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An Experimental Study on Behavior of Sustainable Rubberized Concrete Mixes

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Abstract

In terms of recycling and reuse, today's global generation of waste tire well exceeds its consumption. This has resulted in the accumulation of large stocks of toxic rubber waste that raise health and safety risks. The use of waste tire rubber for the construction of the concrete structure was suggested to combat this challenge. This paper explores tests that were performed with samples of waste tire rubber concrete to evaluate compressive strength, flexural tensile strength, modulus of rupture, and impacts resistance. The main parameters investigated were the rubber ratio as a partial volumetric replacement with fine and coarse aggregate. Chip and crumb rubbers were used to replace coarse and fine aggregate respectively in four different amounts by volume (5%, 10%, 15%, and 20%). Even if the inclusion of waste tire rubber in concrete has specific apparent degradations, the potential benefit seems to overlook the adverse effects and also meet the primary significant value of resolution for rubber waste utilization problems. The results show that the substitution of natural fine or coarse aggregates with crump-chip tier rubber will reduce mechanical properties (compressive, flexural and splitting tensile strength), but increase the impacts resistance to 426% and 396% when 20% coarse aggregates and 20% fine aggregates are replaced by rubber respectively. The proposed mix shows an ability to replace 20% of the aggregate (coarse or fine), and the producing, rubcrete, still structural concrete.

Keywords: Rubber Aggregates; Waste Tire Rubber; Rubberized Concrete; Impact Resistance; Drop Weight Impact Test.

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1. Introduction

Coarse Aggregates (CA) and Fine Aggregates (FA) are one of the primary materials used in concrete manufacturing, but the continuous use of these materials may be scarce. Use waste tire rubber in concrete can be considered a positive step in creating sustainable concrete. Rubberized concrete can be obtained by applying rubber to the concrete mixtures. Rubber waste tires are the primary materials used to produce rubberized concrete or (rubcrete). It defined as concrete with rubber content in it mixes as a partial substitute to its aggregate (fine and /or coarse). Adding crumb rubber to concrete (as a partial substitute for fine aggregates) reduces concrete density, which also improves structure seismic resistance and energy absorption. Rubcrete's major drawback was the loss in compressive and tensile strength due to rubber particles [1]. Recently, researchers have shown increased interest in waste tire rubber reuse in concrete applications.

Eldin and Senouci studied the effect of using crumb and chip rubber as full sand and coarse aggregate replacement. He found that concrete containing a higher proportion of graded rubber has high toughness, but compressive strength,

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splitting tensile strength decreased by about 85% and 75% respectively when coarse aggregate was fully replaced by chip rubber and decreased by about 65% and 50 % respectively when fine aggregate was fully replaced by crumb rubber [2].

Ganjian et al. the mechanical properties such as flexural strength, compressive strength, and tensile strength were studied by replacing coarse aggregate with chip rubber (0%, 5%, 7%, and 9%) with gravel weight. The results showed that compressive strength values decreased by about 10% and 23% when compared to the control mix with mixes have rubber replacement by 7 % and 9 %. The tensile strength reduction was observed up to a replacement of 7 %. Flexural strength did not affect the 5 % rubber percentage significantly [3].

Antil et al. investigated the effects of using crumb rubber as sand in different percentages of substitution (0%, 5%, 10%, 15%, and 20%) by weight. He observed that there is high toughness in concrete containing a higher proportion of rubber. The concrete slump value increased by about 1.08 percent, with the crumb rubber substitute of 10 percent, as well as the results showed the splitting tensile strength, compressive strength, and concrete modulus of rupture reduced by about 37 %, 49 %, and 41 %at this replacement ratio [4].

Bhatt et al. used crumb rubber to replace sand with 0%, 2.5%, 5%, 7.5% and 10% by weight of fine aggregate. They observed a decrease in compressive strength of 29.7% and 45.8% at 7 and 28 days, respectively, at 10 % replacement. At 5% of crumb rubber replacement, the flexural strength comes optimum [5].

Najib N. et al. replaced partial volume of sand by (5%, 10%, 15%and 20%) for different references mixes vary in compressive strength range from 30 MPa to 50 MPa by rubber and check the influence of the replacement on concrete mix result show reduction in the density, decreasing in the rubcrete strength and gave a negative effect on the modulus of elasticity [6].

Several studies were focused on concrete impacts response. Topcu recorded reduced elastic energy capacity and increased concrete plastic energy capacity to substitute coarse aggregates and fine aggregates with coarse rubber chips and fine rubber chips, respectively [7]. Herrandez et al. study the composite behavior of rubcrete; the result showed more advantages in reducing the vibration and impact effects and attributed this to the existence of elasticity properties for rubber particles [8].

The effect of rubber content and particle size on the mechanical properties of concrete has been investigated by Lijuan et al. [9]. Researchers found a decrease in the compressive strength and elastic module of the rubber concrete, which had increased the rubber and the particle size, while the ultimate concrete strain results improved. Therefore, the width, the length, and the number of cracks are decreased with lower rubber content and increased particle size. In replacing coarse aggregates from 10 mm to 25 mm, Aiello and Leuzzi used rubber tires to substitute coarse aggregates with size range from 10 mm to 25 mm. The results indicated a more decrease in compressive strength due to the increase in rubber content with a smaller size. The decline in concrete compressive strength was 47.8 %, 54.4 % and 69.3 %, respectively, at volumetric rubber replacement was 25 %, 50 % and 75 % [10].

Fattuhi and Clark was concluded that rubcrete could be used in the application that needs resistance to vibration, impact, and blast like machinery foundation pad, railway stations, railway buffers, vibrations damper, filling and pipe bedding, pile heads, paving slabs, barriers, and bunkers [11].

Based on the literature survey, it was concluded that rubcrete is a newly developing material that can contribute to improving the ductility of concrete structures, and side by side, reduce non-degradable waste material. The primary purpose of this study includes realizing the options of partially containing west tires rubber in the form of rubber in structural concrete mixes. The critical parameters investigated were the rubber ratio as a volumetric replacement with fine and coarse aggregate. Chip and crumb rubber was used to replace coarse and fine aggregate in four different proportion by volume (0- 20) %, and check their effects on the mechanical properties of the concrete mix.

2. Experimental Program

The laboratory program includes the design of nine types of structural concrete mixes. For all mixes, hardened features (compressive strength, flexural strength, splitting tensile strength, density, and impact resistance) were carried out, and the findings had been evaluated. Figure 1 shows a flow chart of the experimental programs.

2.1. Materials

One of the materials that were used in the experimental works is Type I (ordinary Portland cement). This type conforms to the requirements of the Iraqi specification (IQS No.5/1984) [12] with a relative density of 3.15. A crumb and chip rubber aggregate with a maximum size up to 4.75,11 mm, respectively, without steel wires from General Company for Rubber Industries and Tires/Al-Najaf /Iraq was used in the present work. Waste tire rubber can be classified depending upon the size of rubber particles. Table 1 and Figure 2 show the types of waste tires rubber [9]. The chemical composition and physical characteristics are illustrated in Tables 2. The crushed natural aggregate of 10 mm maximum size and natural sand with maximum size (4.75) mm were used as coarse aggregates and fine aggregates, respectively. The aggregates gradients, which shown in Figures 3 and 4, confirm the requirements of the Iraqi specification (IQS No.45/1984) [13]. Tap water was used in casting and curing of all the specimens.

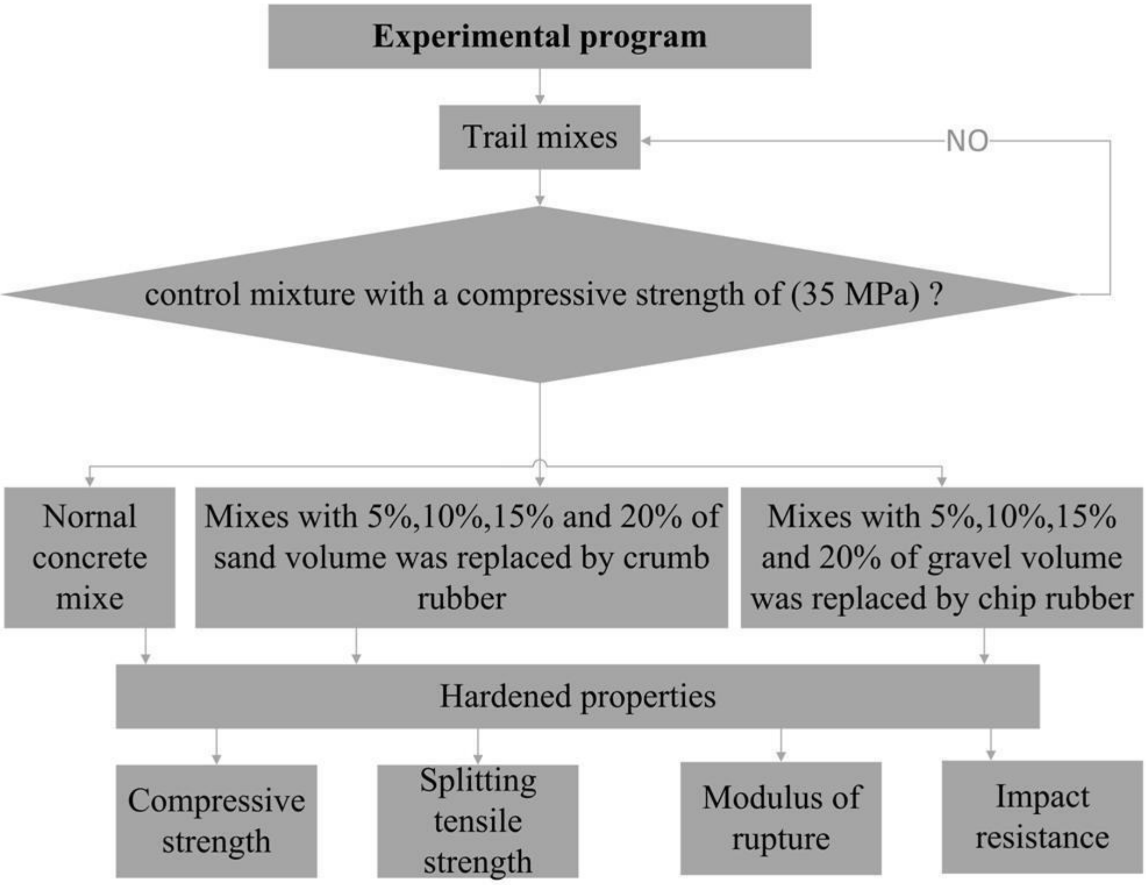


Figure 1. Flow chart of the experimental programs

Table 1. Waste tires rubber classification [9]

Types	Size	Application in concrete
Shredded/chipped	Shredded: Length: (30 0mm-430 mm)- (100 mm-150 mm) Width: 100 mm-230 mm Chip 5 mm- 76 mm	Gravel replacement
Crumb rubber	0.425 mm- 4.75 mm	Sand replacement
Ground rubber	0.0075 mm- 0.475 mm	Cement replacement
Fiber rubber	Length: 8.5 mm-21.5 mm Strips: ≤ 8 mm long	Reinforced fiber

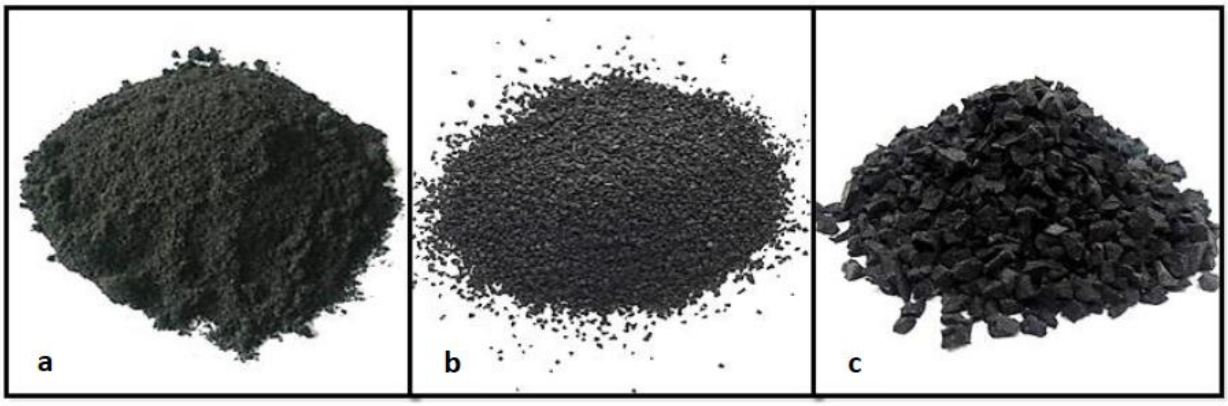


Figure 2. Types of tire rubber: (a) ground rubber, (b) crumb rubber, (c) chip rubber [9]

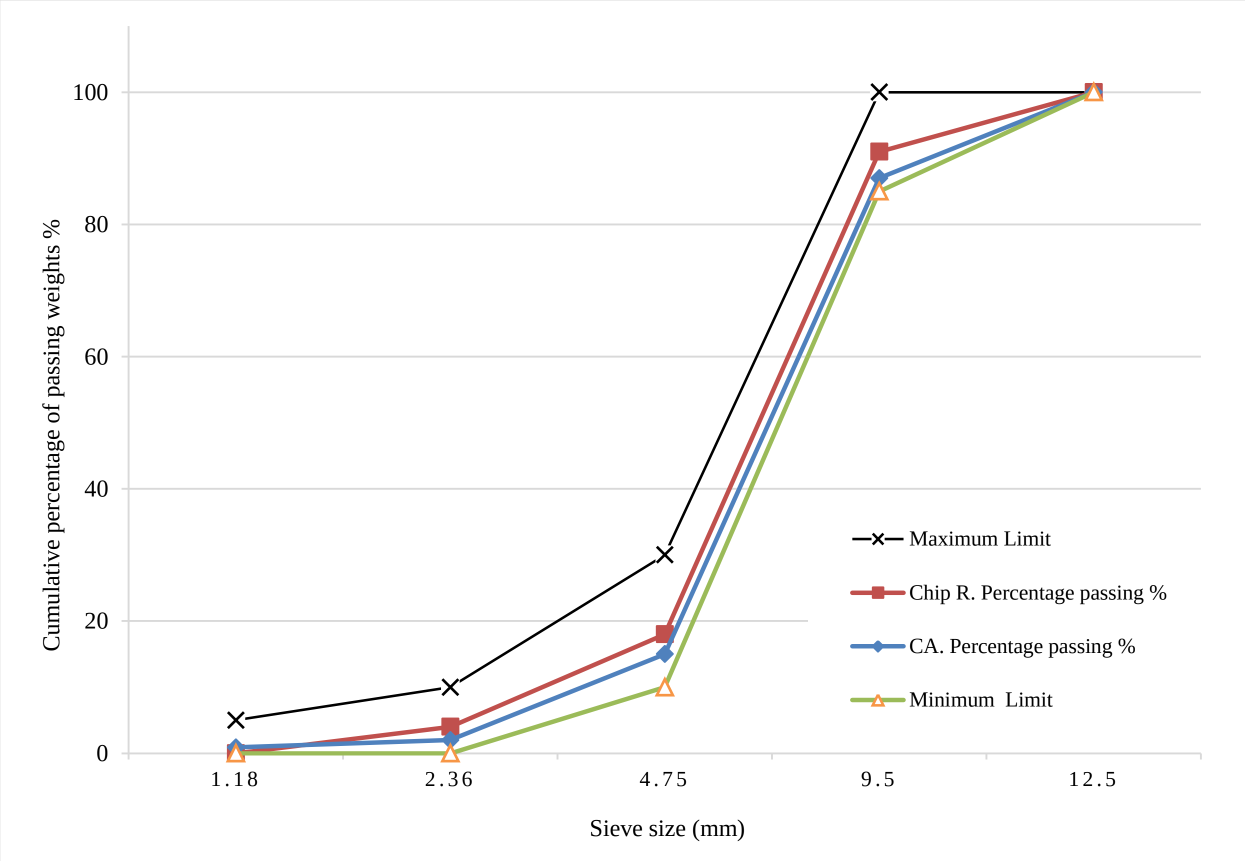


Figure 3. Grading curve of the coarse aggregates and chip rubber according to Iraqi Specification No.45/1984, [13]

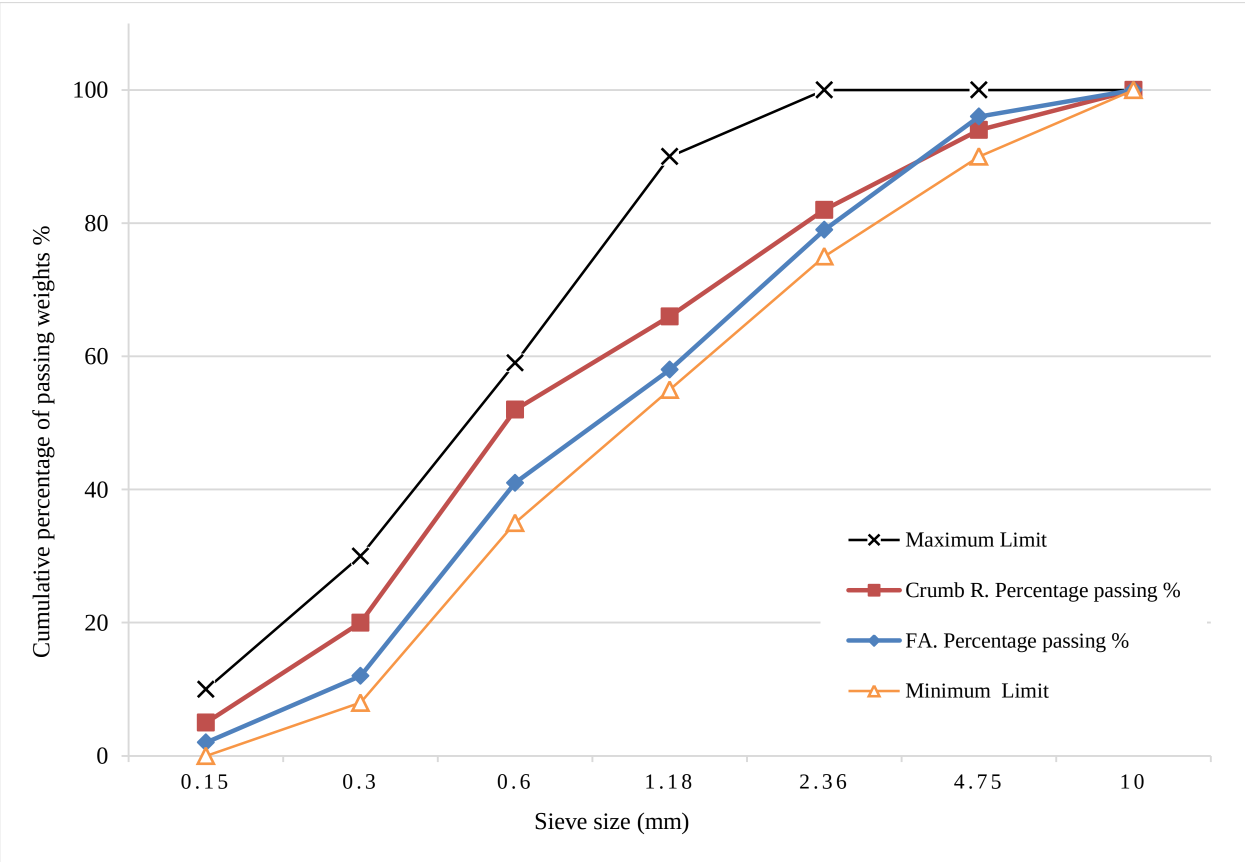


Figure 4. Grading curve of the fine aggregates and crumb rubber according to Iraqi Specification No.45/1984, [13]

Table2. Waste tires rubber chemical and physical characteristics

Chemical composition		Physical properties	
Major rubber components	**Results (%)**	**Properties**	**Results**
Acetone extract	10	Finesse modulus	3.14
Rubber hydrocarbon	25	Specific gravity	1.78
Carbon black content	30		
Natural rubber content	31	Water absorption	2%
Ash content	4		

2.2. Details of Specimens

Details of each of the specimens used in this investigation with their designation, content of crumb rubber, and content of chip rubber are given in Table 3.

Table 3. Details of specimens

No	Designation of specimen	Chip rubber content as a volumetric replacement with coarse aggregate (%)	Crumb rubber content as a volumetric replacement with fine aggregate (%)
1	N	0	0
2	CA 5	5	0
3	CA10	10	0
4	CA 15	15	0
5	CA 20	20	0
6	FA 5	0	5
7	FA10	0	10
8	FA 15	0	15
9	FA 20	0	20

2.3. Concrete Mixtures

Nine mixtures were prepared, and each mix consisted of six cubes of 150 mm size, six cylinders of 100 mm in diameter and 200 mm in height, four prisms of 100×100×400 mm dimensions and concrete cylindrical specimens (150 mm in diameter and 65 mm in height as shown in Figure 5. A goal strength of (21 MPa) was nominated for rubberized concrete because this strength is usually used in structural requests as a minimum requirement. To meet this target of compressive strength, a control mixture with a compressive strength of (35 MPa) was selected. In developing rubberized concrete mixtures, all mixtures contents were kept constant except the coarse and fine aggregate constituents. Table 4 shows the details and mix proportions of controlled and the rubberized concrete mixes.

Table 4. Details of Concrete Mixtures

Mix No.	specimens	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Chip Rubber (kg/m^3)	Crumb Rubber (kg/m^3)	Density of mixes (kg/m^3)
1	N	808.5	768.5	0.00	0.00	2323.00
2	CA 5	768.07	768.5	12.25	0.00	2294.82
3	CA10	727.65	768.5	24.5	0.00	2266.65
4	CA 15	687.22	768.5	36.7	0.00	2238.42
5	CA 20	646.8	768.5	49	0.00	2210.30
6	FA 5	808.5	730.07	0.00	11.17	2295.74
7	FA10	808.5	691.65	0.00	22.35	2268.50
8	FA 15	808.5	653.22	0.00	33.53	2241.25
9	FA 20	808.5	614.8	0.00	44.71	2214.01
Density of materials (kg/m^3)		1,650	1,650	500	480	------
Cement and water content are constant with values of (536.72, 209.3) kg/m^3 respectively. Water/cement ratio is 0.39						

Figure 5. Preparing specimens: (a) Mixing materials, (b) Specimens casting, (c) Specimens curing, (d and e) Preparing specimens for test

3. Hardened Tests

3.1. Compressive Strength

At (7 and 28) days, the compressive strength test was carried out in accordance with BS 1881: part 116: 1989 [14] using (150×150×150) mm cube. The experiment was conducted by using a hydraulic compression machine (2000 kN capacity). The mean value of three specimens was taken. The compressive strength values are computed from the following equations, [14]:

$$fc' = 0.8 * fc \tag{1}$$

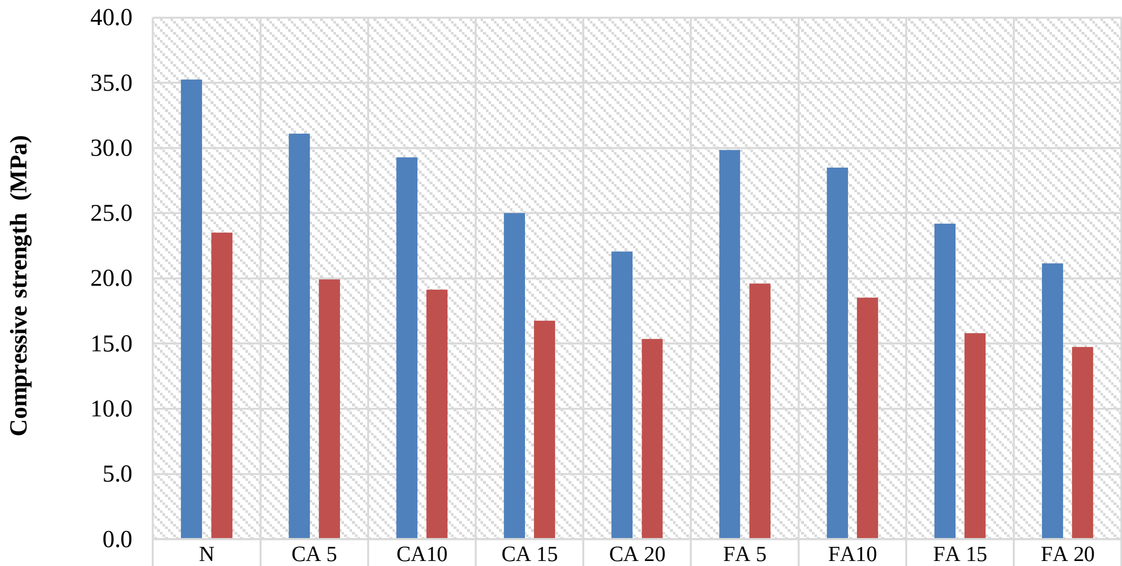
$$fc = \frac{P}{A} \tag{2}$$

Where: fc': Compressive strength (MPa) according to American Standard; fc: Compressive strength (MPa) according to British Standard; P: Applied force (N); A: Area (mm^2).

The results in Table 5 and Figure 6 showed that the compressive strength was decreased as rubber content increased. The reason for this reduction is due to the softness particle of waste tire rubber compared with the particle of aggregates. The adhesion between rubber and cement paste is weak (poor strength of the interfacial transition zone between the rubber particles and cement paste). A small amount of rubber particles tends to move to the upper surface of the molds while casting the specimens because of the lower specific gravity of the rubber particles. The compressive strength of mixes containing rubber instead of fine aggregate decreased more than mixes containing rubber instead of coarse aggregate, and this is due to the surface area of the fine aggregate is higher than the surface area of the coarse aggregate.

Table 5. Compressive strength, splitting tensile strength and modulus of rupture values

Item	Specimens	Compressive Strength (fc')(MPa)				Splitting Tensile Strength (ft) (MPa)				Modulus of Rupture (fr) (MPa)			
		At 7 Days	%Diff.	At 28 Days	%Diff.	At 7 Days	%Diff.	At 28 Days	%Diff.	At 7 Days	%Diff.	At 28 Days	%Diff.
1	N	23.52	0.00	35.26	0.00	2.73	0.00	3.35	0.00	4.51	0.00	5.54	0.00
2	CA 5	19.92	-15.31	31.10	-11.79	2.67	-2.37	3.05	-8.99	4.16	-7.82	5.25	-5.26
3	CA10	19.14	-18.61	29.29	-16.92	2.45	-10.51	2.98	-11.05	4.10	-9.02	4.97	-10.30
4	CA 15	16.76	-28.74	25.01	-29.06	2.16	-21.14	2.63	-21.59	3.60	-20.18	4.29	-22.64
5	CA 20	15.35	-34.74	22.07	-37.40	2.08	-24.03	2.30	-31.40	3.19	-29.22	3.76	-32.20
6	FA 5	19.60	-16.66	29.85	-15.35	2.50	-8.44	2.95	-11.79	4.02	-10.87	4.86	-12.28
7	FA10	18.52	-21.23	28.50	-19.17	2.54	-7.01	2.85	-14.92	4.03	-10.68	4.78	-13.71
8	FA 15	15.80	-32.82	24.21	-31.34	2.16	-21.04	2.54	-24.11	3.32	-26.45	4.23	-23.76
9	FA 20	14.74	-37.30	21.14	-40.03	1.92	-29.71	2.21	-34.14	3.05	-32.31	3.60	-34.98



	N	CA 5	CA10	CA 15	CA 20	FA 5	FA10	FA 15	FA 20
fc' at 28 days	35.26	31.10	29.29	25.01	22.07	29.85	28.50	24.21	21.14
fc' at 7 days	23.52	19.92	19.14	16.76	15.35	19.60	18.52	15.80	14.74

Figure 6. Compressive Strength results of the mixes

Figure 7. Tests of concrete cubes: (a) Compressive strength test machine, (b) Cube with normal concrete, (c) Cube with 5% chip rubber replacement, (d) Cube with 10% chip rubber replacement, (e) Cube with 15% chip rubber replacement, (f) Cube with 20% chip rubber replacement.

Figure 8. Tests of concrete cubes: (a) Cube with 5% crumb rubber replacement, (b) Cube with 10% crumb rubber replacement, (c) Cube with 15% crumb rubber replacement, (d) Cube with 20% crumb rubber replacement

In Figures 7 and 8 for 0% and 5%, replacement ductile failure is noticed. For a 10% to 15% replacement, the specimens showed an elastic response. For 20% replacement formation of the crack is very fast. Cracks formation nearly vertical to the direction of the applied stress. The ultimate load carried by these specimens is less than normal cubes, but toughness is more as related to the other concrete mix.

3.2. Splitting Tensile Strength

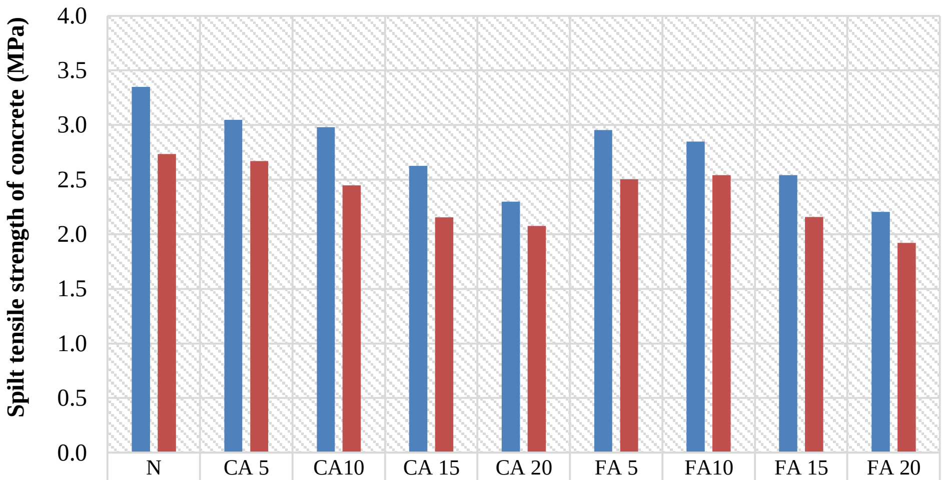
The test was carried out at (7 and 28) days via cylinder (200×100) mm according to ASTM C496 [15], as shown in Figure 9. The cylinder was placed horizontally between two plates of wood to distribute loads of the compressive machine uniformly on the upper and lower sides of the cylinder the average of splitting tensile strength for the three cylinders is calculated from the following equation [15]:

$$ft = 2P/\pi LD \tag{3}$$

Where: ft = splitting tensile strength (MPa); P = failure load (N); D = diameter of cylinder (mm); L = length or height of cylinder (mm).

The results of splitting tensile strength are illustrated in Table 5 and Figure 10. The results show that the reduction in splitting tensile strength was smaller than the reduction in compressive strength. The failure mode of the reference mix (N) experienced a true split of the specimen, the cylinder divided into two halves (brittle failure). But in other mixes containing rubber particles (both crumb or chip) did not exhibit this failure mode. The failure mode of these mixes was gradual instead of brittle.

Figure 9. Splitting tensile test



	N	CA 5	CA10	CA 15	CA 20	FA 5	FA10	FA 15	FA 20
28 Days	3.349	3.048	2.979	2.626	2.298	2.955	2.850	2.542	2.206
7 Days	2.73	2.67	2.45	2.16	2.08	2.50	2.54	2.16	1.92

Figure 10. Tensile strength results

3.3. Modulus of Rupture

This test was carried out as per ASTM C78 [16] by using (100x100x400) mm prism. The test was done by applying two points loads using the flexural machine (150 kN capacity), as shown in Figure 11. The mean value of the two samples was taken to measure the modulus of rupture from the following equation, [16]:

$$fr = \frac{PL}{bd^2} \tag{4}$$

fr = modulus of rupture (MPa)

P = failure load (N)

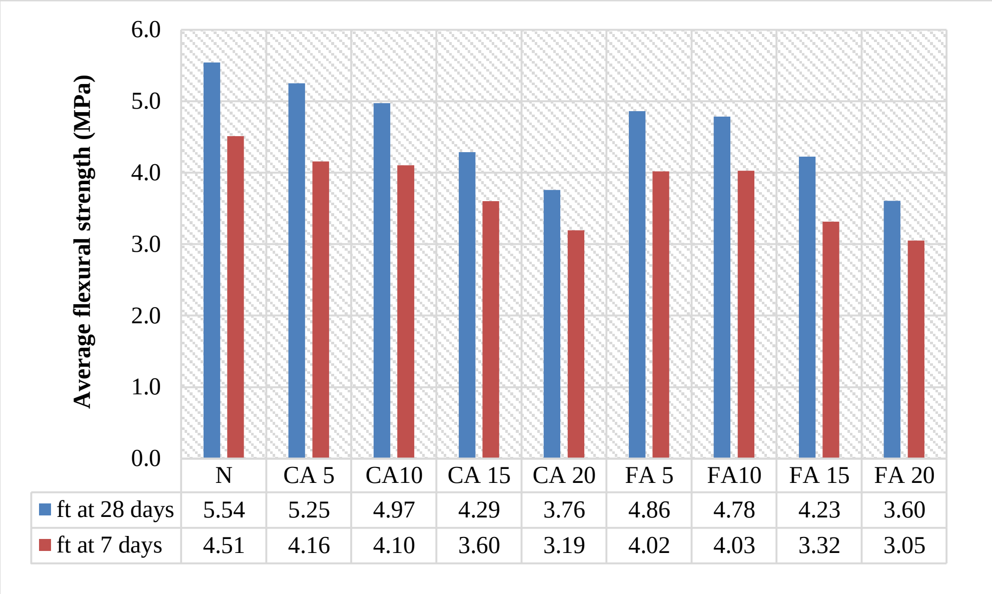
L = span length between supports center to center (mm)

b = width of prism cross-section (mm)

d = depth of prism cross-section (mm)

Table 5 and Figure 12 show the results of flexural strength. The flexural strength was decreased by adding rubber particles. The failure mode of the reference mix (N) shows that the failure of prism occurred in the center of the specimen. This is related to the homogeneity of the mix. In the mixes containing rubber particles, failure mode occurred not exactly in the center of the specimen but still in the range of internal one third because of the non-uniform distribution of rubber, especially in CA20 and FA 20.

Figure 11. Modulus of Rupture test: (a) Flexural test machine, (b) Concrete prism with 5% chip rubber replacement, (c) Concrete Prism with 15% chip rubber replacement



	N	CA 5	CA10	CA 15	CA 20	FA 5	FA10	FA 15	FA 20
ft at 28 days	5.54	5.25	4.97	4.29	3.76	4.86	4.78	4.23	3.60
ft at 7 days	4.51	4.16	4.10	3.60	3.19	4.02	4.03	3.32	3.05

Figure 12. Modulus of Rupture results of the mixes

3.4. Impact Resistance by Drop-weight Test

The drop-weight test is used to calculate the potential energy absorption for concrete cylindrical specimens (152 mm in diameter and 65 mm in height, three specimens per mix) according to ACI Committee 544 [17]. Repeated load by drop steel hammer ball was applied on the specimen from a specific height to reach a specific degree of failure (such as first crack and/or failure crack), and the number of blows was calculated. The unit of the test has simple details, as shown in Figure 13, with a 4.54 kg hammer ball that drops from a height of 457 mm on a solid steel ball with a diameter of 65 mm. The ball was placed in the middle of the specimen, and this specimen was placed in the positioning cups on the base plate. The samples are covered with a thin layer of heavy grease on the bottom and placed in the positioning cup with the finished face up. The hammer ball was dropped repeatedly on the top of the ball, and the number of blows required for the first noticeable crack was reported (N_1). The number of blows (N_2) that caused cracks to be visible and large in such a way that concrete reaches the failure stage and touch the sides of the steel lug also recorded as shown in Figure 14. N_1 and N_2 values were defined as the initial and final factors of crack resistance, respectively.

The impact energy at the initial crack (EI) was calculated by the equation given below in joule (J) [17]:

$$EI = N_1\, mgh \tag{5}$$

Similarly, the impact energy at the ultimate crack, (Eu) was calculated by the equation given below in joule (J) [17]:

$$Eu = N_2\, mgh \tag{6}$$

Where (m) is the mass of drop hammer and its equal to (4.54 kg), (g) is the acceleration due to gravity (9.81 m/s^2), and (h) is the releasing height of drop hammer and its equal to (457 mm).

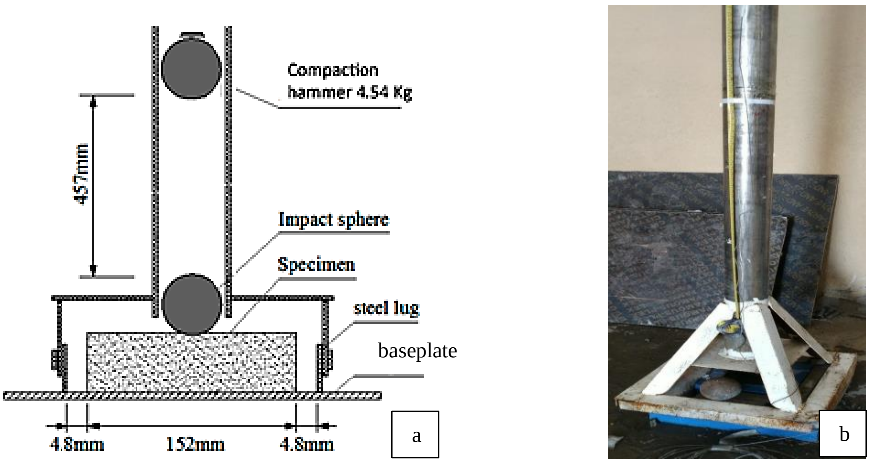


Figure 13. Impact resistance machine: (a) Section through test equipment for impact strength, (b) An Impact test device

Figure 14. The drop-weight test steps: (a) Placing sample in the device, (b) Calibration the steel ball and hummer, (c) First crack appearance of the specimen at (N_1) Blows, (d) Final crack for normal concrete specimen at (N_2) Blows, (e) Final crack for CA 10 specimen, (f) Samples after the test

Table 6. Impact resistance under drop weight test results

Specimens	N_1				N_2				(N_2-N_1) AVG.	Impact Energy (J)	
	Sample 1	Sample 2	Sample 3	AVG.	Sample 1	Sample 2	Sample 3	AVG.		First crack	Ultimate failure
N	40.00	50.00	42.00	44.00	48.00	60.00	54.00	54.00	10.00	874.07	1072.72
CA 5	63.00	74.00	69.00	68.67	74.00	85.00	84.00	81.00	12.33	1364.08	1609.09
CA10	93.00	90.00	81.00	88.00	114.00	115.00	102.00	110.33	22.33	1748.14	2191.80
CA 15	153.00	146.00	138.00	145.67	184.00	175.00	169.00	176.00	30.33	2893.70	3496.28
CA 20	204.00	191.00	197.00	197.33	236.00	224.00	231.00	230.33	33.00	3920.08	4575.63
FA 5	67.00	64.00	58.00	63.00	80.00	69.00	75.00	74.67	11.67	1251.51	1483.27
FA10	91.00	80.00	80.00	83.67	106.00	98.00	97.00	100.33	16.67	1662.06	1993.15
FA 15	142.00	139.00	130.00	137.00	166.00	165.00	156.00	162.33	25.33	2721.54	3224.79
FA 20	181.00	185.00	194.00	186.67	221.00	206.00	215.00	214.00	27.33	3708.18	4251.16

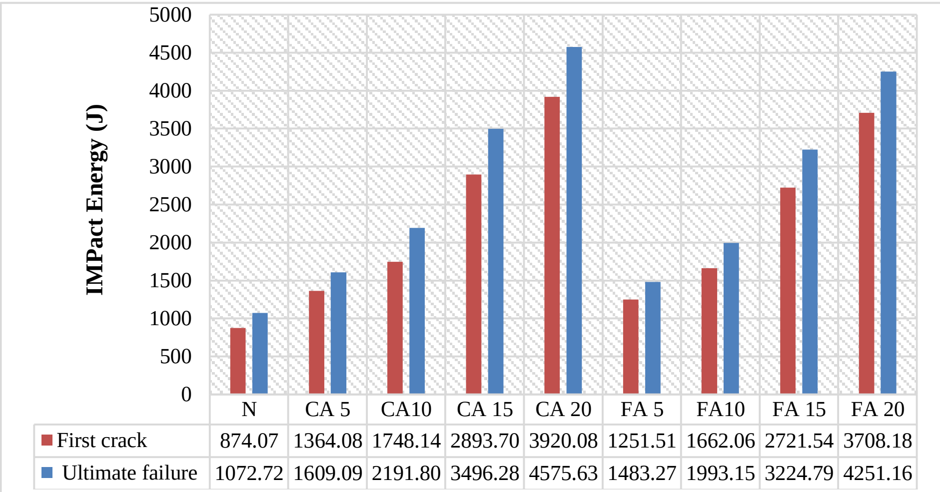


Figure 15. Impact resistance results

Table 6 shows the number of hummer drop for all specimens. It can be seen as shown in Figure 15 that the number of blows necessary to cause the first crack, and the final failure increases dramatically as the level of replacement of the rubber content increases. It was also found that the difference between the numbers of final failure blows and the first notch blows (N2-N1) increases significantly with the increase in the level of rubber replacement. The main reason is that, while the tire rubber replacement level increases, the rubber cement compound will have greater flexibility, and this increase in the level of flexibility will lead to greater energy absorption compared to the control mix. Also, the results proved that the CA replacements are better than FA replacements. As tabulated in Table (6), the replacement of 20% CA and 20% FA by rubber give increments in the impact's resistance equal to 426% and 396%, respectively. These results lead to study the hybrid structures [18-20].

4. Conclusions

The following conclusions are drawn from this study and the observation during the experimental work:

- The mixing of rubberized concrete can be achieved by utilizing the same regular techniques used for typical ordinary concrete;
- The inclusion of tire rubber in concrete mixes rather than a natural aggregate as partial replacement decreases the unit weight of concrete, as expected;
- The impact resistance of concrete will improve due to the substitution of the fine and coarse aggregate by rubber waste tire, but the coarse aggregate replacement is the better;
- The replacement of 20% CA and 20% FA by rubber give increments in the impacts resistance equal to 426% and 396%, respectively;
- The number of blows started from blow cause first crack to the ultimate crack was increased significantly when the waste tier rubber replacement increased that's mean the decrease in brittleness of concrete or an increase in ductility of rubberized concrete are achieved comparing with normal concrete;
- The characteristic strength (compressive strength, splitting tensile strength, and modulus of rupture) decreased when fine and coarse aggregates replaced with crumb and chip rubber, respectively. Replacing the rubber instead of the coarse aggregate is better than replacing it with fine aggregates in current mixes so that mix design and fine to coarse aggregate ratio have a considerable influence on results. A gradual and continuous loss of mixes strength has happened when the waste tire rubber replacement ratio increased;
- The percentages waste tire rubber replacement ratio more than 20 with natural aggregate in volume lead to a more negative effect in hardening properties of concrete while the ratio of (5-10) % have hardening properties near the normal concrete with better ductility and energy abortion.

5. Acknowledgement

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6. Conflicts of Interest

The authors declare no conflict of interest.

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