficult to handle fires(Kordoghli et al., 2014). The recycling of tires that have reached the "end of life" has become one of the most important concerns in the fields of research and the environment. Every year, an estimated one billion expired tires are thrown into landfills, all over the world. According to estimates(Roychand et al., 2020), 50% of it is recycled, and the rest remains a source of pollution. One of the innovative solutions was the use of rubber crumbs in the production of rubberized concrete. In order to determine the different material qualities

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of concrete, including tire particles, extensive research has been done over the past twenty years. Rubberized Concrete (RC) is a type of concrete in which crumpled, used tire crumb rubber is used to replace a part of the fine aggregate (sand). The rubber tires are cut and shredded and ground to form rubber crumbs in the form of crumbs ranging in size from 4.75 mm to 75 mm. The method of replacement is volumetric or weight, with replacement rates such as (5%, 10%, 15...etc.). Several studies have been carried out on the addition of tire waste-derived crumb rubber to the concrete-mix for the production of various structural elements of rubber concrete(Sukontasukkul & Chaikaew, 2006) and (Youssf et al., 2015). According to (Noaman et al., 2016) The results showed that rubberized concrete mixtures with crumb rubber levels of 5%, 10%, and 15%, respectively, were reduced by 12.7%, 21.7%, and 26.0%. The reduction in modulus of elasticity was similar to that in compressive strength. (Abdulameer Kadhim & Mohammed Kadhim, 2021) evaluated the mechanical properties of concrete reinforced with crumb rubber. When crumb rubber content was increased from 5%, 10%, 15%, and 20%, respectively, the results showed a drop in compressive strength by 15%, 19%, 31%, and 40%, and a decrease in splitting tensile strength ranging from 11%, 14.9%, 24.1, and 34% for crumb rubber content of 5%, 10%, 15%, and 20%, respectively. It was found that as the percentage of rubber volumetric replacement increases, the deflection at the same load increases as well. However, (Liu et al., 2016) found that crumb rubber concrete has less mechanical strength. Both the 20% replacement of fine aggregate (sand) and the entire mixture had qualities that were suitable for use in practical applications.

The objective of this study was to analyze the behaviour of RC-deep beams by GFRP rubberized concrete, including the mechanical properties of rubberized concrete in terms of density, compressive strength, tensile strength, modulus of elasticity, and structural test.

2. Experimental program

2.1. Materials

As shown in Figure (1) materials used, in this investigation, specimen casting was done using Ordinary Portland Cement Type 1, which is a commercially available. The chemical and physical characteristics of this type of cement are listed in Tables 1 and 2, respectively, and they are in accordance with Iraqi standards (No. 5–2019). Crushed coarse aggregate with a maximum size of 12 mm and natural sand with a maximum size of 4.75 mm were utilized, Tables 3 and 4 illustrate the findings of the sieve analysis of fine and coarse aggregate, which were confirmed to be in compliance with Iraqi Specification No. 45. Crumb rubber was used with a specific gravity of 1.1 and a particle size range of 4.75–0.075 mm by employing the ratios of volumetric replacement (0, 10, and 20%) regarding the fine aggregate (sand). Figure (2) the result of the sieve analysis of crumb rubber, which was sieved according to ASTM C136 (2014).

Fig.1 Materials used in study (A) Cement, (B) Coarse aggregate, (C) Fine aggregate and (D) Crumb rubber.

For deep beam flexural testing, specimens were reinforced with GFRP bars and standard conventional steel bars. Glass fibre reinforced polymer (GFRP) has been used in this experimental as a longitudinal reinforcement with a diameter of 12mm and represents the main reinforcement. GFRP bars were helically wrapped and slightly sand-coated, and the surface of the GFRP bars was deformed. Steel reinforcement has a diameter of 6 mm. Both Longitudinal and side bars are the two available forms of reinforcement. The first reinforcement was used for longitudinal reinforcement, while the second one was employed for side reinforcement. Table (5) illustrates the mechanical properties of the used reinforcements.

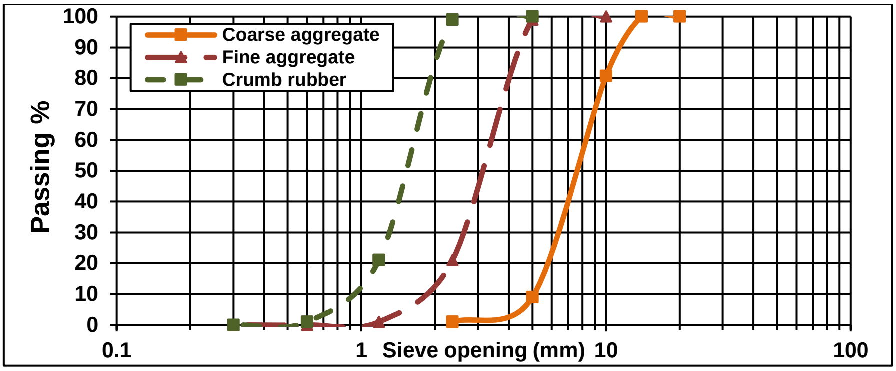

Fig.2 Particle size distributions of three type of aggregates.

Table 1- The Chemical Composition of the Cement.

Compound	Percentage by weight	Iraqi standard No. 5/2019 Limits
CaO	64.1	-
Fe_2O_3	3.4	-
SiO_2	21.1	-
Al_2O_3	3.81	$\leqslant$ 3.5
MgO	2.2	A maximum of 5%
Main compounds	**Oxide % by Weight**	**Iraqi standard No. 5/2019 Limits**
C3A	5.4	≤ 3.5%
C4AF	14.62	-
C3S	19.42	-
C2S	49.45	-

Table 2- Cement physical properties.

Test type	Results	limit of Iraqi specification IQS 5/2019
Initial setting time (min)	160	≥ 45 min
Final setting time (min)	245	Not more than 600 min
Fineness by Blaine method (cm^2/g)	2530	≥ 2500
Compressive strength at 2 days (MPa)	12.5	≥ 10 MPa
Compressive strength at 28 days (MPa)	42.5	≥ 32.5 MPa

Table 3- Fine aggregate sieve analysis

Sieve Size (mm)	Cumulative Passing %	Iraqi specification limits (NO. 45 /1984)
10	100	100
4.75	98	90-100
2.36	84	75-100
1.18	71	55-90
0.6	54	35-59
0.3	16	8-30
0.15	3	0-10

Table 4- Coarse aggregates sieve analysis

Sieve Size (mm)	Cumulative passing %	Iraqi specification limits (NO. 45 /1984)
20	100	100
14	100	90-100
10	80.7	50-85
5	9	0-10

Table 5- The mechanical properties illustration of the used reinforcements.

Type materiel	Diameter (mm)	Area $(mm)^2$	Yield stress (MPa)	Ultimate strength (MPa)
Steel	6	28.27	596	613
GFRP	12	113	-----	822

2.2. Mixing Proportions

In order to achieve the needed workability and compressive strength, this study used the ACI 211 method from the American Concrete Institute. The water-cement ratio (w/c) used in the design was 0.47, and the compressive strength was (35 MPa). Depending on how much crumb rubber each mixture included, three different concrete compositions were created. The ingredients for each of these three combinations are listed in Table 6.

Table 6- Mixing proportions

Mixes	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	Crumb rubber	*w/c*
Mix1	420	1015	800	210	0	0.47
Mix2	420	1015	720	210	36.4	0.47
Mix3	420	1015	640	210	72.4	0.47

2.3. Mixing method

In general, the same mixing technique was used throughout the experiment to guarantee that all mixtures encountered the same conditions. The rotary mixer had a 0.07 m3 capacity, and its internal surface had been cleaned and moisturized before usage. The first step was to prepare the weights of the items needed and used for each sample. The addition of coarse and fine aggregate was then made, and the mixture was completed in four minutes. Cement was then added and combined with the aggregate. Rubber was added, and after making sure that the dry components were mixed together, water was progressively added while mixing for five minutes to produce a new and homogeneous concrete mix.

2.4. Specimens

To measure density, compressive strength, tensile strength, and static modulus of elasticity and structural behavior of deep beams, three cubes (100 mm x 100 mm x100 mm), three cylinders (100 mm x 200 mm), three cylinders (150 mm x 300 mm), and one cylinder (150 mm x 300 mm) and deep beam with dimensions (b = 150, h = 300 mm, L= 1400 mm) were constructed for each mixture.

In this study, six simply supported deep beams reinforced with GFRP bars were constructed and tested up to failure under four-point loading, as shown in Fig 3 and Fig.4 shows details of reinforcement and diemantion deep beams and setup samples, respactivly. All the beams had the same rectangular cross-section with constant dimensions (b = 150, h = 300 mm, L= 1400 mm). Based on the main reinforcement ratio, two sets of deep beams were created ($\rho_1 = 0.0085 \; and \; \rho_2 = 0.0113$), and each group represented three samples with a difference in the content of rubber crumbs, which represents (0%, 10%, and 20%) as shown Table 7. Additionally, for longitudinal and side reinforcement, steel bars with a diameter of 6 mm are used as skin for deep beams.

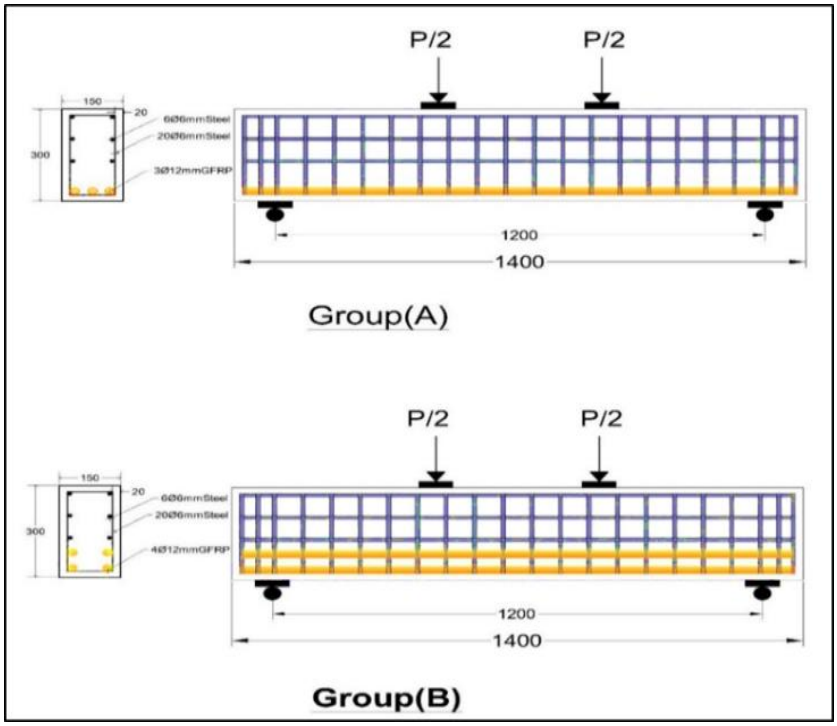

Fig.3 Details of test samples.

Table 7 – Details of test samples.

Specimen Name	Rubber content %	No. of GFRP	Main reinforcement ratio
R1-0%	0%	3	0.0085
R1-10%	10%	3	0.0085
R1-20%	20%	3	0.0085
R2-0%	0%	4	0.0113
R2-10%	10%	4	0.0113
R2-20%	20%	4	0.0113

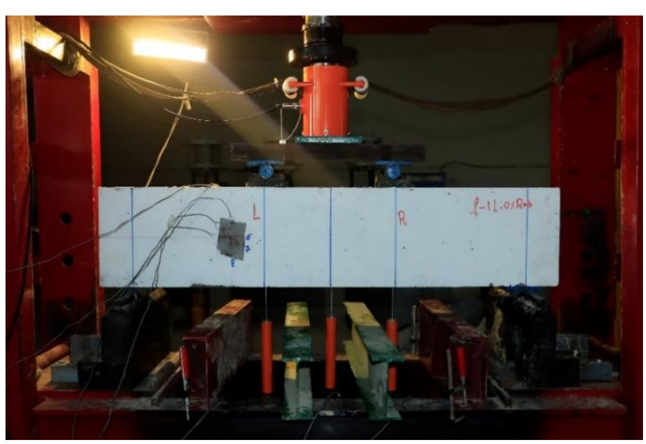

Fig.4 Details of setup samples.

3. Results and Discussions

3.1. Fresh and mechanical properties

3.1.1 Slump

Workability is an essential property of fresh concrete that has a significant effect on its final strength, according to(ASTM C143) . It mostly depends on the characteristics of the primary component utilized to produce the concrete mix. With an increase in rubber content, a rubber concrete mix becomes less workable. Table 8 lists the results obtained in this study. During the investigation, several rubber-to-freshly mixed concrete ratios (0, 10%, and 20%) were examined. The slump of the mixture containing 0% rubber was 90 mm, 10% rubber caused the slump to be 80 mm, and 20% rubber caused the slump to be 70 mm(Roychand et al., 2020).

Table 8 - Results of slump test.

Mixes	Crumb rubber Content by volume %	Slump(mm)	Difference percent %
Mix1	0%	90	-
Mix2	10%	80	-11.1
Mix3	20%	70	-22.2

3.1.2 Density

The results of the density examination can be seen in Table 9 below in accordance with the specification BS 1881: 114 (British Standard Institiution, 1983). By adding crumb rubber in place of fine aggregate to the concrete mix, a minor drop in density could be seen. The decreased relative density of the rubber crumb in comparison to the fine aggregate (sand) density is the cause of the decrease in density.

Table 9- Density test results.

Mixes	Crumb rubber Content by volume %	Density (kg/m^3)	Difference percent (%)
Mix1	0	2355	-
Mix2	10	2350	-0.21%
Mix3	20	2256	-4.2%

3.1.3 Compressive strength

According to (ASTM C39),the compressive strength of the concrete is one of the most significant variables considered The compressive strength examination results for each mix are listed in Table 6 below and are presented as an average of three specimens in Table 10. The compressive strength decreased by 24.5%, and 44.9% with increases of crumb rubber in concrete mixes by 10% and 20%, respectively, as compared to the reference mix. The reason for the decrease in compressive strength is attributed to the weakness of the interface between the rubber granules and the cement paste, where a void-like structure is formed, thus weakening the cohesion of the concrete when exposed to a compressive load(Nematzadeh et al., 2021). Figure 5 illustrates the failure modes of cylinders under compressive strength.

Table 10- Compressive strength results.

Mixes	Crumb rubber Content by volume %	Compressive Strength(MPa)	Difference percent (%)
Mix1	0	39	-
Mix2	10	29.5	-24.4
Mix3	20	21	-44.9

Fig.5 Failure mode of cylinders specimens.

3.1.4 Splitting tensile strength

According to (ASTM C469), one of the most essential characteristics of concrete is its split tensile strength, which helps determine the load at which concrete parts may crack. Figure 6 shows the results of the tensile splitting strength test for the tested samples. The results indicate a decrease in the tensile strength of 19% and 45% for the rubberized concrete with a content of 10% and 20%, respectively, compared to the reference sample. This decrease in concrete splitting tensile strength may be due to decreased cohesion between the cement paste and the soft tire particles, an increase in the (w/c) ratio in the mortar surrounding the rubber particles as a result of the particles' lack of water absorption, and a weaker boundary layer as a result. Figure 7 shows a comparison of the failure rates of conventional and rubberized concrete samples.

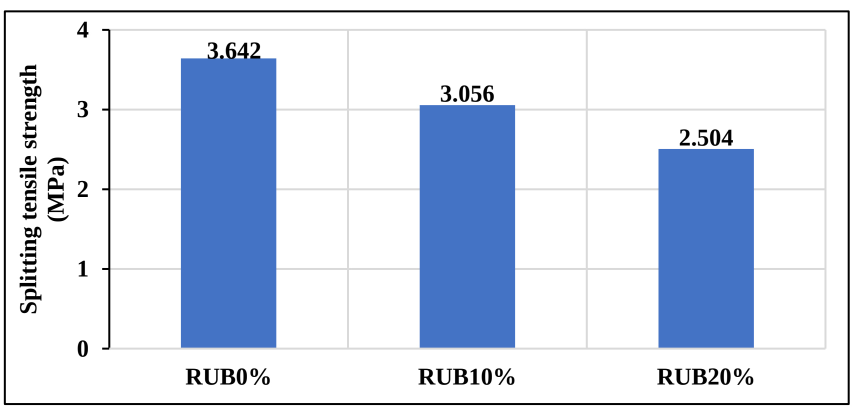

Fig.6 Splitting tensile strength results.

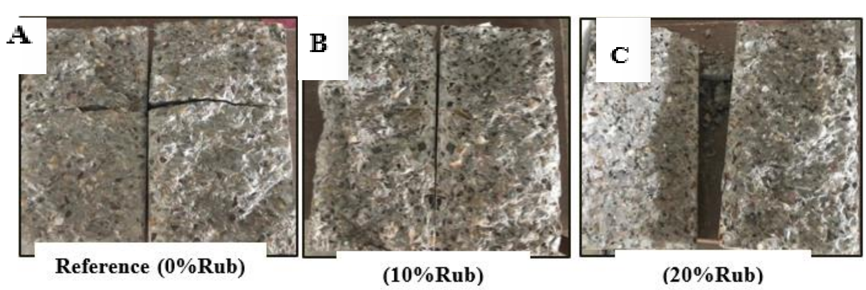

Fig.7 Specimens after splitting tensile test (A) Normal concrete, (b) 10% Rubberized concrete, and (c) 20% Rubberized concrete.

3.1.5 Modulus of elasticity

The results of the modulus of elasticity test are shown in Fig.8. For each of the concretes including crumb rubber by 10% and 20%. The rubberized concrete appeared to have a lower modulus of elasticity than the reference by 14.2% and 17.8%, respectively. According to (Eisa et al., 2020), rubber has a lower elasticity modulus than fine sand aggregate, which is the cause of this decline.

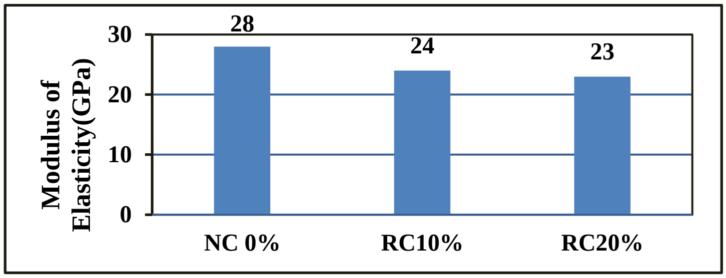

Fig.8 Modulus of elasticity results.

3.2. Deep Beams test results

Table 10 shows the main experimental results for the test specimens, including the first crack load, ultimate load, toughness, and maximum strain measured for the GFRP bars in the tensile region.

Table 10- Results of deep beams.

Specimen	First crack, Pcr,kN	Difference percent, Pcr, %	Ultimate load, Pu, kN	Difference percent, Pu, %	Mid-span defection at ultimate load, mm	Toughness (kN.mm)	Max.Tenion Strain
R1-0% Rub (References)	48.2	------	221	----	5.41	570.8	0.0137
R1-10%Rub	45.9	-4.6	291	31.6	10.38	1868.1	0.0326
R1-20% Rub	47	-2.4	310	40.3	13.4	2704.7	0.0246
R2-0% Rub	57.9	20.1	219	-0.9	4.62	581.5	0.0130
R2-10% Rub	41	-14.9	356	61	13.9	3070.7	0.0211
R2-20% Rub	45	-6.6	317	43	11.11	2292.8	0.0222

3.2.1 Load-deflection curve

The load-midspan deflection curves in Fig. 9 show that increasing the crumb rubber content decreased the stiffness drop rate at the first cracking, which raised the ultimate load for all deep beams. However, the failure load of these specimens increased when compared to the reference. According to Fig. 9, as the crumb rubber ratio increases, the load-deflection curve generally moves upward, resulting in a higher load-carrying capacity. Crumb rubber absorbs energy, increasing the sample's load-capacity (Sandeep et al., 2022). The ultimate load (Pu) increased by 31.6%, 40.3%, 61%, and 43% for samples (R1-10%Rub, R1-20% Rub, R2-10% Rub, and R2-20% Rub), respectively.

Figures 10 and 11 compare the load-deflection responses of various specimens to a reference sample. Compared to the reference sample (R1-0%), the slope of the load-deflection response of the rubberized concrete samples was found to be lower. This demonstrates that the crumb rubber samples are more flexible than the reference sample. Rubber's lower modulus of elasticity may be one of the reasons for the decreased these specimens' stiffness. This, therefore, allowed them to undergo considerable deformation when compared to normal concrete.

When compared to the reference sample, it was observed that the maximum deflection of every sample rose (R1-1L-0%) with increased rubber content. The deflection (Δ_{max}) increased by 91.8%, 147%,156%, and 105% for samples (R1-10%Rub, R1-20% Rub, R2-10% Rub, and R2-20% Rub), respectively.

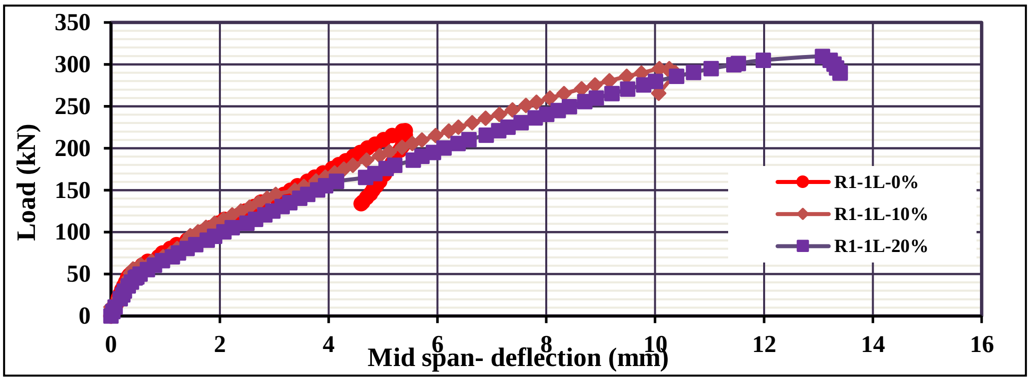

Fig.9 Load -deflection curve for all samples.

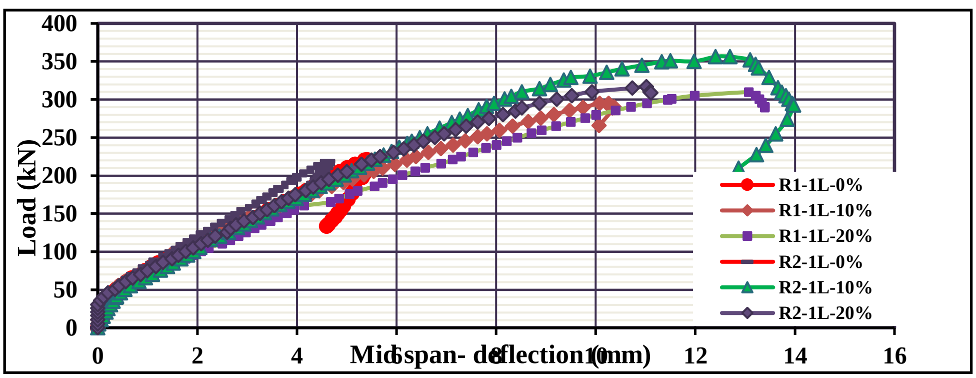

Fig.10 Load -deflection curve for reinforcement ratio (R1) and different crumb rubber content%.

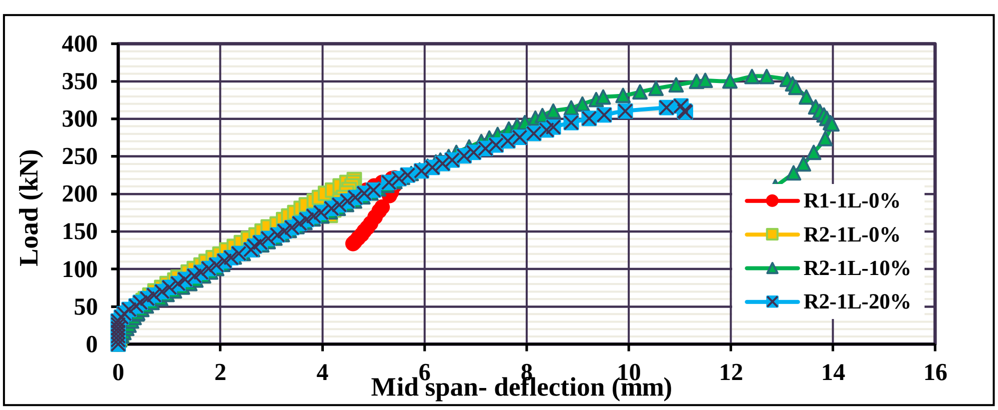

Fig.11 Load -deflection curve for reinforcement ratio (R2) and different crumb rubber content%.

3.2.2 Toughness

Toughness is described as a material's ability to absorb energy before fracturing. It denotes the area under the load-deflection curve from zero to maximum load. The area under the load-deflection curve was calculated by the AutoCAD program. The results of the toughness obtained at different replacement ratios of crumb rubber are shown in Fig. 12. The toughness considered here was obtained by calculating the area under the load-deflection curve up to the maximum load value. The results shown in Table 10 indicate that the toughness is significantly improved with an increase in the percentage of crumb rubber in rubber concrete. This is due to the ability of low-toughness crumb rubber to improve energy absorption capacity. Compared with the reference sample (R1-0%), it was found that the rate of increase in toughness increased with increasing crumb rubber content in concrete by 227.2%, 437.9%, 373.8%, and 301.6% for the samples (R1-10% Rub, R1-20% Rub, R2-10% Rub, and R2-20% Rub), respectively. On the other hand, as expected, rubberized concrete samples reinforced with GFRP bars showed a high ability to resist high loads with an increased loading rate before failure occurred. The key to such systems is their ability to absorb large quantities of energy while still supporting loads under extreme deflections.

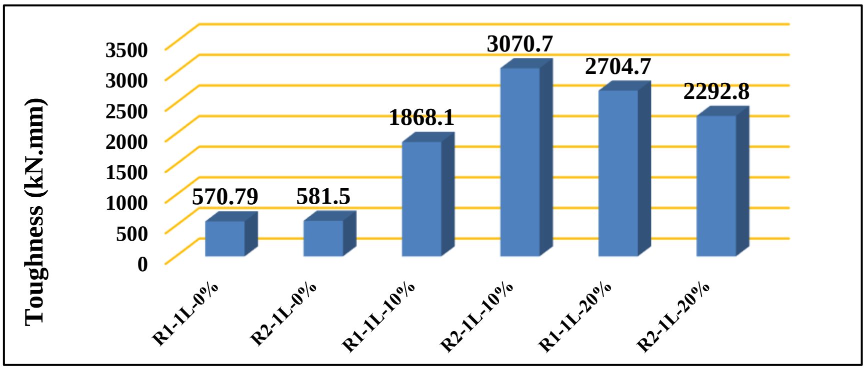

Fig.12 Toughness resulte for all samples.

3.2.3 Load-strain relationship

Table 10 shows the longitudinal GFRP bar strains recorded at the mid-span of tested deep beams. When the proportion of crumb rubber was increased from 10% to 20%, the maximum strain at tension sides increased significantly. The results obtained from the stress gauge showed that with the increase in the content of crumb rubber in the concrete, the rate of increase was 79.5%, 54.0%, 62.0% for samples (R1-20% Rub, R2-10% Rub, R2-20% Rub, respectively, compared with sample reference.

4. Conclusions

Based on the experimental data presented in the preceding section, the following conclusions can be drawn, which included mechanical properties for mixers and structural testing:

1. The workability of the rubberized concrete mixture decreased with increased rubber content (10%, and 20%).
2. The compressive strength of the rubberized concrete mixture decreased by about 24.4%, and 44.9% for crumb rubber content 10% and 20% respectively, as compared to the reference normal concrete mix.
3. increase in crumb rubber content to 10% and 20% reduces splitting tensile strength by 19% and 45%, respectively.
4. A slight decrease in modulus of elasticity could be observed by replacing crumb rubber in the concrete mixture.
5. It was found in the deflection load curve that increasing the crumb rubber content led to an increase in the final load before final failure occurred, while the first crack load decreased, as cracks appeared faster in the rubber concrete.
6. The toughness of the rubberized concrete mixture showed higher values with increasing crumb rubber content. The mixtures performed better due to increased energy absorption. This leads to an increase in the bearing capacity of the samples before reaching the final load and failure occurs.

It is proposed in the following work to use processed rubber crumbs in various amounts or to employ this rubber powder in connection to concrete mixtures. To develop prediction models, deep beams made of rubberized concrete were examined for behaviour using the Finite Element Method., especially their response to direct fire.

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