



## Some Properties of Sustainable Concrete with Rubber Waste Aggregate

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### HIGHLIGHTS

- The properties of Sustainable Concrete with well-graded coarse and fine rubber aggregates are studied
- The mix 15 R-C 20 with a density of 1952.5 kg/m<sup>3</sup> can be Produced
- The mechanical properties of RBC are reduced in comparison to normal concrete

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### ABSTRACT

The cumulative quantities of non-biodegradable solid tire waste, which are byproducts of transport vehicles, contribute to environmental pollution.. This study seeks to address this issue by investigating the impact of using this waste as a replacement for natural coarse and fine aggregate in varying ratios (10%, 15%, and 20% as coarse aggregate, and 5%, 10%, and 15% as fine aggregate by volume) to create sustainable concrete. All mixtures incorporate 10% silica fume (SF) as a cement replacement by weight. Results reveal decreased workability, fresh density, compressive, and splitting tensile strength with increasing rubber replacement proportions. However, utilizing tire rubber aggregate leads to the production of structural lightweight concrete (LWC), with advantages such as reduced oven dry density. Notably, a 20% replacement of coarse rubber waste and 15% replacement of fine rubber waste yield compressive strengths of 48.80 MPa and an oven-dry density of 1952.5 kg/m<sup>3</sup>, respectively, classifying these concrete mixes as structural lightweight concrete.

## 1. Introduction

The construction sector has recently embraced the challenge of integrating sustainability into production processes by finding more environmentally friendly raw materials or incorporating solid waste into concrete as aggregates and studying its properties. Using waste tire rubber in cementitious concrete to replace specific natural aggregate is one of the solutions for reusing waste rubber. This effort may be environmentally friendly as it helps to dispose of used tires and prevent environmental degradation. Therefore, recycling and reusing tires are considered a severe environmental problem [1-3]. Millions of tires are annually reaching the end of their useful life, contributing a large amount of non-degradable solid waste to the environment [4]. This technique is also economically viable, as specific expensive natural aggregates can be preserved [5, 6]. In the past, the building industry accepted the challenge of substituting synthetic resources for natural aggregates in concrete manufacturing [7,8]. Several researchers are currently studying the use of recycled rubber particles in concrete to produce so-called rubberized concrete [9-11]. The significance of this type of concrete, in addition to the environmental benefits, comes from the ability of rubber particles to dissipate high energy, so that when used in concrete structural members, they can be beneficial and positively affect the building in general [12,13]. Although many types of research focus on using recycled rubber in manufacturing concrete, most of the reported studies have been on concrete with scrap tires used as a substitute for natural aggregate to produce normal-strength concrete. Few studies investigated the effect of adding reclaimed rubber to high-strength lightweight concrete. Therefore, additional research is necessary to evaluate the performance of this type of concrete using recycled rubber. One of the most viable solutions could be the preservation of natural resources to decrease their effect on the environment, garbage disposal, and climate change [14,15], and improve the fatigue resistance, ductility, hardness, impact resistance, toughness, and other characteristics of concrete [16]. Furthermore, it is used to enhance thermal and sound insulation, energy absorption, and fracture resistance [17]. Thus, spent tires can be recycled into asphalt, culverts, paving stones, brick walkways, and acoustic panels [18]. Many researchers have studied the properties of concrete containing waste tire rubber.

Rashad [1] studied the effect of rubber crumbs as a replacement for fine aggregates in concrete. Most researchers have testified that, from a mechanical standpoint, substituting sand with tire rubber reduces the workability, fresh density, split tensile strength, compressive strength, and flexural strength of concrete. These reductions in mechanical characteristics are mainly

attributable to the low mechanical properties of tire rubber aggregates and the weak bond between tire rubber particles and other concrete components. Yet, research has shown that rubberized concrete is lighter, and less costly than traditional concrete.

Holmes et al. [19] used rubber instead of natural sand at a 15% replacement ratio. The compressive strength of concrete without rubber was greater than 50 MPa and noted that when replacing the sand with rubber waste, the compressive strength was reduced to 35 MPa. Ozbay et al. [20] observed that the compressive strength of concrete decreased when natural sand was partially replaced with shredded rubber (3-0 mm) at 5%, 15%, and 25% by volume. The reduction in compressive strength was approximately 4%, 10%, and 26% when 5%, 15%, and 25% of rubber grit were added with compressive strength of 60 Mpa, 58.4 Mpa, and 45.5 MPa, respectively. Záleska et al. [21] used tires with a rubber basis (0/4 fine rubber and 4/8 coarse rubber aggregate). A reduction in dry density and mechanical properties and a significant improvement in thermal properties were observed. Ling et al. [22] investigated a reduction in the compressive strength and density of concrete blocks when natural sand (0-4 mm) was replaced with rubber (1-5 mm) as a substitution by volume up to 50%. The reduction increased as the rubber grit content increased. After 28 days of curing, the compressive strength of concrete with a w/c ratio of 0.45 decreased by 2%, 19%, 24%, 33%, 35%, 48%, 66%, and 66%, respectively, with the addition of 5%-50%, rubber sand. When 50% of the sand was substituted by rubber, the density decreased by about 8%. The compressive strength and density values are 9.5 MPa, and 1992 kg/m<sup>3</sup>, respectively, at 50% by the natural rubber-substituted sand volume. Pelissier et al. [23] investigated the effect of silica fume on concrete made from waste tire rubber of 10% as a substitute for fine natural aggregate. The results illustrate that rubber concrete without silica fume showed a decline in compressive strength of up to 67% compared to the reference mixture, while concrete with silica fume had only a reduction of 14%.

There are very limited studies on the properties of high-strength lightweight concrete with tire rubber waste as a volumetric replacement to natural coarse and fine aggregates. The main objective of this experimental study is to produce a new sustainable strength lightweight concrete material that contains tire rubber waste, which is available in large amounts in Iraq. This leads to many advantages, recycled tire rubber waste gets rid of this waste which has great benefit to environmental sustainability, and produces sustainable high strength lightweight concrete for many construction applications.

## 2. Experimental Work

### 2.1 Materials Used

In this research work, different materials, including Ordinary Portland cement, fine aggregate (sand), coarse Aggregates (gravel), condensed silica fume (SF), tire rubber waste, and High Ranged Water Reducing Admixtures (HRWRA) in addition to water were used to produce different concrete mixtures.

#### 2.1.1 Cement

Ordinary Portland Cement CEM I with the trademark of (Mass), produced by Bazian Company Iraq was used in this study that conformed to Iraqi Standard No,5 /2019 [24].

#### 2.1.2 Natural Aggregates (coarse and fine)

Coarse natural aggregate from Badra region, Wasit Governorate, was used. The maximum particle size of aggregate is 12 mm with a specific gravity of 2.65, sulfate content (SO<sub>3</sub>) of 0.06%, and water absorption of 2%, the laboratory tests showed that it conforms to Iraqi standard specifications No. 45/1988 [25] are shown in Table 1. Natural sand with a maximum size of 4.75mm had been applied. The results show that the fine aggregate used conforms to Iraqi Standard No.45/1988 [25] are shown in Table 2.

**Table 1:** Grading and properties of coarse aggregate

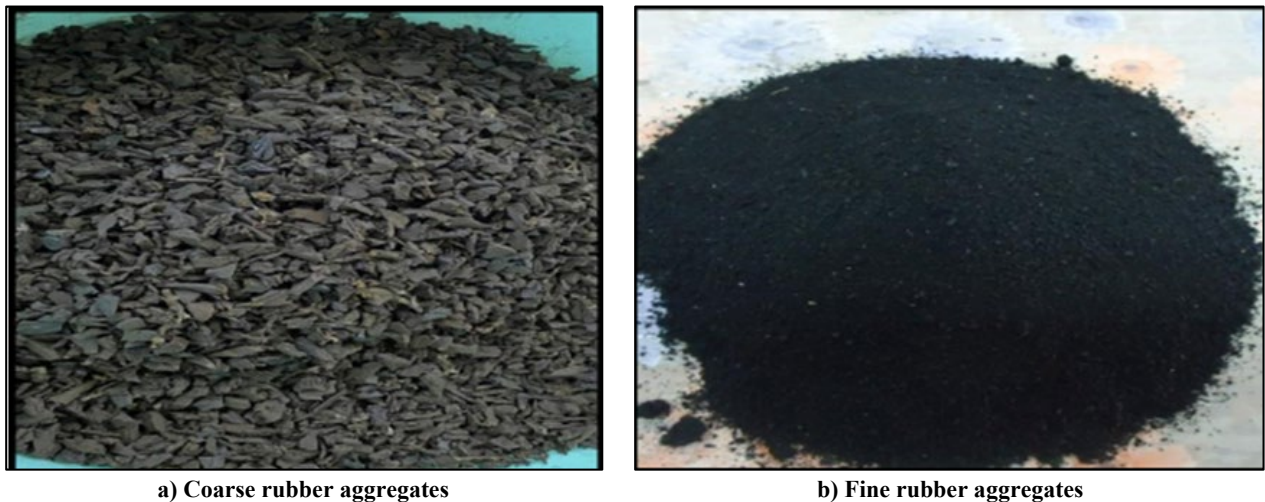
Sieve Size (mm)	Passing %	Limits of the Iraqi specification No.45/1984 (10 mm) nominal single size
14	100	90-100
10	95	85-100
5	10	0-25
2.36	1	0-5
Other properties		Limits of Iraqi specification No.45/1984 [2]
Specific gravity	2.68	
Absorption %	0.55	
Sulfate content as SO <sub>3</sub> %	0.09	≤0.1%

**Table 2:** Grading and properties of fine aggregate

Sieve Size (mm)	Passing %	Limits of the Iraqi Specification No.45/1984 zone (2)
4.75	100	90-100
2.36	87	75-100
1.18	69	55-90
0.60	58	35-59
0.30	20	8-30
Other properties		Limits of Iraqi specification No.45/1984 [2]
Specific gravity	2.60	
Absorption %	2.00	
Dry loose-unit weight kg/m <sup>3</sup>	1595	
Sulfate content as SO <sub>3</sub> %	0.2	≤0.5

### 2.1.3 Tire Rubber Waste

Coarse rubber aggregates (CRA) with a 10 mm maximum particle size from shredded tires and fine rubber aggregates (FRA) with a maximum size of 4.75 mm, which were obtained from the waste tire recycling (Diwaniyah tire factory), were used. Figure 1(a and b) shows the samples of rubber waste aggregate used in this investigation. The specific gravity is 1.003 for (FRA) and 1.08 for (CRA). Several mechanical processes were carried out to cut and prepare this rubber to the required size. The process began with cutting tires in large particle sizes, then the size gradually decreased, and the cycle continued, which led to more particles in small sizes. This process broke tires into dimensions of less than half a millimeter to 20 mm. Table 3 demonstrates the grading of the coarse rubber aggregates, while Table 4 displays the characteristics of the fine rubber aggregates utilized in this study.

**Figure 1:** Types of tire rubber waste aggregates used in this investigation**Table 3:** Grading of Coarse Rubber Aggregates

Sieve size (mm)	Passing (%)	Limits of Iraqi specification No.45/2016
14	100	100
10	61.5	85-100
4.75	1.36	0-25
2.36	0.19	0-5

**Table 4:** Sieve Analysis of Fine Rubber Aggregates

Sieve size (mm)	Passing (%)	Limits of the Iraqi standard No.45/2016
4.75	100	90-100
2.36	98	75-100
1.18	80	55-90
0.6	40	35-59
0.3	20	8-30
0.15	4	0-10

### 2.1.4 High-Range Water Reducing Admixture (HRWRA)

In all the mixes, a chemical admixture with a trademark of "Sika ViscoCrete®-5930" was used. This type is free from chlorides and is compatible with ASTM C 494-14 type F [26].

### 2.1.5 Silica Fume (SF)

Silica fume (SF) is a pozzolanic substance with significant activity. It is a byproduct of silicon or ferrosilicon metal production. Silica fume which is used in this investigation is commercially available as MEYCO MS 610 from the chemical company BASF [27]. The results indicate that the employed silica fume meets the criteria of ASTM C1240/2015 [28].

### 2.1.6 Water

Tap water was used to mix and cure the concrete specimens.

## 3. Design and Specimens Preparation

Mix proportions of 1:1.19:1.8 of cement, sand, and gravel by mass with cement content of 525 kg / m<sup>3</sup> with 0.28 W/C ratio and variable HRWRA dosage to achieve the same workability of 100±5 mm slump for all mixes were used. 10% SF has been used as a mass substitute for cement to enhance strength and reduce permeability in combinations. To obtain sustainable, environmentally friendly, and lightweight concrete, these materials were mixed with proportions of tire waste as fine and coarse natural aggregates with different contents to obtain low density and acceptable strength that meets all structural requirements of concrete using coarse and fine rubber tires as a replacement to natural coarse and fine aggregates in different ratios of (10, 15, 20% coarse, and 5,10 and 15% fine) by volume to produce sustainable Concrete. Seven mixtures were prepared the first mix is a control mix, without rubber is called reference concrete (R0), where it is required for comparison; six mixtures named (rubberized concrete) with different contents of the rubber waste aggregates were prepared, and all the details of the concrete mixtures that prepared in this investigation are shown in Table 5. In the mixing procedure, an electric rotary mixer with a capacity of 0.1m<sup>3</sup> was utilized. Before adding the materials, the inner surface of the mixer pan was cleaned to remove any stuck concrete and then washed with water. After mixing the cement, silica fume, and coarse and fine aggregate for one minute, most of the mixing water (approximately 70%) was added to the dried mixture, which was then mixed for one minute. Next, the specified amount of superplasticizer was mixed with the remaining (30%) mixing water before being added to the mixture, which was then mixed for two minutes to finish the process. The whole mixing time was approximately five minutes. All the molds were filled with concrete layers and compacted. The mixture was left inside the molds for 24 hours and covered with a nylon sheet at laboratory temperature. The concrete specimens were removed from the molds and were immersed in the curing water until the testing time.

**Table 5:** Details of Concrete Mixes with varying rubber waste content (kg/m<sup>3</sup>)

Concrete Mixture symbol	Cement (kg/m <sup>3</sup> )	Gravel (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	Silica fume (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	HRWRA (L/m <sup>3</sup> )	CRA* (kg/m <sup>3</sup> )	FRA* (kg/m <sup>3</sup> )
R0	525	945	624.75	52.5	147	7	0	0
R- C 10	525	851.455	624.75	52.5	147	7	38.51	0
R- C 15	525	803.1	624.75	52.5	147	7	57.77	0
R- C 20	525	755.98	624.75	52.5	147	7	77.03	0
5 R -C 20	525	755.98	593.48	52.5	147	7	77.03	11.83
10 R -C 20	525	755.98	562.21	52.5	147	7	77.03	23.65
15 R-C 20	525	755.98	530.94	52.5	147	7	77.03	35.47

\*CRA; Coarse rubber aggregates, FRA: Fine rubber aggregates

## 4. Results and Discussion

### 4.1 Workability

The workability of concrete mixes is illustrated in Figure 2. The slump test is done immediately after concrete mixing according to the ASTM C143 [29]. The results of the slump test indicated that the workability of the concrete mixes declined with increasing the rubber content when the replacement ratio of tire rubber was up to (15 R-C 20). We conclude that the highest percentage was in the reference mixture, where it is 100mm, and it is decreasing to record a 4.54% stagnation decrease between the reference mixture and rubber concrete (15 R-C 20), which is the highest decrease we recorded when replacing 20% coarse rubber and 15% fine rubber (coarse and fine rubber together), which is 105 mm. the reduction in the slump value for all the mixtures with tire rubber aggregate was within the specified limits of 100±5 mm that not required to adjusted by adding additional dosage of HRWRA. The reason may be due to the increase in the inter-particle friction between the rubber aggregate and the other mix constituents (due to the surface texture of the rubber particles) and the overall reduction in the unit weight of the plastic mixture [30]. In addition to the nature and surface roughness of this type of aggregate, that leads to a decrease in the workability of the matrix, which has been reported by Gupta [31].

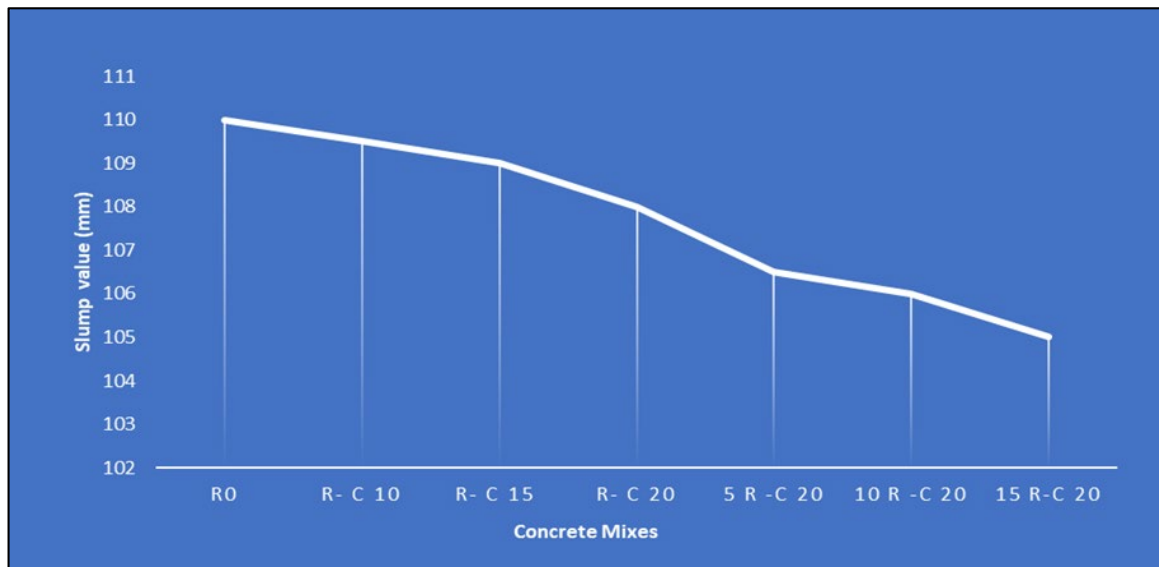


Figure 2: The slump value for different concrete mixtures

## 4.2 Density

### 4.2.1 Fresh Density

Figure 3 shows the fresh density of the reference and concrete mixes containing different contents of tire rubber waste. The fresh density was conducted according to ASTM C567/2015 [32]. The results illustrate a decrease in the fresh density as the content of the tire's rubber waste was increased. We note that (C 10 to 15 R-C 20) results in a lower density in tire rubber concrete than the reference mix, as in Figure 4, which is the highest decrease for a mixture containing 20% coarse rubber and 15% fine rubber (15 R-C 20) as a volumetric substitution to natural coarse and fine aggregate is about 13.14% compared to the reference concrete. This is due to the porosity and also because the fine rubber has a specific gravity of 1.003, which is less than the specific gravity of fine aggregate (2.60). The coarse rubber has a specific gravity of 1.08, which is less than the specific gravity of the total coarse aggregate (2.68), and this has been reported by [1,33].

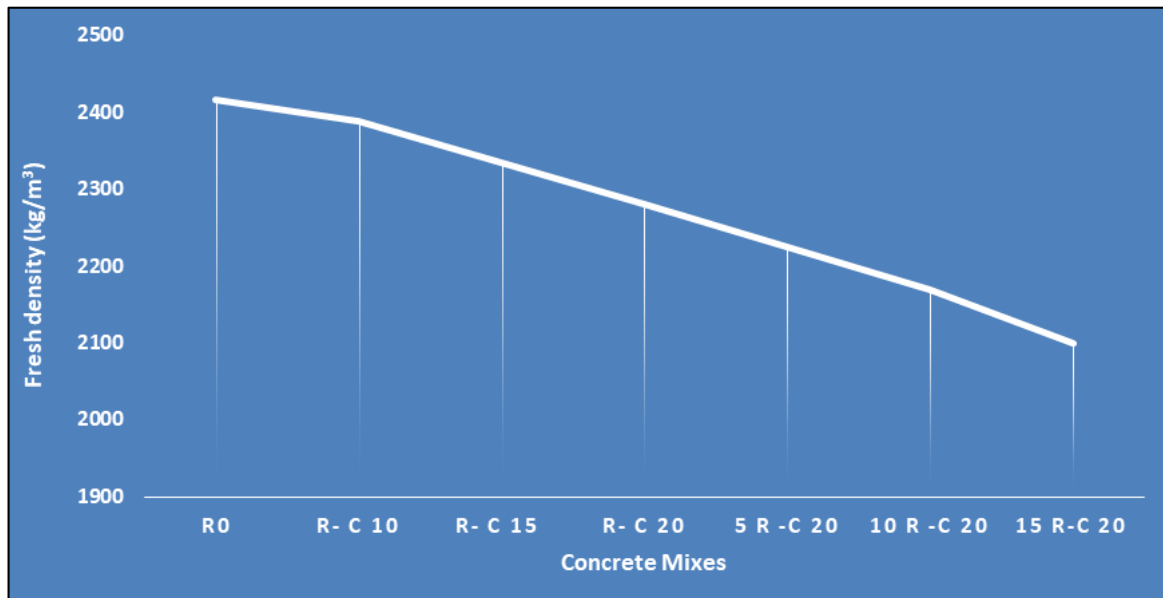


Figure 3: Fresh density at 28 days for different concrete mixtures

### 4.2.2 Oven Dry Density

Figure 4 shows the effect of incorporating tire rubber waste in concrete on the dry density of concrete mixes. The test was performed by ASTM C567/2015 [32] using cylindrical specimens with 100 mm diameter and 200 mm height at 28 days. All mixtures with rubber waste have a lower density compared to the reference concrete that does not contain rubber in its composition, and the reason is due to the presence of pores in the microstructure of concrete and also because tire rubber has a specific gravity less than the specific gravity of natural aggregate [31]. Therefore, the dry density of concrete is reduced by using rubber aggregates. This behavior was demonstrated by researchers [19,21,31]. Concrete containing 20% coarse and 15% fine

rubber waste as a volumetric replacement to natural coarse and fine aggregate (15 R-C 20) has a dry density of 1952.5 kg/m<sup>3</sup>. This concrete mix can be classified as lightweight concrete according to [34] if the measured density is less than 2000 kg/m<sup>3</sup>.

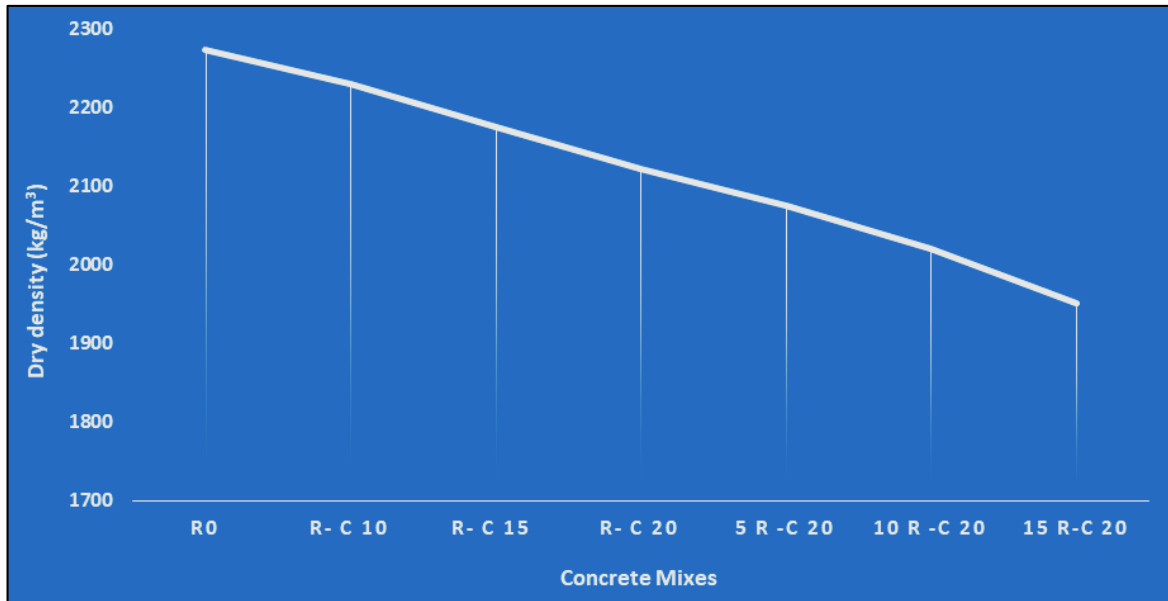


Figure 4: Oven dry density at 28 days for different concrete mixtures

### 4.3 Compressive Strength

According to the findings of the compressive strength test results at 7 and 28 days of age, the effect of the inclusion of different contents of tire rubber waste as a partial replacement to natural fine and coarse aggregate is shown in Figure 5. The compressive strength was calculated for cubic concrete samples of 100 mm [35]. The results show that the highest compressive strength was recorded for the reference mixture of 84.95 MPa at 28 days, while at the age of 7 days, it reached 67.72 MPa. Generally, the compressive strength increases with age for all concrete specimens. It can be due to the effects of curing and the hydration process of all concrete mixtures. The compressive strength gradually decreases with the increase in the content of tire rubber as a partial replacement for the natural aggregate. The percentage of rubber added to replace 20% coarse and 15% fine reached the highest drop in compressive strength of 48.80 MPa, at 28 days. Therefore, this might be acceptable for similar construction applications [1,20,21]. The decline in the strength is attributed to the weak bonding of rubber waste aggregate with the cement paste. All concrete mixtures that include tire rubber waste in different proportions have high compressive strength and are classified as high strength normal weight concrete that can be used in various structural applications, except for the last mix, which contains 20% coarse rubber aggregate with 15% fine rubber aggregate (15 R-C 20). This mix is classified as high-strength lightweight concrete that can be used as structural lightweight concrete.

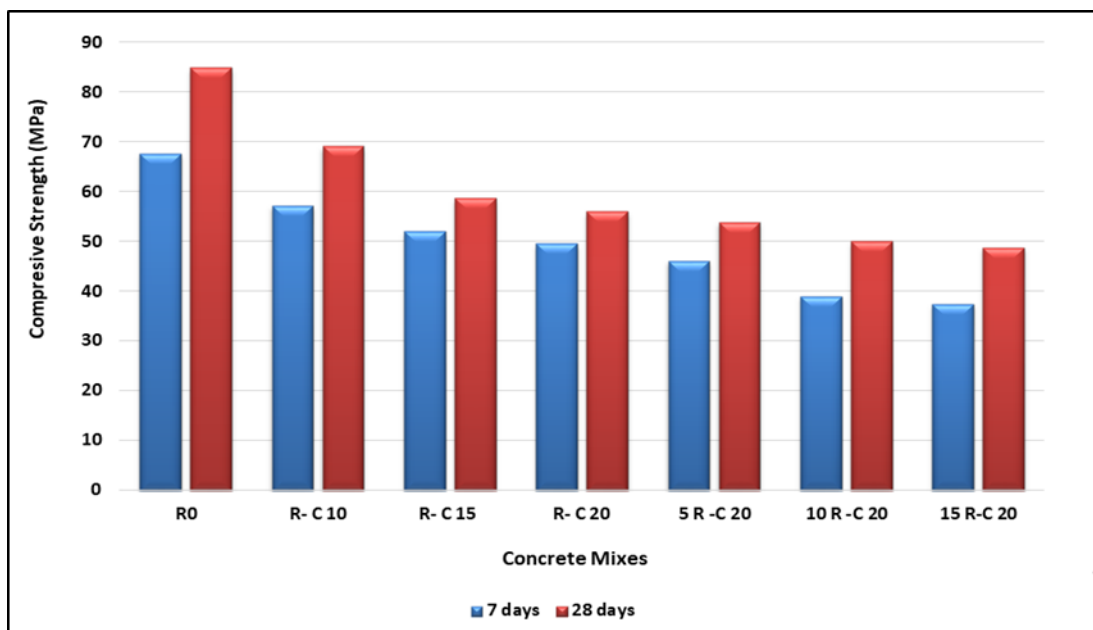


Figure 5: Compressive strength of reference and concrete mixes containing rubber waste at different ages

#### 4.4 Splitting Tensile Strength

The splitting tensile strength test was carried out according to ASTM C496–07 [36]. The results of the splitting tensile strength at 28 days of reference samples (without tire rubber waste aggregates) and concrete specimens with different contents of rubber waste aggregates are shown in Figure 6. The negative influence of tire rubber waste on the splitting tensile strength of concrete which similar to the reduction pattern in the compressive strength. The results show a slight decrease in the splitting tensile strength of about 6.12% for concrete samples containing 10% tire rubber waste compared to reference [1]. The splitting tensile strength is significantly reduced for other mixtures due to the increased content of rubber in the mix [1]. The percentage reduction is 20.65%, 26.19%, 27.34%, 29.44%, and 31.74% for concrete mixes R- C 15, R- C 20, 5 R -C 20, 10 R -C 20, and 15 R-C 20%, respectively. This behavior is similar to that observed by Rashad [1]. Concrete specimens not containing tire rubber waste aggregates fail and split into pieces with a splitting strength of 5.23 MPa. However, there was no division into two parts when the natural aggregates by tire rubber waste, especially in the mixture containing 20% coarse rubber aggregate and 15% fine rubber aggregate, and the strength of the rubber concrete was 3.57 MPa. The waste tire rubber particles made the concrete more ductile, and the sudden failure did not happen as illustrated in Figure 7.

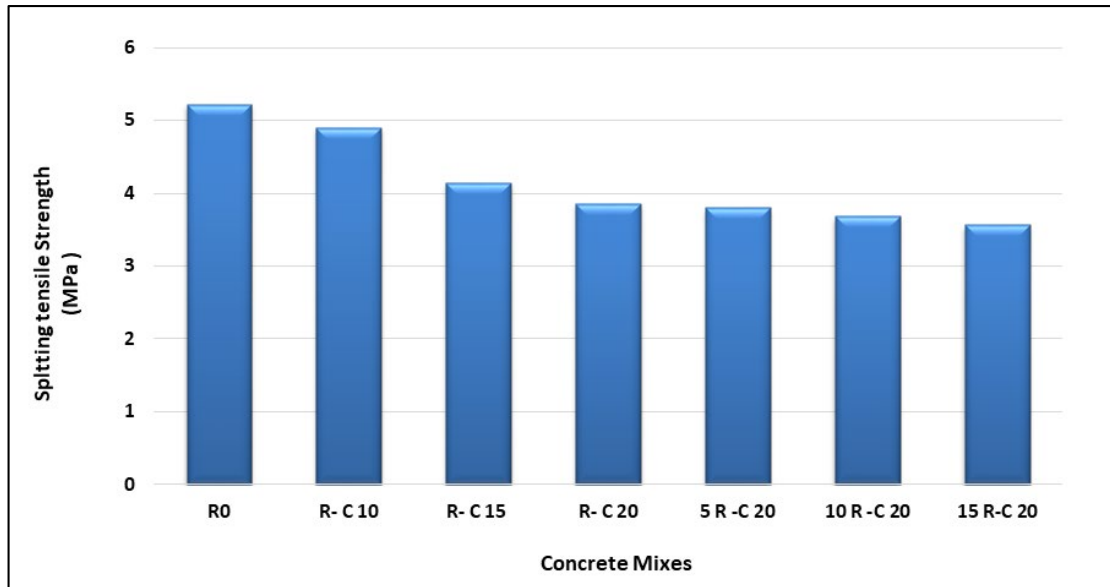


Figure 6: Splitting Tensile Strength of reference concrete and mixes containing rubber waste at 28 days age



Figure 7: Failure Mode for specimen's concrete under splitting tension

#### 5. Conclusions

Based on the results of the experimental work in this investigation, the following conclusions can be made:

- 1) The density of concrete with rubber waste aggregate decreases as the content of the rubber aggregate increases. High-strength lightweight concrete with a dry density of 1952.5 kg/m<sup>3</sup> was produced due to the existence of rubber waste aggregate mainly with 20% coarse rubber aggregate and 15% fine rubber aggregate as a volumetric replacement to natural aggregate.

- 2) The increase in tire rubber waste content significantly affects compressive and splitting tensile strength, especially when coarse rubber aggregate is replaced by gravel. It is possible to avoid a decrease in strength if the fine aggregate is replaced by fine rubber waste aggregate so that the total replacement of coarse and fine aggregate does not exceed 35% of the total content. The percentage reduction in compressive strength and splitting tensile strength for concrete specimens containing 20% coarse and 15% fine rubber waste aggregate by volume is 42.55%, and 31.74%, respectively, compared with the reference specimens.
- 3) High-strength lightweight concrete with tire rubber waste shows ductile failure under compression and tension stresses.

#### Author contributions

Conceptualization, W. Khalil, E. Dawood and R. Motloq; methodology, W. Khalil; software R. Motloq; validation, W. Khalil, E. Dawood and R. Motloq; formal analysis, W. Khalil and E. Dawood; investigation, R. Motloq; resources, R. Motloq; data curation, R. Motloq; writing—original draft preparation, R. Motloq; writing—review and editing, W. Khalil and E. Dawood; visualization, R. Motloq; supervision, W. Khalil and E. Dawood; project administration, W. Khalil and E. Dawood. All authors have read and agreed to the published version of the manuscript.

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#### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

#### Conflicts of interest

The authors declare that there is no conflict of interest.

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