



## **MECHANICAL PROPERTIES OF CONCRETE WITH RECYCLED SHREDDED RUBBER PARTICLES**

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**Abstract:** The waste tires from vehicles are continually increasing in the world and disposal of waste tires has become a global problem and required to find an adequate recycling system. As a method of recycling of waste tires, rubber particles of tire can be used in concrete and it has become a preferable solution for disposing waste tires. The goal of this research is to study the mechanical properties of recycled shredded rubber particles extracted from scrap tires in concrete to introduce a sustainable waste management system and subsequently to reduce the use of non-renewable resources in concrete. In this paper, fine aggregates of concrete were partially replaced with recycled shredded rubber particles less than 5 mm in size. Concrete cylinders with different proportion of rubber up to 50% of fine aggregates by volume were prepared and tested under compression. Also, specimens without rubber were prepared and tested as control specimens. The compressive strength and elastic modulus of the specimens are analyzed to characterize the behaviour of concrete. Overall, increasing the content of shredded rubber decreased the strength and elastic modulus, however increased the ductility of failure. It seems 40% shredded rubber content is the maximum to be recommended for more in-depth studies. This is an on-going research and more results will be presented at the time of the conference.

### **1 INTRODUCTION**

Use of scrap tire particles in concrete is environmental friendly as it helps to reduce the use of natural resource for concrete and introduces the waste management of scrap tires. On the other hand, it will affect on the health of people and animals, if waste tire recycling process cannot be managed in a proper manner over the years. As a method of recycling of waste tire, rubber particles of tire can be used in concrete and it has become a preferable solution for disposing waste tires. Three different sizes of recycled tires can be normally taken into research as rubber powder (partially replace with cement), crumbed rubber less than 5 mm in size (partially replace with fine aggregates) and rubber chips larger than 5 mm in size (partially replace with course aggregates) in concrete.

Many researchers (e.g. Li et al., 2014, Bisht et al., 2017, Yousf et al., 2016, Atahan and Yucel 2012, and Blessen and Ramesh 2012) were involved to find the chemical and physical properties of concrete with recycled shredded rubber particles. Most of the studies have shown the reduction of compressive strength, tensile strength and the modulus of elasticity with an increment of shredded rubber in concrete mixture and on the other hand, increment of shredded rubber in concrete had improved the durability and freezing-thawing resistance of concrete. For example, Liu et al. (2016) experimented the mechanical and chemical properties of crumbed rubber concretes and found that 20% crumbed rubber in concrete were reduced the compressive strength by 3.9% and splitting tensile strength by 2.5% compared to the results of 0% crumbed rubber concrete sample but increased the durability, freezing-thawing resistance and sulfate resistance. However, the experimental results have shown that a 20% replacement of rubber could be the acceptable values of mechanical properties. Marie (2016) investigated the behavior of rubberized concrete when

increasing the rubber content using the Ultrasonic Pulse Velocity Test (UPV) with shredded rubber particle sizes 4.75 to 0.15 mm and designed to target the compressive strength 25MPa at 28 days. The results showed that the UPV values decreased with the increase of rubber particle and it was concluded that up to 25% replacement of shredded rubber for the concrete could get the acceptable range of compressive strength. Mendis et al. (2017) experimented the effect of rubber particles on the flexural behaviour of steel-reinforced crumbed rubber concrete beams using shredded rubber mix contained less than 4 mm rubber particle sizes and it was concluded that the failure patterns of the beams were very similar to the normal concrete beams and lower tensile strength with compared to the normal concrete.

Most of the experimental studies concluded that 20 to 25% crumb rubber (less than 5 mm in size) replacements by volume of fine aggregates provided the acceptable range of mechanical properties to the concrete. But, those were based on their results and still couldn't find the exact recommendation with detailed material proportions and recommended code of practice. Also, most of the previous researches have based on crumb rubber (less than 5 mm in size with almost round particles) and could see very less interest in investigating of the properties of shredded rubber concrete less than 5mm in size replace with fine aggregate. Hence, the focus of this study is to analyse the strength, stiffness, and energy absorption of shredded rubber concrete using deferent proportions of 0 to 50% rubber less than 5 mm in size replaced with fine aggregate to comprehend the definite shredded rubber proportion to the concrete.

## 2. EXPERIMENTAL PROGRAM

### 2.1 Specimen Layout

A total of 24 concrete cylinders (100 mm diameter and 200 mm height) was prepared and tested under compression loading. The replacement of fine aggregates from shredded rubber by volume was used to prepare concrete mix at different percentages of 0, 10, 20, 30, 40, and 50% (by volume of fine aggregates) as shown in Table 1. Four identical specimens were prepared in each group. The specimens without shredded rubber were designed as control specimens.

Table 1: Test matrix and mix proportions of concrete specimens

Group #	Specimen group ID	Shredded rubber content (%)	Water/cement ratio	Cement (Kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	Coarse aggregate (kg/m <sup>3</sup> )	Fine aggregate (kg/m <sup>3</sup> )	Shredded rubber (kg/m <sup>3</sup> )
1	R0	0	0.33	656.8	221.1	949.8	567.5	0.0
2	R10	10	0.33	656.8	221.1	949.8	510.7	16.9
3	R20	20	0.33	656.8	221.1	949.8	454.0	33.9
4	R30	30	0.33	656.8	221.1	949.8	397.2	50.8
5	R40	40	0.33	656.8	221.1	949.8	340.5	67.8
6	R50	50	0.33	656.8	221.1	949.8	283.7	84.7

### 2.2 Material Properties

General use Portland cement was used for this study. Fine aggregate (natural sand) with bulk density 1791 kg/m<sup>3</sup> and coarse aggregate having a maximum size of 12.5 mm with bulk density 1666 kg/m<sup>3</sup> were used. Shredded rubber particles were used for this study with bulk density 535 kg/m<sup>3</sup>. Figure 1 shows the shredded rubber particles used in this experimental program and Figure 2 shows the particle size distribution of shredded rubber, fine aggregates (sand), and coarse aggregates (gravel). The average particle size remained on the Sieve No. 04 was approximately 28 mm long. The figure shows that the shredded rubber used in this study had a gradation curve between the fine and coarse aggregates. A constant water cement ratio of 0.33 was considered for this experiment and the dosage of superplasticizer (PLASTOL 6400) 2 ml per 1 kg of cement was added to achieve the required workability for the mixture. The mix proportions of six groups are shown in Table 1.



Figure 1: Various sizes shredded rubber particles used in this study

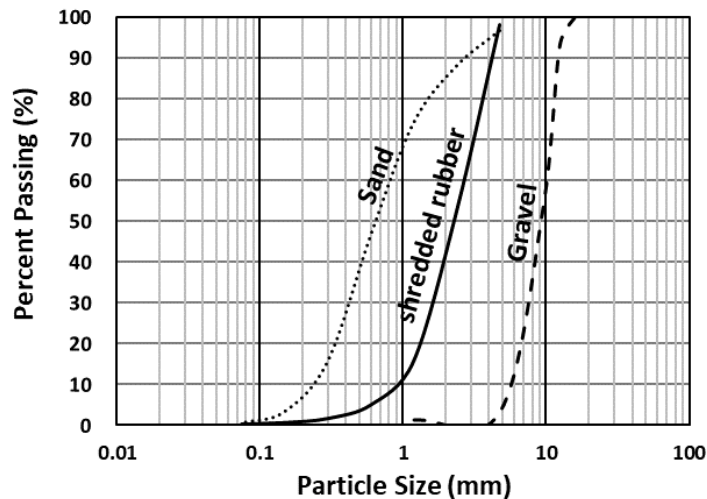


Figure 2: Particle size distribution of shredded rubber, fine aggregates, and coarse aggregates

### 2.3 Specimen Preparation

As shown in Figure 3, cylindrical plastic molds with a size of 100 mm diameter and height of 200 mm were used to cast all specimens. Since the two number of control specimens, 3.357 Kg coarse aggregates and 1.805 Kg fine aggregates (sand) added to the mortar mixing machine as shown in figure 3 and mixed around 2 minutes in dry condition. After that, 2.232 kg cement also added to the mixture and mixed another 1 to 2 minutes as required. Then, measured water 785ml added to the mixture regularly during operation of the mixing machine and 5ml superplasticizer also add to each mixture and continue another 2 to 3 minutes. The same procedure was followed for the all other mixtures with adding shredded rubber to the finer aggregate as specified in section 2.1 specimen layout. All concrete mixes were placed in cylinders which were already cleaned and applied mould oil, with three equal layers and compacted using 10 mm tamping rod each layer 25 times. Four specimens in each group were prepared. The samples were kept at curing room for 28 days. The density of each specimen was calculated by taken weight of each sample after 28

days dividing the volume of the specimen. specimens were weighed under dry condition after days. Calculated densities are tabulated in Table 2. Capping of the samples were done using sulfur mortar to give a smooth surface to concrete cylinders for applying compressive load.



Figure 3: Specimen preparation

With reference to the results taken from the average density, it could be clearly identified that the increment of shredded rubber in concrete mix had decreased the density of the concrete. The increment of the shredded rubber from 0% to 20% decreased the density  $2530.73 \text{ kg/m}^3$  to  $2441.76 \text{ kg/m}^3$  (3.52% decrease) also, the increment of the crumbed rubber from 0% to 50% decreased the density  $2530.73 \text{ kg/m}^3$  to  $2343.11 \text{ kg/m}^3$  (7.41% decrease). In addition to that, the results show, the density reduction rate has increased at 1.51%, 2.01% and 2.6% from R0 to R10, R10 to R20 and R20 to R30 respectively and from R30 to R50, the increment rate has decreased.

Table 2: Density of concrete specimens containing shredded rubber

Specimen ID	Average Density ( $\text{kg/m}^3$ )	Standard Deviation ( $\text{kg/m}^3$ )	Coefficient of Variation (%)	Density Reduction (%)
R0	2530.73	24.64	0.97	0.00
R10	2492.52	16.36	0.66	1.51
R20	2441.76	18.41	0.75	3.52
R30	2375.88	58.48	2.46	6.12
R40	2403.71	16.17	0.67	5.02
R50	2343.11	11.53	0.49	7.41

## 2.4 Test Setup and Instrumentation

The instrumentation setup for compression test was arranged as shown in figure 4. LP1 and LP 2 were fixed straight in the centre of the cylinder from  $180^\circ$  to measure the lateral strain during the test and LP3 and LP4 were fixed into the steel rings to measure the axial strain. These LPs were used to measure axial and lateral displacement during the test. The axial deformation referred to in this paper is the average value of the LP3 and LP4. The 100 mm gap between the two ring's center to center was maintained for each test. A steel cylinder was used to achieve the enough room for LP no. 03 and 04 during the test. The compressive strength test was done by minimizing the eccentricity as zero and the computer programmed to deform the

specimens at a rate of 0.4 mm per minute. The specimens were compressed until it did not seem safe to deform the specimen any further.

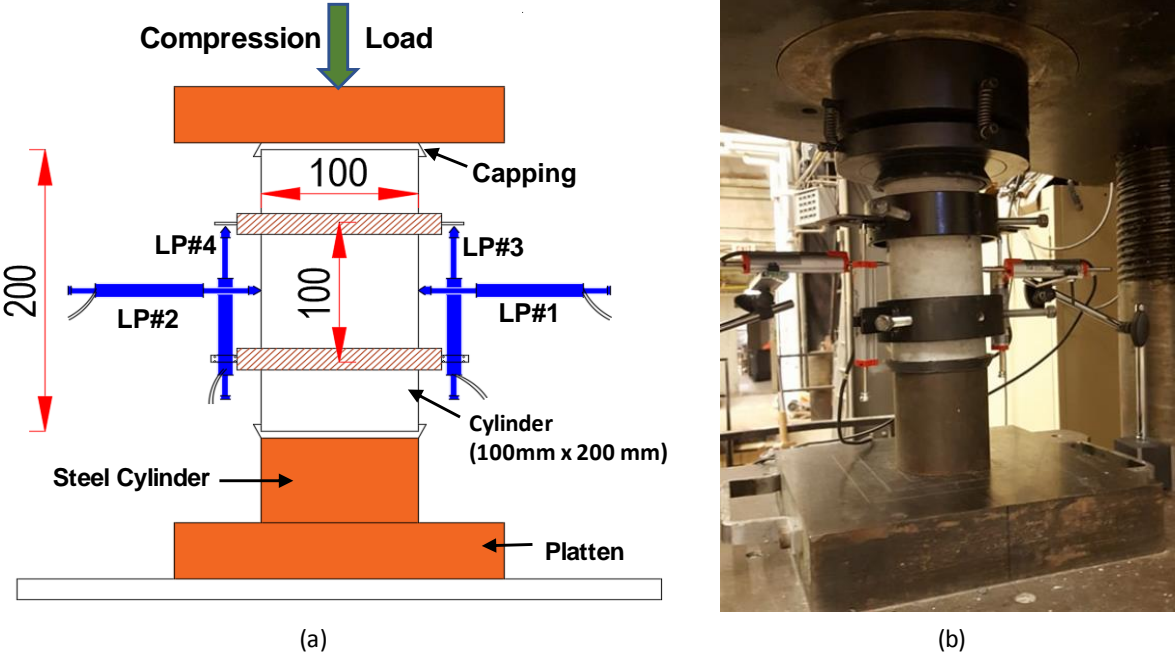


Figure 4: Test setup and instrumentation: (a) schematic of test setup and (b) photo of setup

**3. RESULTS AND DISCUSSION**

**3.1. Failure Modes**

Figure 5 shows the specimens failure modes after the tests. It should be noted that, the R0 cylinder (control) was failed as more brittle compared to the other specimens and behaviour of brittle failure was decreased with an increment of shredded rubber. The failure cracks were generated approximately in vertical direction for the specimens, but R50 specimen was shown the horizontal direction failure cracks too. Overall, increasing the shredded rubber content changed the mode of failure from typical diagonal cracks to a combination of longitudinal and transverse cracks. Three more specimens of each group will be tested to have a better understanding of the behavior of the specimens.

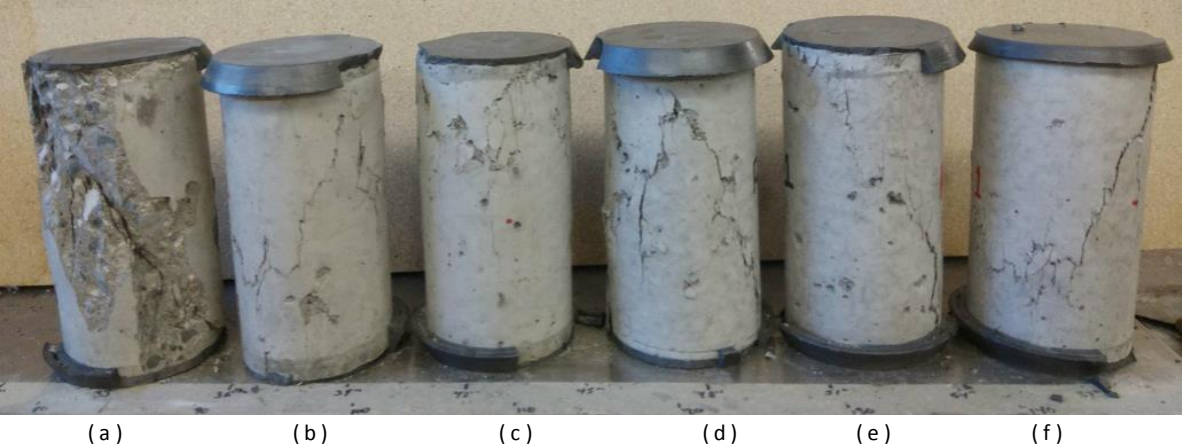


Figure 5: Failure mode of the specimens: (a) R0; (b) R10; (c) R20; (d) R30; (e) R40; and (f) R50

### 3.2. Effect of Shredded Rubber on Concrete Strength

Figure 6 (a) illustrates the effect of shredded rubber on concrete strength. The results generally show that the increasing of shredded rubber content in concrete decreased the compressive strength. Maximum compressive strength ( $f_c$ ) of concrete was reduced by 26.0%, 30.2%, 42.0%, 43.1% and 70.0% for the R10-1 (57.5 MPa), R20-1 (54.2 MPa), R30-1 (45.1 MPa), R40-1 (44.2 MPa) and R-50-1 (23.3 MPa) respectively compared to the control specimen R0-1 (77.7 MPa). Also, the maximum strength reduction for the R10-1 to R20-1 calculated as 5.7% compared to the R10-1 compressive strength and R20-1 to R30-1 calculated as 16.8% compressive strength reduction compared to the R20-1. As shown in Figure 6 (a), it seems there is a significant strength, drop after 40% shredded rubber content. So, 40% shredded rubber content might be considered as a maximum shredded rubber content. More specimens need to be tested to make a reliable recommendation.

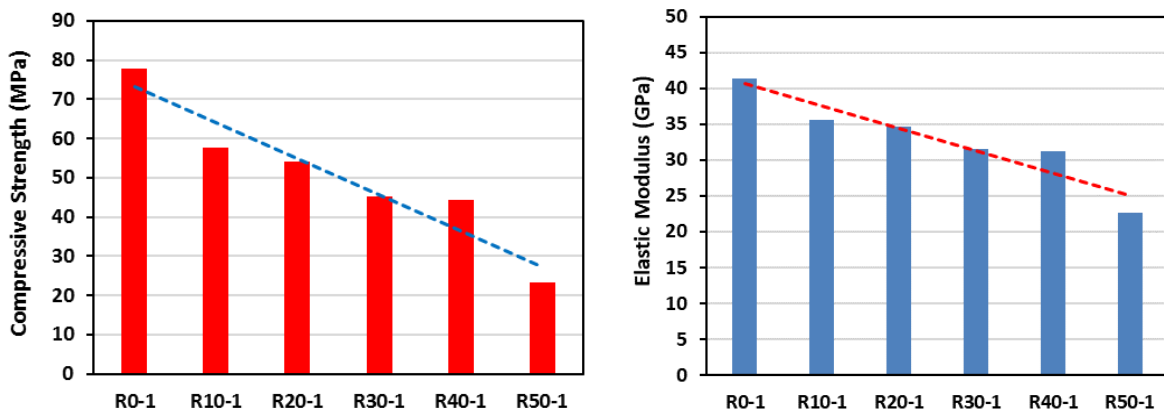


Figure 6: Effect of shredded rubber on: (a) concrete strength and (b) elastic modulus

### 3.3. Effect of Shredded Rubber on Concrete Elastic Modulus

The elastic modulus also has decreased due to the increment of the shredded rubber in concrete. The results in Figure 6 (b) show the elastic modulus of the test specimens obtained by fitting a straight line in the test data up to 45% of peak stress. The elastic modulus decreased by 14.0%, 16.4%, 23.7%, 24.6% and 45.2% for the R10-1 (35.6 GPa), R20-1 (34.6 GPa), R30-1 (31.6 GPa), R40-1 (31.2 GPa) and R-50-1 (22.7 GPa) respectively compared to the control specimen R0-1 (41.4 GPa). Similar to the compressive strength, it seems there is a significant elastic modulus drop after 40% shredded rubber content. More specimens need to be tested to make a reliable recommendation.

### 3.4. Effect of Shredded Rubber on Stress-Strain Curve

Figure 7 shows the stress-strain curves of the test specimens. The results show that the increasing of the shredded rubber content from 0 to 50% gives a lower slope (modulus) to the stress-strain curve with reducing the maximum axial stress (as explained above in section 3.2) and the strain at the peak stress. The specimen with 20% shredded rubber content showed a significant post peak behavior, indication the potential for higher energy absorption (area under the curve). Testing the rest of the specimens will provide a solid platform to evaluate the energy absorption capacity of the specimens. Moving forward in this research, concrete containing large quantity of shredded rubber can be used for cases under lateral confining pressure where the confinement can compensate the lack of strength due to shredded rubber. It has been shown that confinement is more effective on low strength concrete in comparison with high strength concrete (Sadeghian et al., 2008, Sadeghian and Fam 2015).

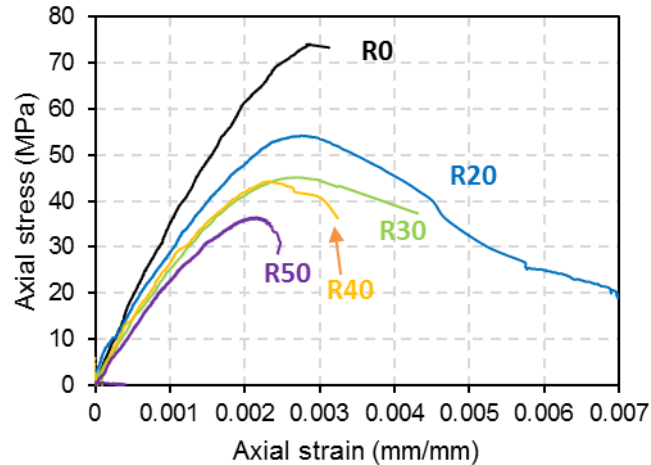


Figure 7: Stress-strain behavior of test specimens

#### 4. CONCLUSIONS

In this paper, the behaviour of concrete containing recycled shredded rubber particles was studied. Concrete cylinders (100 mm diameter and 200 mm height) were prepared by replacing of fine aggregates with shredded rubber at different percentages of 0, 10, 20, 30, 40, and 50% (by volume of fine aggregates) and tested under compression load. The results showed that the rubber weakened the compressive strength and elastic modulus of concrete. For example, the cylinders with 50% shredded rubber content lost 70.0% of compressive strength and 45.2% of elastic modulus, whereas the density decreased only 7.4%. It was observed during the tests that the brittle failure of control specimen was changed to less brittle failure with increasing the rubber content. Also, the failure patterns of the concrete from typical diagonal cracks was changed to a combination of longitudinal and transverse cracks. Considering the results of this experiment, the shredded rubber used for the partial replacement for natural fine aggregates up to 40% might be recommended in an acceptable range due to control specimen mixture design was targeted to achieve the compressive strength of 44 MPa. As this is an ongoing project, more tests are continuing to get the appropriate results considering the performance of different types of mechanical properties due to the increment of the shredded rubber in concrete. More results will be presented at the time of the conference.

#### 5. ACKNOWLEDGEMENTS

The authors are grateful for all the supports of the lab technicians (Brian Kennedy, Jesse Keane and Blair Nickerson) and students (Koosha Khorramian, Priyanka Garikapati and Mostafa Abyaneh) in conducting this study at Dalhousie University, Canada.

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