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Research Article

Ductility of simply supported rubberized concrete beams

Ahmed Youssef Kamal [a,*]

[a] *Department of Civil Engineering, Benha University, Benha, Egypt*

ABSTRACT

Dispose of waste rubberized tires become a dangerous problem around the world, represented a big serious risk to the sur-rounded environment. Many studies show that over 1000 million tires reach their expired date yearly and this figure is anticipated to be 5000 million tires by reaching 2030. A minor part of them is employed as recycled materials and the residual amount is stockpiled or buried. This paper aimed to successfully utilize the vast amounts of tire rubber waste existing currently in landfills. This paper represents a practical investigation of the ductility performance of the reinforced rubberized concrete beams. Thirteen reinforced concrete beams simply supported, with waste rubber tires mixtures vary from 0 to 8 percentage as aggregates replacements, were tested by mid-span load. Therefore, to examine the ductility performance of reinforced rubberized concrete beams, three sets of samples were made. In the first group, coarse aggregates in the concrete mix were replaced by different percentages of the waste rubber partials, while for the second group, crumb rubber was replaced for the fine aggregates, and for the third one, a mix of waste and crumbed rubber were replaced for both types of aggregates. Experimental results of rubberized specimens were also compared with that of the reference beam (without rubber replacement), the comparison results declare that concrete contains rubber particles is less ductile than conventional concrete.

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1. Introduction

Concrete properties depended on aggregates type, additives, and methodologies of preparation, now we can make an environmentally beneficial by using recycled material. One of the recycled materials is rubberized concrete in which a certain percentage of both coarse and fine aggregates can be partially replaced by waste particles of rubber. Vulcanized rubber material extracted from tires is highly durable, has good strength and deformability, and can maintain its volume under stress, thus making it an ideal material to replace mineral aggregate for highly deformable concrete. Rubberized concrete has attracted a lot of attention from researchers to research its effect on concrete mechanical properties (Guo et al., 2014; Sienkiewicz et al., 2017; Pham et al., 2019; Pham et al., 2020; Khusru et al., 2020). Many studies provided the advantages for rubberized concrete over the normal one, such as energy absorption capacity, lightweight, and acceptable workability. Replacing both types of aggregates with waste particles of rubber also enhanced the capacity of the energy absorption, and the fracture energy results in more ductile post-cracking behavior (Wang et al., 2020). An experimental study has declared that the imparted energy per unit weight in the rubberized concrete is higher than that of the one without, rubberized concrete localized the damage of the impacted load, led to slow down the stress wave velocity (Pham et al., 2020). From the durability view, the concrete with rubber particles is more vulnerable to chloride, water, and chemical attacks, also the depth of carbonation is higher than the depth of carbonation for normal concrete and increased by increasing the rubber percentage, indicating more exposure to steel corrosion (Pham et al., 2019). Although by comparing the estimation of service life for the normal concrete mix and that of rubberized concrete, it is clear that the service life of the concrete contains rubbers particles is

* *Corresponding author*. Tel.: +2-013-322-8887 ; E-mail address: aykmar@yahoo.com (A. Y. Kamal)
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shorter than that of normal concrete (Pham et al., 2019). On the opposite view, increasing the rubber replacement percentage results in a noticeable reduction in both compressive, tensile strengths and the elasticity modulus of the concrete, it observed that replacing coarse aggregate results in great reduction than that of replacing fine one (Wang et al., 2020; Khatib and Bayomy, 1999; Hernandez-Olivares et al., 2002; Boudaoud and Beddar, 2012; Zhu et al., 2018). More recently, it was also found that concrete contains rubber enhanced the lateral strain under axial loading (Bompa et al., 2017; Raffoul et al., 2017). In the way to reduce the disadvantages of the rubberized concrete, adding Fibber Reinforced Polymers in the crumb rubber concrete increase the strength of concrete contain rubber particles (Youssf et al., 2017). Using welded wire mesh improved the structural performance of the rubberized concrete beams in front of shear failure; the mode of failure changed from shear to flexural or compressive failure, deflections at failure increased by using both single and double layer of welded wire mesh. The highest rate of increase in maximum deflection was obtained in the case of using 20% of crumbed rubber (Sharaky et al., 2020). Some studies concluded that the phenomena of strain localization affect member ductility. Fifty concrete slabs simply supported reinforced by welded wire mesh were tested to examine this phenomenon, the wire space and diameter were the two major parameters, the study explains the great effect of this phenomenon on the slab's ductility (Shwani et al., 2019).

2. Experimental Program

Thirteen simply supported reinforced concrete beams were tested under mid-span concentrated load, as shown in Fig. 1 and Table 1. The effect of replacing coarse and fine aggregates with rubber particles on the ductility and flexural capacity of the tested beams was experimentally examined.

Fig. 1. Test setup.

Table 1. Mix proportion of the specimens (all amounts in kg for one cubic meter).

Beam		Cement	Water	Coarse agg.	Fine agg.	Waste rubber	Crumbed rubber
B1		450	170	1000	750	---	---
B2	Group A	450	170	980	750	20	---
B3	Group A	450	170	960	750	40	---
B4	Group A	450	170	940	750	60	---
B5	Group A	450	170	920	750	80	---
B6	Group B	450	170	1000	735	---	15
B7	Group B	450	170	1000	720	---	30
B8	Group B	450	170	1000	705	---	45
B9	Group B	450	170	1000	690	---	60
B10	Group C	450	170	980	735	20	15
B11	Group C	450	170	960	720	40	30
B12	Group C	450	170	940	705	60	45
B13	Group C	450	170	920	690	80	60

2.1. Specimen details and test program

All the tested reinforced concrete beams were cast with the same concrete dimensions (square cross-section with 150 mm side length, and 1500 mm total length with 1300 mm net length). The main longitudinal tensile reinforcement of the tested beams was two deformed steel bars with a diameter of 12 mm, equivalent to the main reinforcement ratio of 0.01, with average yield strength, and tensile strengths of 37 and 54 kg/mm^2 respectively, and with an average elastic modulus of 20900 kg/mm^2. While the compressive reinforcement was two steel bars with a diameter of 12 mm (with the same properties of tension steel). Seven vertical mild steel closed stirrups with 8 mm diameter were used for shear resistance along the beam, with average yield strength, and tensile strengths of 24 and 36 kg/mm^2 respectively, all-steel bars results were according to the direct tensile testes (ASTM E8/E8M–16), the arrangement of reinforcement are shown in Fig. 2. All beams were designed to have a flexural failure. Test specimens were divided into three groups (A, B and C) four beams for each, in addition to reference beam B1 (without rubber replacement). For the first group (A), the coarse aggregates were replaced by different volume percentages of waste tire rubber (2, 4, 6 and 8%) for beams (B2, B3, B4, B5) respectively. For the second group (B), crumb rubber was replaced for fine aggregates by different volume percentages of crumb rubber (2, 4, 6 and 8%) for beams (B6, B7, B8, B9) respectively. And for the third one (C), a mix of waste and crumbed rubber was replaced for both coarse and fine aggregates by different volume percentages of rubber (2, 4, 6 and 8%) for beams (B10, B11, B12, B13) respectively. The identification and mix proportion of tested beams are illustrated in Table 1 (all values in kg/m^3).

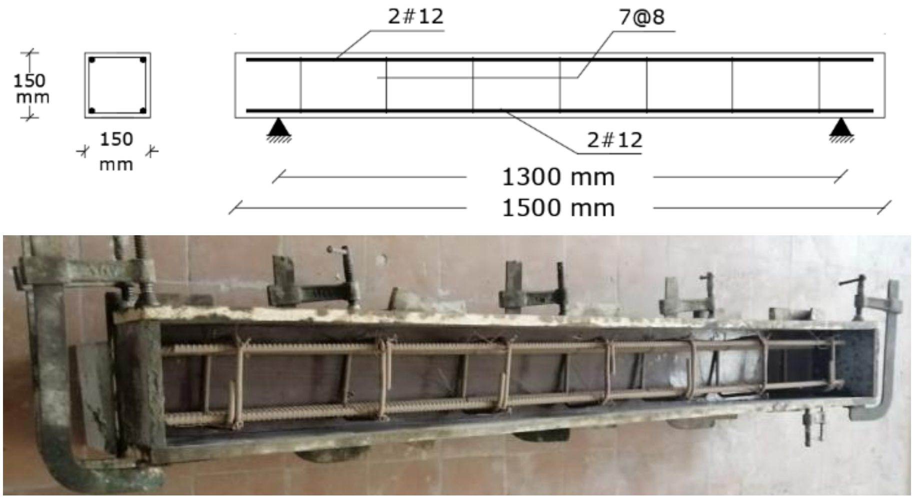


Fig. 2. Dimensions and reinforcement configuration of the specimens.

2.2. Material properties, mix proportion and casting

For reference beam mixtures, the cement content and the water to cement ratio (w/c) were equal to 450 kg/m^3 and 0.37, respectively, in addition to 7.5 kg/m^3 additive of superplasticizer (Sika ViscoCrete 3425), the fine and coarse aggregates contents were 750, 1000 kg/m^3 respectively, then the fine and coarse aggregates were replaced by volume with various percentage for each beam as indicated before. For all mixtures, dolomite with a nominal maximum size of 10 mm, fineness modulus of 7.73 and air void contents of 0.45, was used as coarse aggregate, while sand free from impurities and with fineness modulus of 3.31 and air void contents of 0.35, was used in the mixture as fine aggregate. Rubber particles were produced by mechanical grinding of tire rubber waste. Waste tire and crumb rubber were with a nominal maximum size of 10 and 2 mm respectively, fineness modulus of 7.66, 4.9 respectively, and air void contents of 0.55, 0.5 respectively, waste tire and crumb rubber are shown in Fig. 3. The particles distribution analysis of all aggregates is shown in Table 2. A mechanical vibrator was used for compactions to avoid honeycombing and segregation.

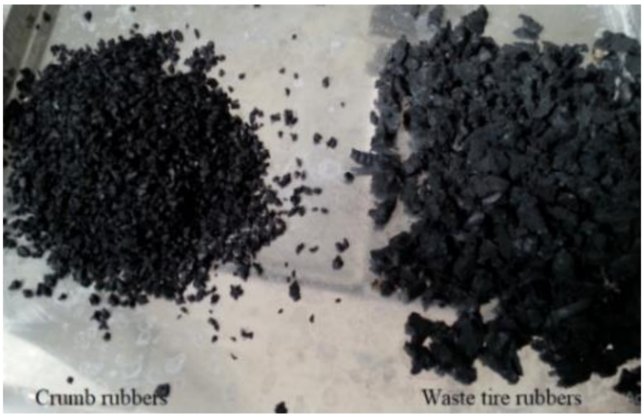


Fig. 3. Rubber particles.

Table 2. Particle distribution analysis.

Sieve size (mm)	Cumulative weight passing %			
	Dolomite	Sand	Waste tire	Crumb
38	100	100	100	100
25	100	100	100	100
19	100	100	100	100
10	27.2	100	29	100
4.75	0.1	98.9	5.1	100
2	0	92.3	0	11.2
0.85	0	61.7	0	0.48
0.425	0	13.1	0	0.24
0.25	0	2.8	0	0.12
0.15	0	0.4	0	0.08

2.3. Test setup and instrumentation

All beams were tested by using a hydraulic jack with a maximum capacity of 100000 kg, and a loading rate of 500 kg/min, the load was applied to the beam mid-span, as shown in Fig. 1. The mid-span deflection was monitored using linear variable different transformers (LVDT's) while the loads were recorded from a calibrated load cell. The deflection readings and loads were recorded using a data logger.

3. Test Results and Discussion

3.1. Concrete properties

Table 3 shows the concrete mix properties, modulus of elasticity was calculated by empirical formula based on ACI 318-14. Fig. 4 shows the effect of waste and crumbed rubber replacement on the concrete compressive strength (f_{cu}). A reduction in the concrete compressive strength was observed. The reduction reached (51, 50 and 57 %) for groups (A, B and C) respectively, at a replacement percentage of 8% compared with that of the reference beam. It was observed that the reduction was greater in groups (B and C) than that for the group (A), the reduction was (14, 27 and 37%) for groups (A, B and C) respectively, at a replacement percentage of 4% compared with that of the reference beam. On the other hand, the reduction in the tensile strength was (18, 34 and 50%) for groups (A, B and C) respectively, at a replacement percentage of 4% compared with that of the reference beam, as shown in Fig. 5. The observed reduction in both compressive and tensile strength was due to the low stiffness and strength of rubber.

Table 3. Concrete mix properties.

Beam	Compressive strength (kg/cm²)	Tensile strength (kg/cm²)	Modulus of elasticity (kg/cm²)
B1	791	79	418009
B2	784	70.6	416156
B3	684	65.0	388710
B4	493	39.5	330340
B5	388	40.0	292761
B6	671	60.4	384998
B7	583	52.4	358865
B8	485	38.8	326641
B9	400	40.0	327317
B10	567	45.3	356705
B11	500	40.0	332340
B12	385	38.8	291627
B13	343	34.2	275261

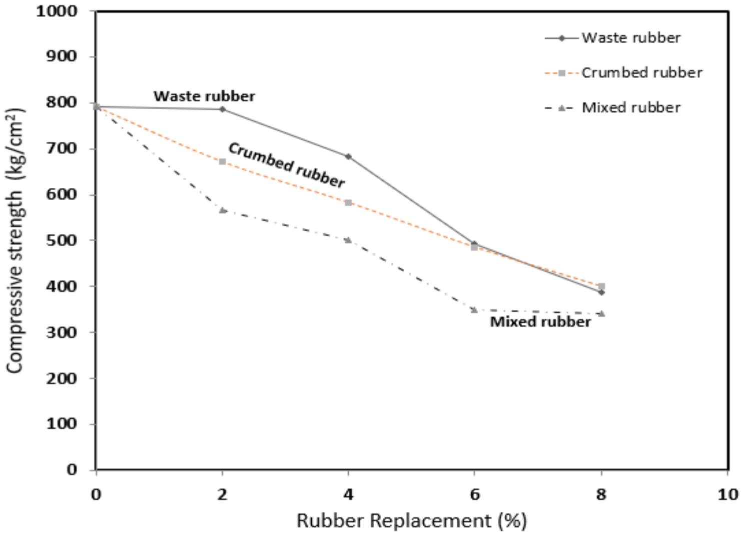


Fig. 4. Effect of rubber replacement on the concrete compressive strength.

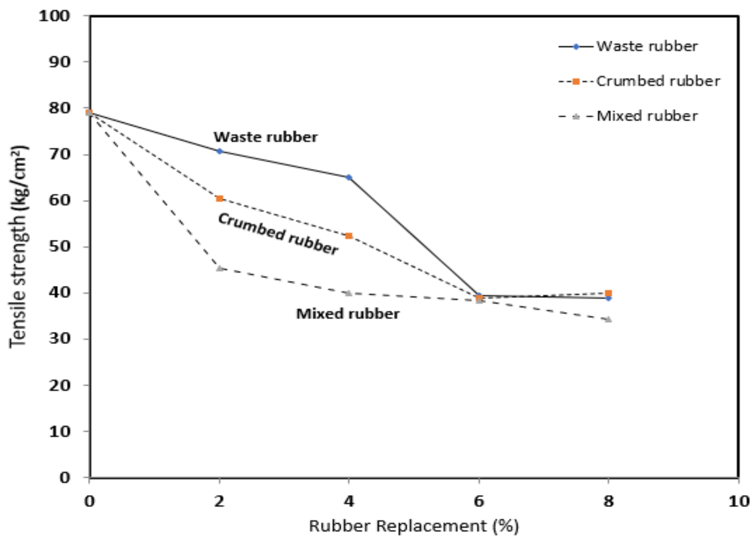


Fig. 5. Effect of rubber replacement on the concrete tensile strength.

3.2. Load capacity

The experimental results of the tested beams are presented in Table 4.

Table 4. Experimental results.

Beam	P_y (kg)	Δy (mm)	P_u (kg)	Δu (mm)	DI
B1	4590	5.26	5679	18.93	3.60
B2	4707	6.27	5266	18.62	2.97
B3	4798	6.47	5161	10.64	1.65
B4	4692	6.41	4951	10.50	1.64
B5	4714	6.33	4893	9.27	1.46
B6	5169	6.52	5553	12.80	1.96
B7	5050	7.84	5574	15.10	1.93
B8	5230	7.20	5671	13.75	1.91
B9	5371	6.70	5662	12.50	1.87
B10	5483	6.10	5641	13.36	2.19
B11	5128	6.19	5551	13.50	2.18
B12	5227	6.22	5531	11.00	1.77
B13	5105	6.36	5221	10.47	1.65

The first column represents the beam identification, while the second and third column shows the yield load (P_y) in (kg) and its corresponding mid-span deflection (Δ_y) in (mm), the fourth and fifth columns show the ultimate load (P_u) in (kg) and its corresponding mid-span deflection (Δ_u) in (mm). The ductility index (DI) of the beams was reported in the sixth column. Finally, the failure mode was the same for all models (flexural failure). From Table 4, it was detected that the yield load of the beams with coarse aggregates (group A) replaced by (2, 4, 6, 8%) increased by 3 % on average compared with the reference beam. Also, it was detected that the yield load of the beams with fine aggregates (group B) replaced by (2, 4, 6, 8%) increased by (12, 10, 14, 17%) respectively compared with the reference beam. While it was observed that the yield load of the beams with both coarse and fine aggregates (group C) replaced by (2, 4, 6, 8%) increased by (19, 11, 14, 11%) respectively compared with the reference beam. The maximum load capacity of the beams with coarse aggregates (group A) replaced by (2, 4, 6, 8%) decreased by (8, 10, 13, 14%) respectively compared with the reference beam. Also, it was detected that the maximum load capacity of the beams with fine aggregates (group B) replaced by (2, 4, 6, 8%) decreased by 1% on average compared with the reference beam. While it was observed that the maximum load capacity of the beams with both coarse and fine aggregates, (group C) replaced by (2, 4, 6, 8%) decreased by (1, 1, 2, 8%) respectively compared with the reference beam.

3.3. Load-deflection relationship

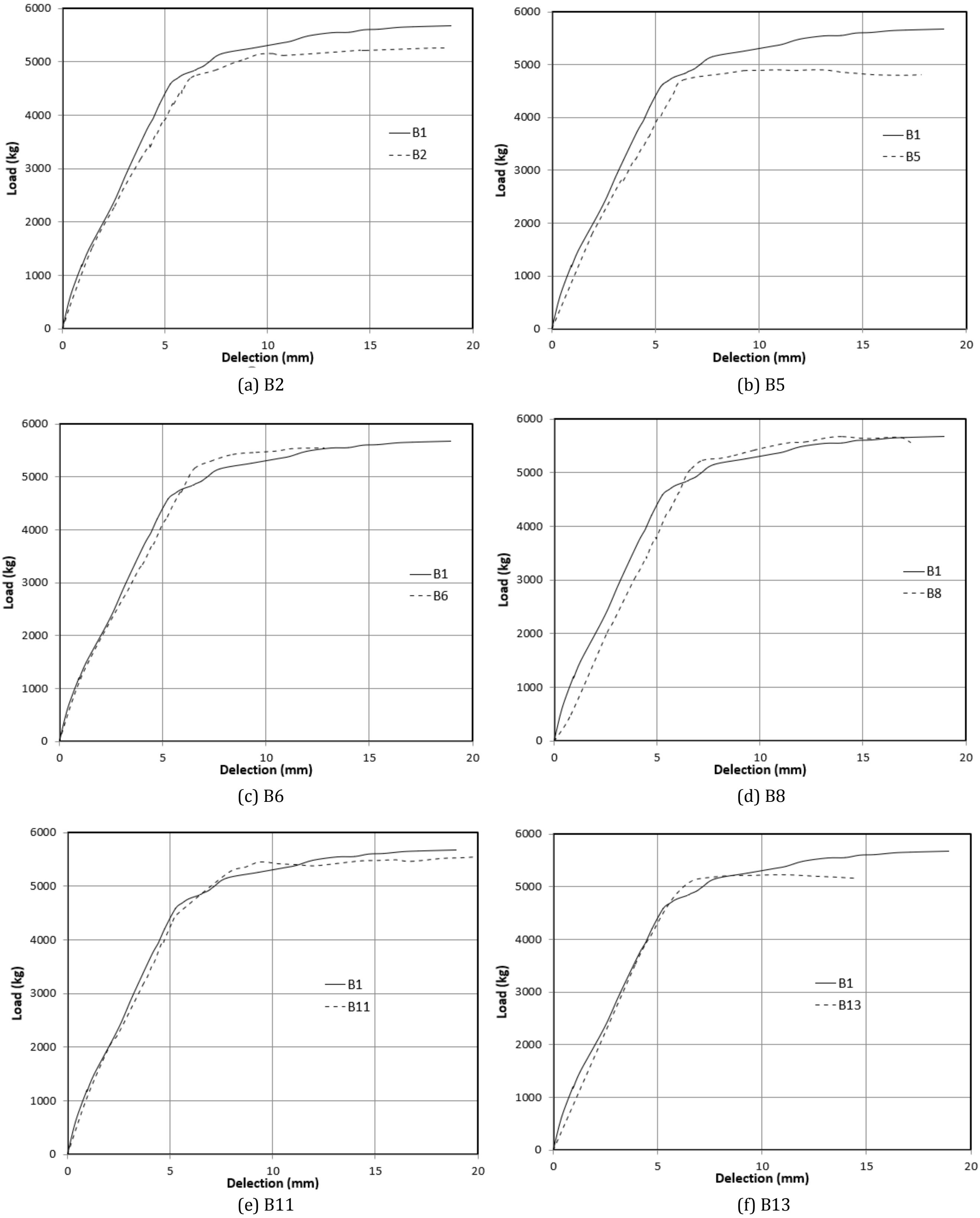
The relation between the loads and the values of mid-span deflection obtained experimentally are plotted in Fig. 6 for a sample of tested beams. Results show that, in all cases of aggregates replacement (Group A, B and C), there was a convergence in deflection values at beginning of loading between all beams, but at yield load, there was an increase in mid-span deflection equal to (20, 34 and 18%) on average for (Group A, B and C) respectively compared with that of a beam with no aggregates replacement. But at failure load, there was a decrease in mid-span deflection equal to (2, 44, 44 and 51%) for (B2, B3, B4 and B5) respectively compared with that of a beam with no aggregates replacement (B1), decreasing record 30% on average for a group (B), and (30, 29, 42 and 45%) for (B10, B11, B12 and B13) respectively compared with that of a beam with no aggregates replacement. Moreover, the partial replacement of coarse and fine aggregate with rubber decreased the beam stiffness up to yield load, after that up to failure load the stiffness of reference beam was less than that with partially aggregates replacement.

3.4. Failure modes

Failure mode for all models was a flexural failure, (began with initiation of flexure cracks at the tension zone propagated towards the loading point followed by steel yielding before initiation of compressive crushing in the compression zone), as shown in Fig. 7. Aggregates replacement delayed the tension cracks initiation by (13, 30 and 6% in average) for (Group A, B and C) respectively compared with that of a beam with no aggregates replacement.

3.5. Ductility

Ductility index (DI) was defined as the ratio between the deflection at the ultimate load (Δu) and the deflection at the yielding load of the beams (Δy). The ductility index for all the test specimens was calculated and listed in Table 4. It can be noticed that the ductility index decreased in all percentage of aggregates replacement showing low ductility, for coarse aggregates replacement, ductility index decreased by (18, 56, 56 and 60) for (B2, B3, B4 and B5) respectively compared with that of a beam with no aggregates replacement (B1). Also, for fine aggregate replacement, the ductility index de-creased by (47%) on average for (group B) compared with that of a beam with no aggregates replacement (B1). While increasing the percentage of coarse and fine aggregates replacement percentage from 2 to 8% results in decreasing the ductility index by (40, 40, 50 and 54%) for (B10, B11, B12 and B13) respectively compared with that of a beam with no aggregates replacement (B1). The above results assured the negative effect of the aggregates replacement by rubber on the ductility index.



(a) B2 (b) B5

(c) B6 (d) B8

(e) B11 (f) B13

Fig. 6. Experimental load-deflection curves.

(a) B1

(b) B2

(c) B3

(d) B4

(e) B5

(f) B6

(g) B7

(h) B8

(i) B9

(j) B10

Fig. 7. (continued)

(k) B11

(l) B12

(m) B13

Fig. 7. Failure modes of the beams.

4. Conclusions

This paper represents an experimental investigation on the beam ductility and flexural performance of a simply supported rubberized concrete beam. The tested models were cast utilizing rubberized and normal concrete with different percentages of rubber replacement. Based on the experimental results, the subsequent conclusions are drawn:

- When the coarse or fine aggregate partial was replaced by 4% waste or crumbed rubber, the value of compressive strength was (14 and 27%) respectively lower than that of specimens without rubber replacement. Moreover, by increasing the percentage of coarse or fine aggregate replacement to 8% the value of the compressive strength decreased by 50% for both when compared to that of concrete without rubber replacement.
- When the coarse and fine aggregate partial was replaced by 2% waste and crumbed rubber, the value of compressive strength was 30% lower than that of specimens without rubber replacement. Moreover, by increasing the percentage of rubber replacement to 8% the value of the compressive strength decreased by 57% when compared to that of concrete without rubber replacement.
- The beams cast with rubber replacement for coarse aggregates showed a decrease in the beam load capacity than those without by 10% on average, while that with fine aggregates replacement showed a slight decrease.
- The beams cast with rubber replacement for both coarse and fine aggregates showed a slight decrease in the load capacity than those without, while that with rubber replacement of 8% showed a decrease of 10% in the load capacity than those without.
- The partial replacement of coarse and fine aggregates with rubber decreased the beam stiffness up to yield load, after that up to failure load the stiffness of beam with no aggregates replacement was less than that with partially aggregates replacement.
- The partial replacement of coarse and fine aggregates with rubber does not affect the beam failure mode. The partial replacement of coarse and fine aggregates with rubber delayed the tension cracks initiation by (13, 30 and 6 %) for (coarse, fine, coarse, and fine aggregates replacement) respectively compared with that of a beam with no aggregates replacement.
- The partial replacement of coarse and fine aggregates with rubber harms the beam ductility. Increasing the aggregates replacement up to 8%, resulting in decreasing the ductility index to (60, 48 and 54 %) for coarse, fine, both coarse and fine aggregates replacement respectively, compared with that of a beam with no aggregates replacement.

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