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The effect of chip rubber on the properties of concrete

Ammar A.H. Beiram [a], Hayder M.K. Al-Mutairee [b]

[a] *Technical Institute of Al-Mussaib, Al-Furat Al-Awsat Technical University, Babil, Iraq*
[b] *College of Engineering, University of Babylon, Babil, Iraq*

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ABSTRACT

The main aim of this paper is to investigate the properties of various concrete mixtures obtained by partially substituting coarse aggregate with different volume percentages of waste tyre rubber particles (10%, 20%, and 30%). Workability, density, compression strength, splitting strength, strength of rupture, elastic modulus, impact resistance, and conductivity of thermal behavior were assessed, and a comparative assessment of various rubber concrete mixes was suggested in order to determine the best rubber percentage in terms of the mechanical qualities of the rubberized concrete. The rubberized concrete mixtures have a lower density and workability than normal concrete. The compressive strength values and other characteristic strength indicated a greater drop in mechanical characteristics of rubberized concrete. When 30% gravel was supplanted with chips rubber, the impact resistance and thermal conductivity of rubberized concrete increased by 356% and 20.6%, respectively, indicating better energy absorption, ductility indicators, and insulating properties in the values found for rubberized concrete.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Latest Developments in Materials & Manufacturing.

1. Introduction

WTR (Waste tire rubber) is a non-degradable substance that is not adequately recycled. Due to the cross-sectional structure of the polymeric matrix and additions such as stabilizers, the natural degradation of WTR takes a very long time. When WTR is burned, harmful gases are released. Landfilling and burying significantly contaminate the soil, rivers, and air. It contaminates the land by destroying beneficial microbes and emitting poisonous gases [1–3].

Concrete can be manufactured in a variety of ways, depending on the proportions, chemicals, and methods used in the mix design. Used car tire rubber particles have recently been used to replace standard aggregates in the production of rubberized concrete. Researchers and engineers have been very interested in researching the mechanical properties of this relatively new concrete concept [4].

Khorami et al. explored the impact of using rubber chips instead of coarse aggregate on the performance of concrete, such as compression, splitting tensile, flexural, and elastic modulus. When 10% of the gravel is substituted with rubber, the (compressive, splitting, flexural) strength and elastic modulus of rubberized concrete are all significantly reduced by around 23%, 13%, 20%, and 25%, respectively [5].

Dumne investigated the experimental reclaimed rubber tyre aggregates as a partial substitution for gravel in the concrete mix. To assess the quality of concrete mixes, tests such as slump, density, and compression strength are performed on various concrete mixes. To make rubberized concrete, four distinct concrete mixes with partial substitution of coarse particles by 0%, 5%, 10%, and 15% with rubber by an equal volume of rubber are made. According to test results, replacing rubber aggregates with coarse aggregates by 15% by volume resulted in a considerable drop in compressive strength of 55.21% and a unit weight of 14.33% when compared to standard concrete [6].

Marie 2017 looked into the possibility of combining different percentages of aggregate (recycled concrete) with rubber particles to produce a combination of recyclable aggregate-rubberized concrete with acceptable physical and mechanical properties and low thermal conductivity. The conductivity of the thermal combination of recyclable aggregate-rubberized concrete is reduced by 36.8% compared to conventional concrete when 20% of natural coarse aggregates are replaced with aggregate (recycled concrete) by weight and 10% of sand is replaced with rubber crumb by volume [7].

Miller and Tehrani 2017 examined the mechanical properties of lightweight aggregate concrete made from tires. The lightweight

E-mail addresses: ammar@atu.edu.iq (A.A.H. Beiram), eng.hayder.mk@uobabylon.edu.iq (H.M.K. Al-Mutairee)

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coarse material was replaced by volume with tire-derived aggregate. Both cylindrical and beam samples, replacement ratios ranging from 0% to 100% in 20% increments were used. Cylinders were used to measure (compressive, splitting) strength, and modulus of elasticity. Beam specimens were used to study the modulus of rupture, hardness, and reactivity to an impacting flexure. As the amount of rubber in a product grows, the static mechanical characteristics drop. When rubber substitution quantities of 80% and 100% are utilized, flexural toughness improves. According to the findings, the material appears to be suitable for situations where energy absorption is a major consideration [8].

Kadhim and Al-Mutairee examines the compressive strength, flexural tensile strength, modulus of rupture, and impact resistance of waste tire rubber concrete samples. With fine and coarse aggregate, the rubber ratio was employed as a volumetric substitute. To replace coarse and fine aggregate, chip and crumb rubber were used in four different proportions by volume (5%, 10%, 15%, and 20%). The findings show that substituting sand or gravel with tier rubber reduces characteristics (compression, rupture, and tensile), while impact resistance growing by 426% and 396%, respectively, when 20% of the gravel and sand are substituted by rubber. The waste rubber can replace 20% of gravel or sand and the resulting rubberized concrete is still structural concrete [9].

Based on the findings of the literature review, rubber concrete is a new material that has the potential to improve the ductility of concrete structures while also reducing non-degradable waste. One of the key characteristics studied was the rubber percentage as a volumetric partial substitute of coarse aggregate. The effects of replacing coarse aggregate with chipped rubber in four varying quantities by volume (0%, 10%, 20%, and 30%) on the mechanical behavior of concrete mix were examined.

2. Experimental program

An experimental program was created to look at the main qualities of several rubberized concrete mixtures. Slump, density, compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, thermal conductivity, and impact resistance, tests were all conducted, and the results were analyzed. A flow chart of the experimental programs is shown in Fig. 1.

2.1. Materials

Ordinary Portland cement was employed in this investigation; cement is required to satisfy the constraints of the specification (Iraq Specification No. 5, Second Modification, 2010) [10]. Tables 1 and 2 demonstrate the chemical characteristics and physical properties of cement. Fine aggregate with a max. size of 4.75 mm was used as fine aggregate, which met Iraqi criteria (Iraq Specification No.45, Second Modification, 2010). zone (2) [11], as shown in Table 3. In this experiment, the coarse aggregate is rounded gravel with a max. size of 14 mm. IQS No.45, Second Modification, 2010 is used to verify the coarse aggregate grade [9], as shown in Table 4. Cutting leftover tyre rubber and running it through a 14 mm sieve were used to gather rubber samples for the investigation. The stated size was chosen so that the grading would be similar to coarse aggregates. Tables 5, 6 and Fig. 2 show the qualities of scrap tire rubber, chemical and physical properties, and particles of chip rubber respectively. Glenium 54 (G54), a water-reducing additive with a wide range of applications, is used to improve the workability of concrete mixtures. It is produced by the company (BASF) and fulfills the ASTM C494/C494 M requirements [12]. Every one of the samples was cast and cured with water from the tap.

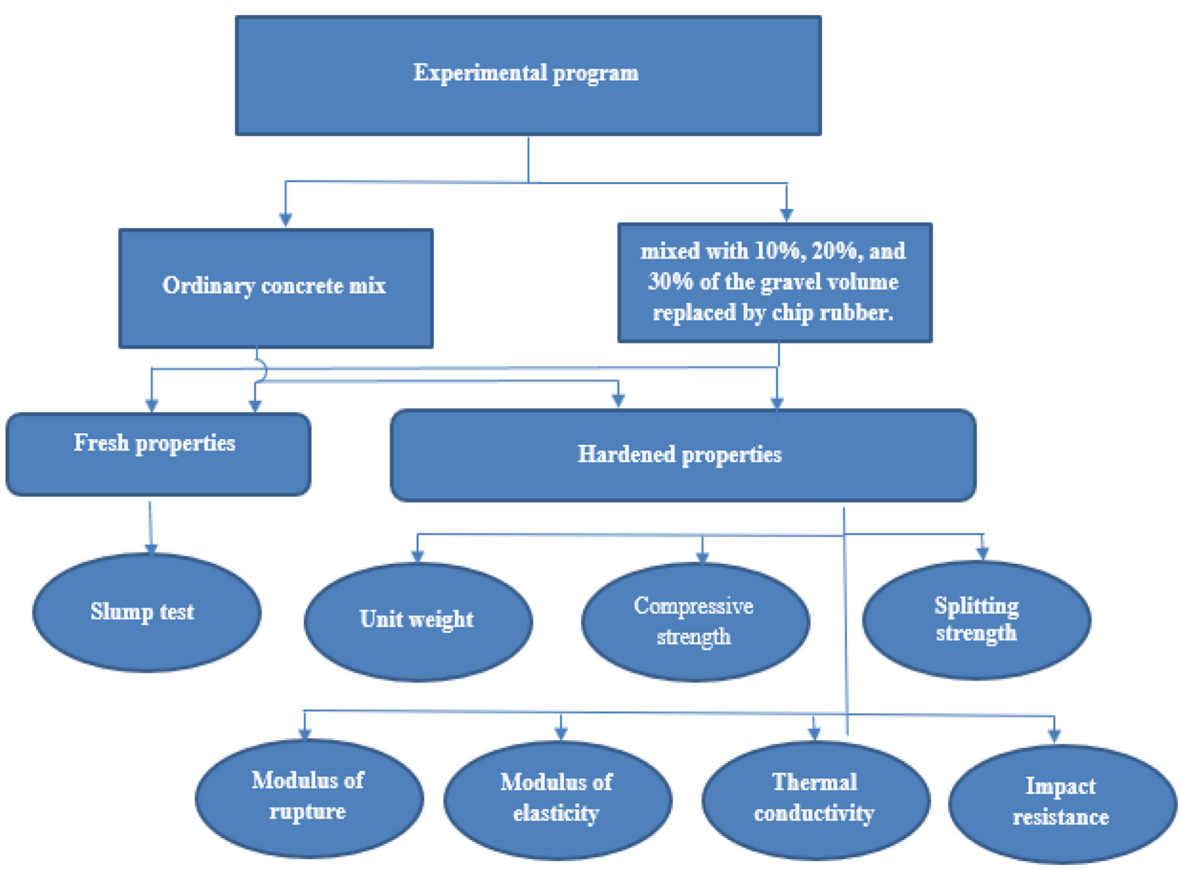

Fig. 1. The experimental programs' flow diagram.

Table 1
Chemical characteristics of cement.

Oxides298	Content, %	Iraqi criteria (No.5/2010), %
CaO	62.5	–
SiO_2	21.3	–
Al_2O_3	4.2	–
Fe_2O_3	4.4	–
MgO	3.6	<5
SO_3	2.05	<2.5
Free lime	0.82	–
L.O.I.	3.35	<4
L.S.F.	0.91	0.66–1.02
Insoluble residue	1.18	<1.5

Table 2
Cement's physical properties.

Properties	Result	Iraqi criteria (No.5)
Setting time (Vicat apparatus)		
Initial setting, min	105	≥45
Final setting, hrs	3.5	≤10
Compressive strength, MPa		
3 days	18.1	≥15
7 days	27.8	≥23

Table 3
Sand sulfate content and sieve analysis.

Mesh opening (mm)	Percentage of passing, %	Iraqi criteria (No.45), %
10	100	100
4.75	94.6	90–100
2.36	83.9	75–100
1.18	70.6	55–90
0.60	40.2	35–59
0.30	13.4	8–30
0.15	4.9	0–10
Sulfate content		
Property	Result	Iraqi specifications (No.45)
SO3, %	0.32	≤ 0.5

Table 4
Gravel sulfate content and sieve analysis.

Mesh opening (mm)	Percentage of passing, %	Iraqi criteria (No.45), %
20	100	100
14	95.4	90–100
10	63.1	50–85
5	4.9	0–10
0.075	0.09	≤3
Sulfate content		
Property	Result	Iraqi specifications (No.45/ 1984)
SO3, %	0.072	≤0.1

Table 5
Sieve analysis of chip rubber.

Mesh opening (mm)	Percentage of passing, %	Iraqi criteria (No.45), %
20	100	100
14	98.1	90–100
10	70.4	50–85
5	3.2	0–10

Table 6
Chemical and physical qualities of rubber.

Chemical structure		Physical characteristics	
Essential rubber elements	Values (%)	Properties	Values
Extract of acetone	10		3.15
Rubber hydrocarbon	25	Finesse modulus	1.78
Carbon black content	30	Specific gravity	
Natural rubber amount	31	Water absorption	2.06%
Ash amount	4		

Fig. 2. Chip rubber.

2.2. Details of specimens

Table 7 lists the characteristics of each specimen utilized for this study, including its designation and chip rubber percentage.

2.3. Concrete mixing

Before beginning the mixing procedure for normal strength concrete, weigh and pack all quantities of the raw materials (gravel, sand, and cement) in a clean plastic container. All concrete combinations are mixed mechanically using a 0.1 m^3 electrical mixer. With few modifications, the general mixing process is adapted from ASTM C192 [13]. The following are the steps in the mixing process:

Table 7
Specifications of specimens.

No.	Specimen symbol	Percentage of rubber (%)
1	R0	0
2	R10	10
3	R20	20
4	R30	30

– The mixing water is divided into two parts. The major one (approximately 75%) is mixed separately with the entire amount of super plasticizer (G54) for nearly 1 min.
– Before the mixer operates, coarse aggregate, chip rubber, and a portion of mixing water (approximately 25%) are added, and the mixer is operated for a few revolutions ($\leq$0.5 min) before being turned off.
– The fine aggregate, cement, and the majority of the mixing water plus G54 are then fed into the mixer, which is then run for 3 min.
– After that, the mixer is allowed to rest for 1 min.
– After that, the concrete materials are mixed for another 2 min.

So, disregarding rest time, the total mixing time is roughly 5.5 min. The specifications and mix quantities for the concrete mixtures are listed in Table 8.

3. Testing of specimens

3.1. Fresh concrete properties-slump test

As indicated in Fig. 3, the following check was done to determine the workability of normal and rubberized concrete in line with (ASTM 143M-12) [14].

Fig. 3. Slump test.

3.2. Properties of hardened concrete

3.2.1. Density

The test was done to determine the density of normal and rubberized concrete**.**

3.2.2. Compressive strength test

To monitor the compressive strength development of concrete mixes over time, at (7 and 28) days, this test is achieved using (150 × 150 × 150) mm cubes in accordance with BS 1881-part 116 [14] and 150 × 300 mm cylindrical specimens in accordance with ASTM C39 [15]. At the prescribed age, three cubes and cylinders are formed for each mix. The specimens are immersed in tap water after de-molding until they are tested.

Fig. 4. Compressive strength testing machine.

3.2.3. Splitting tensile strength

According to ASTM C496 [16], splitting tensile strength was tested using cylindrical concrete specimens with a diameter of 100 mm and a height of 200 mm. Automatic compression testers with a capacity of 2000 kN were used to test the specimens at age 7 and 28 days. The splitting test arrangement is shown in Fig. 4.

3.2.4. Modulus of rupture

On normal strength concrete specimens, flexural strength (modulus of rupture) tests are performed in accordance with (ASTM-C78-02) [17]. After curing them in a water container within the lab for (7, 28) days, flexural strength tests are performed on six prism specimens (100 * 100 * 400 mm). The flexural machine (150 kN capacity) was used to test the beam as a simply supported beam with third point load, as indicated in Fig. 5.

3.2.5. Modulus of elasticity

According to the method (ASTM C469-14) [18], cylindrical specimens with a dimension of (100 × 200) mm were used to test the

Table 8
Mixes symbols and proportions.

Mix symbol	Cement, kg/m^3	Sand, kg/m^3	Gravel, kg/m^3	Chip rubber kg/m^3	w/c	Super-plasticizer, kg/m^3
R0	440	710	1050	0	0.36	2.33
R10	440	710	945	31.82	0.36	2.33
R20	440	710	840	63.64	0.36	2.33
R30	440	710	735	95.45	0.36	2.33

Fig. 5. Flexural machine.

concrete modulus of elasticity. To avoid any strength losses, the two surfaces of the cylinder were well smoothed with the help of electric grinding. All samples were tested using a hydraulic machine with a capacity of roughly (1000 kN). With a sensor length of 100 mm, linear displacement measurement (LVDT) was used. Fig. 6 depicts the LVDT sensor testing machine and installation technique.

3.2.6. Impact resistance by drop-weight test

According to ACI Committee 544 [19], the drop-weight test is done to evaluate the potential energy absorption for concrete cylinder samples (152 mm and 65 mm) diameter and depth respectively, three samples were evaluated for each blend). The number of blows was calculated after a fall steel hammer sphere was repeatedly dropped on the sample from a given height to obtain the appropriate grade of failure (as well as first and/or failure crack). Fig. 7 depicts the test unit, which consists of a 4.54 kg hammer sphere dropping from a height of 457 mm onto a heavy steel sphere with a diameter of 65 mm.

The following Eqs. (1) and (2) in joule (J) [18] were used to compute the impact resistance at the first crack (EI) and the final crack (Eu).

$$\mathrm{EI} = N1mgh \tag{1}$$

Fig. 6. Modulus of elasticity test system.

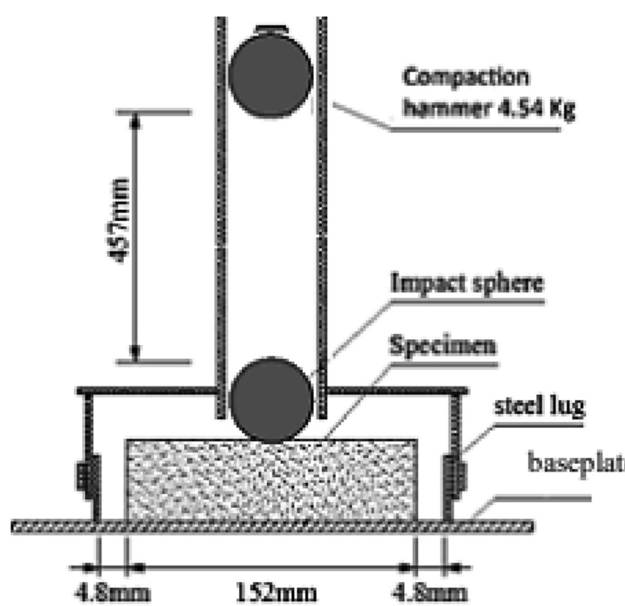

Fig. 7. Section through test equipment for impact strength.

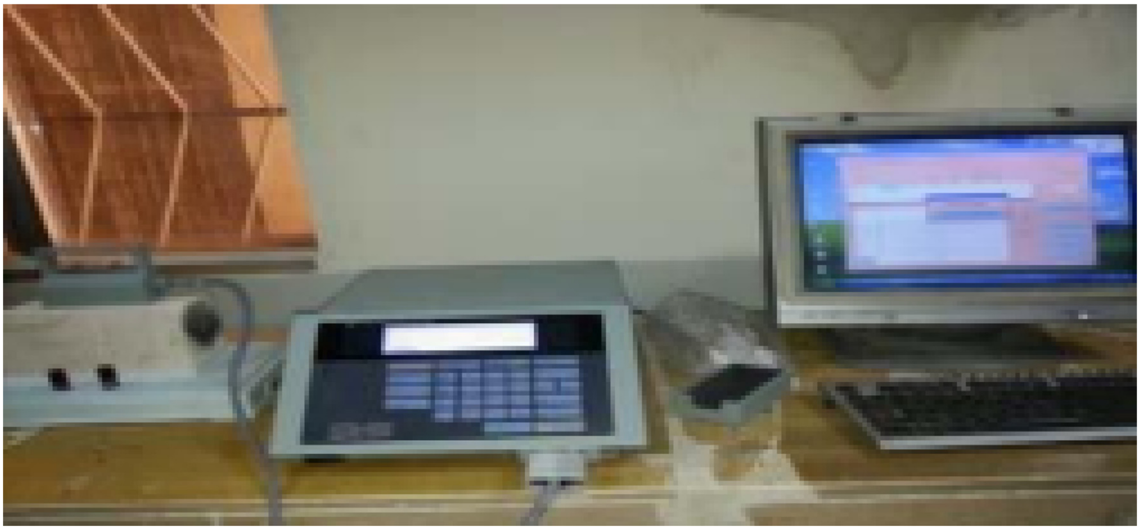

Fig. 8. Test of thermal conductivity [21].

$$\text{Eu} = N2mgh \quad (2)$$

When (m) is the fall hammer's mass., (g) is the gravitational acceleration (9.81 m/s^2), and (h) is the releasing height of the fall hammer, (N_1) the number of impacts on first visible crack, (N2) blows amount that caused cracks to be visible and large.

3.2.7. Thermal conductivity

According to ASTM C1113/C1113M 09 (2013) [20], this test was performed with a Quick Thermal Conductivity Meter (QTM-500) as shown in Fig. 8. On cube specimens with dimensions of (150 × 150 × 150) mm, thermal conductivity test is carried. Four specimens were processed and dried for 24 h in an oven at 110 ± 5 °C. For each specimen, the test was repeated three times, providing three values of thermal conductivity with a standard deviation of <3%, and the average value was computed.

4. Results and discussion

4.1. Slump test

Table 9 shows the finding of tests for slump on four concrete mixtures. The workability of all the combinations was good, and there were few discrepancies between them. By increasing the volumetric ratio of rubber replacement with natural aggregate, the workability reduced, according to the findings

4.2. Density of concrete

Table 10 list the densities of four different mixing samples. When rubber is used as a partial volumetric replacement for coarse aggregate in reference concrete mixtures, these values decline. Because coarse aggregate has a higher specific gravity than chip rubber and rubber particles have a hydrophobic nature that repels water from rubber surfaces and traps air on their rough surface, the density of rubberized concrete mixtures is lower than that of reference mixtures. Increasing the volumetric rubber replacement ratio increases the air content in a specific volume of rubberized concrete.

Table 9
The slump values for different mixes.

Mix. symbol	Slump value (mm)	%Difference.
R0	135	0.00
R10	121	−10.37
R20	103	−23.07
R30	85	−37.04

Table 10
The density values for different mixes.

Mix. symbol	density of mixes (kg/m^3)	%Difference.
R0	2411	0.00
R10	2325	−3.57
R20	2252	−6.59
R30	2192	−9.08

4.3. Compressive strength test

The compression strength dropped as the rubber percentage grew, as seen in Table 11. The difference in particle softness between scrap tire rubber and aggregates is the cause of this reduction. Rubber and cement paste have a poor adherence. (The interfacial transition area between the rubber particles and the cement paste has low strength.)

The experimental result shows that the ratio of compression strength per the American Standard to compression strength per the British Standard is between (0.8–0.81). According to (IRAQI Code 1/1987) [22] to find the value of (f'c) for normal concrete used the ratio (0.8–0.85).

4.4. Splitting tensile strength

Table 12 depicts the results of the splitting tensile strength test. The loss in splitting tensile strength was below the compression strength drop, according to the findings. The control mix (R0) failure mode resulted in an actual split of the sample, with the cylindrical splitting onto two pieces (brittle failure). However, this failure mode did not appear in other chip rubber-based mixtures. Instead of being brittle, these mixtures failed gradually.

4.5. Modulus of rupture

The results of rupture strength are shown in Table 12. When rubber particles are added to concrete, the flexural strength is reduced. The failure mode of the control mix R0 indicates that

Table 11
Compressive strength values.

Mix. symbol	(fc) for cube (MPa)				(fc') for cylinder (MPa)		fc'/fc
	At 7 days	%Diff.	At 28 days	%Diff.	At 28 days	%Diff.	
R0	34.28	0.00	43.58	0.00	34.97	0.00	0.802
R10	28.90	−15.69	35.37	−18.84	28.67	−18.02	0.811
R20	23.40	−31.74	29.10	−33.23	23.46	−32.91	0.806
R30	19.63	−42.74	22.65	−48.03	18.31	−47.64	0.808

fc': Compression strength (Mpa) per the American Standard.
fc: Compression strength (Mpa) per the British Standard.

Table 12
Splitting tensile strength, modulus of rupture and modulus of elasticity values.

Mix. symbol	Splitting Tensile Strength (ft) (MPa)				Modulus of Rupture (fr) (MPa)				Modulus of Elasticity (GPa)	
	At 7 days	% Diff.	At 28 days	% Diff.	At 7 days	% Diff.	At 28 days	% Diff.	At 28 days	% Diff.
R0	2.79	0.00	3.65	0.00-	3.64	0.00-	4.67	0.00-	27.68	0.00
R10	2.54	−8.96-	3.18	12.88-	3.09	15.11-	3.95	15.42-	21.228	−23.31
R20	2.25	19.35-	2.83	22.46-	2.57	29.40-	3.20	31.48-	16.582	−40.09
R30	1.93	30.82	2.36	35.34	2.16	40.66	2.58	44.75	13.705	−50.49

the prism failed at the specimen's center. This has to do with the mix's homogeneity. The mode of failure happened not exactly in the middle of the sample, but still within the region of the inner one third, because of the non-uniform spread of rubber in the mixtures containing rubber particles.

4.6. Modulus of elasticity

Table 12 displays the young module results for a variety of mixtures. As can be observed, using leftover tire rubber instead of coarse material reduces elasticity modulus. When utilizing concrete as a base case for a hybrid compound made up of two components, namely aggregate and cement, it is clear that the influence of aggregates is due to elastic modulus and the volume ratio among these particles in concrete. As a result, the higher the elasticity modulus of aggregates, the higher the elasticity modulus of concrete. Increased rubber substitution for gravel particles in concrete lowers elastic modulus and, as a result, the elastic modulus for concrete, which is mainly correlated here to the proportion of rubber provided, due to the lower rubber module of elasticity.

4.7. Impact resistance by drop-weight test

The number of blows required to create the initial crack and the final failure grows considerably when the rubber content is replaced as tabulated in Table 13. It was also discovered that as the quantity of rubber replacement increases, the discrepancy between both the numbers of ultimate failure blows and initial notch blows (N2-N1) grows dramatically. The fundamental reason for this is that while the amount of tire rubber replaced increases, the rubber cement combination becomes more flexible, when contrasted to the reference mix, this results in higher absorption.

Table 14
Conductivity of the thermal for each mixture.

Mix. symbol	Thermal conductivity (W/m K)	Differences %
R0	1.1614	––
R10	1.1355	2.23
R20	1.0315	11.18
R30	0.9221	20.6

4.8. Thermal conductivity

Table 14 displays the conductivity of the thermal for all the concrete mixtures that have been made. The thermal conductivity values drop as the amount of rubber increases, according to the findings. Thermal conductivity values decreased 20.6% for rubberized concrete with 30% replacement.

The retain air, which rose with the rubber percentage because of the cement mortar's weak adhesion to the face of the chipped rubber particles, led to a portion of the thermal conductivity drop. The lower conductivity of the thermal for rubber particles than the cement paste causes the decline in conductivity of the thermal for rubberized concrete. Further, the reduction in conductivity of the thermal is linked to the entry of air into the concrete matrix, resulting in a lower weight.

5. Conclusion

The findings of this experimental study on the mechanical behavior of rubberized concrete lead to the following conclusions:

Table 13
Drop weight lab tests for impact resistance.

Mix. symbol	N1 ave. for 3 sample	N2 ave. for 3 sample	N2-N1	Impact Energy (J)		
				First crack	Ultimate failure	Diff. %
R0	52	60	8	1058.39	1221.22	0
R10	89	106	17	1811.47	2157.48	76.67
R20	168	197	29	3419.40	4009.66	228.33
R30	236	274	38	4803.45	5576.88	356.66

- The impact resistance of concrete will increase by 356% as a result of the replacement of 30% of the coarse aggregate with rubber chips.
- When chip rubber replacement increased, the number of blows from blow causing first crack to ultimate crack rose dramatically, implying an improvement in the ductility of rubberized concrete when compared to conventional concrete.
- Concrete's thermal conductivity can be decreased by 20.6% by replacing 30% of the coarse aggregate with rubber chips. Rubberized concrete improved thermal conductivity could be useful as an insulating material and contribute to environmental protection. It is recommended to use rubberized concrete for structural purposes.
- The workability of concrete is reduced by 37.04% when the percentage of chip rubber in the concrete mix is increased to 30%.
- When 30% of coarse aggregate is replaced with chip rubber, the density of rubberized concrete mixtures is 9.08% smaller than that of guideline mixtures.
- As the amount of rubber in concrete grows, the static mechanical characteristics drop. Where at 30% replacement, compressive strength, splitting tensile strength, and modulus of rupture are all reduced by 47.64%, 35.34%, and 44.75%, respectively.
- By substituting 30% of coarse particles with chip rubber in concrete, the modulus of elasticity is reduced to 50.49%.

CRediT authorship contribution statement

Ammar A.H. Beiram: Writing – original draft, Supervision, Software. **Hayder M.K. Al-Mutairee:** Conceptualization, Methodology, Visualization, Validation, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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