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## Experimental study of rubber particles from recycle tires as concrete aggregates

R Irmawaty<sup>1</sup>, H Parung<sup>1</sup> and N Md Noor<sup>2</sup>

<sup>1</sup> Department of Civil Engineering, Faculty of Engineering, Universitas Hasanuddin Jl. Poros Malino KM. 06 Bontomarannu, Gowa, 92171, Indonesia

<sup>2</sup> Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia 86400 Parit Raja, Batu Pahat, Malaysia

Email : rita\_irmaway@yahoo.co.id

**Abstract.** The Waste tire is one of the largest waste contributors. Due to the abundant amount of waste tires that would require the proper way to utilize waste tires as an aggregate replacement in concrete. Crumb rubber is a fiber-shaped material, which is produced from shred or scrap of post-used tires from trucks. Tire Chips is a material that consists of small pieces of waste rubber tires. This study explores the ameliorative effects of rubber particles on some properties of concrete. The objectives of this work is to present the mechanical properties of concrete (compressive strength, modulus of elasticity and split tensile strength) with variations of crumb rubber + tire chips 0%, 10%, 20% and 30% on fine and coarse aggregate volumes. Two types of rubber particles (crumb rubber and tire chips) have been used in the rubberized concrete mixtures replacing partially natural aggregates. Cylinder-shaped test object with 100 mm in diameter and 200 mm in length. Compressive strength testing was conducted at 3, 14 and 28 days. While the modulus of elasticity and split tensile strength were tested at 28 days. The results showed that the weight of the concrete volume decreased by 3.5% in each addition of 10% crumb rubber + tire chips. Compressive strength and split tensile strength decreased with increasing the number of crumb rubber + tire chips in concrete. The decrease in compressive strength was 24% on the addition of up to 10% crumb rubber + tire chips, while the split tensile strength decreased by 16%. Adding more than 10% of crumb rubber + tire chips to fine and coarse aggregate volumes is not recommended.

### 1. Introduction

With the increase in infrastructure development, environmental factors are also expected to get serious attention. The use of gravel and sand as concrete material which is a natural resource that cannot be renewed, so it is necessary to look for alternatives to these materials. One alternative is the use of aggregate from waste truck tire materials. Waste truck tires are one of the biggest waste contributors and this material cannot be biodegradable easily. If burned, there will be incomplete combustion which produces carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) which is very dangerous for health and the environment.

There are two sizes of cuts from truck tire waste, namely crumb rubber and tire chips. Crumb rubber is a fiber-shaped material, which is produced from shred or scrap of post-used tires from trucks. Tire Chips is a material which consists of small pieces of waste rubber tires with size 0.5 - 3 in. From its size distribution, crumb rubber can be categorized as fine aggregate and tire chips as coarse aggregates. In Indonesia, research related to rubberized concrete that utilizes tire waste as an aggregate

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substitute has not been done well. But in developed countries, a lot of research has been done to utilize the waste.

Divides used tires into four groups, namely : Large or rough (3/8 and 1/4 inches); Medium (10-30 mesh or 0.079 - 0.023 inches); Good (40-80 mesh or 0.016 - 0.007 inches); Very good (100-200 mesh or 0.006 - 0.003 inches) [1].

Tested the compressive strength and flexural strength of rubberized concrete. Use two types of gradations with different rubber volumes. The results showed that there was a decrease in compressive strength of about 65% when the fine aggregate was completely replaced by crumb rubber. In addition, the decrease in compressive strength is higher (75%) and 50% flexural strength when the coarse aggregate is completely replaced by the tire chips. Concrete containing rubber does not show brittle failure when testing compressive strength and flexural strength is carried out. An in-depth analysis shows good potential when using tire waste as a concrete mixture using Portland cement because it increases toughness to cracks. However, the right mix design is needed to optimize the volume of rubber in the concrete mixture.

Rubber waste was also investigated as aggregate substitution for concrete using Portland cement [3]. Two types of rubber tire waste used are crumb rubber as a fine aggregate replacement and chips as coarse aggregate substitutes. This study was divided into 3 groups. In the first group, only crumb rubber was used to replace fine aggregates. The second group, tire chips were used to replace coarse aggregates. In the third group, used crumb rubber and tire chips in the concrete mixture. In this group the volume of rubber is the same between the crumb rubber and the tire chip where the volume of rubber used by the three groups ranges from 5-100% of the aggregate volume. The results show that the use of crumb rubber / tire chips of more than 20% of aggregate volume causes a significant decrease in compressive strength.

Where the surface of crumb rubber is treated by immersing it in a solution of sodium hydroxide (NaOH), to increase the hydrophilicity of the rubber surface [4]. Assuming that sodium hydroxide will hydrolyze carboxyl and/or acid group on the rubber surface. Samples were tested after 28 days of curing. To determine the nature of the bond between the surface of rubber and cement, the micrograph of the sample was obtained using a SEM (Scanning Electron Microscope). The micrograph of the surface bond of the cement sample with 10% rubber indicates the area of rubber particles seems to have been pulled out. And this study also noted that with immersion of NaOH, rubber particles less attractive compared rubber that was not immersed in NaOH. Microscopic examination also showed that the presence of sodium hydroxide (NaOH) on the rubber surface could increase adhesion, flexural strength, modulus of elasticity, compressive strength, and abrasion resistance tests using samples which had been immersed with 10% NaOH.

Most of the previous research was carried out analytically and experimentally in the laboratory. The main finding is that rubber concrete has a decrease in compressive strength even though it can increase ductility. This study aims to determine the mechanical properties of waste rubber concrete using local materials and maximum volume that can be used in concrete.

## 2. Experimental Programs

Laboratory studies were carried out to evaluate compressive strength, elastic modulus and indirect tensile strength concrete containing crumb rubber.

### 2.1. Materials

Portland Composite Cement (PCC) that meets SNI 15-7064-2004 Indonesian cement production is available in the market is used as a binding material. Crushed stone (aggregate maximum size of 20 mm and a fineness modulus 6.72) and river sand (fineness modulus 2:56) meet standards SNI 03-1968-1990 for coarse and fine aggregate. Source of aggregate from the Jeneberang river, Bili-bili. table 1 presented the physical properties of aggregates.

**Table 1.** Aggregate physical characteristics.

Characteristics	Crushed stone	Sand river
Specific gravity		
Dry oven	2.49	2.40
Surface dry (SSD)	2.58	2.46
Water absorption, %	3.31	1.01

## 2.2. Specimen

Cylindrical specimens of 100 x 200 mm and beams of 100 x 100 x 400 mm were used in this study. Each type of test consists of 3 specimens. There are 4 variations of the design mix with 0%, 10%, 20% and 30% substitution of crumb rubber + tire chips on the fine aggregate and coarse aggregate volume, as presented in table 2. Crumb rubber and tire chips before mixed into the concrete immersed for  $\pm 30$  minutes in 10% NaOH solution. Tests carried out were compressive strength (3, 14 and 28 days), split tensile strength and elastic modulus (28 days) using Universal Testing Machine (UTM). The specimen is cured in fresh water until the age of testing.

**Table 2.** Mix design rubberized concrete (RC) in kg/m<sup>3</sup>.

Material	NC	RC-10	RC-20	RC-30
Water	230.82	230.82	230.82	230.82
Cement	450.00	450.00	450.00	450.00
River sand	547.36	519.99	492.62	465.25
Crushed stone	931.58	885.0	838.42	791.84
Crumb rubber	-	10.36	20.72	31.08
Tire chips	-	21.29	42.57	63.86

The crumb rubber used in this study passed No. 4 and retained on sieve No. 100. Whereas the tire chips passed the  $\frac{3}{4}$ " sieve and retain No. 4. Physical appearance of crumb rubber and tire chips can be seen in figures 1.

**Figure 1.** Crumb rubber, Tire chips and types of testing.

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## 3. Results and Discussion

### 3.1. Fresh concrete properties

The slump test measurement aims to determine the slackness of concrete mixtures, which can illustrate the workability of concrete to be stirred, transported, poured, and compacted without causing segregation of the constituent material. The results of slump testing is presented in table 3. Slump

values decreased with increasing percentage of crumb rubber and tire chips in concrete, but still met the slump test target of  $10 \pm 2$  cm.

**Table 3.** Slump value.

Name	Volume of rubber (%)	Slump (cm)
NC	0	12.5
RC-10	10	11.5
RC-20	20	10
RC-30	30	8.5

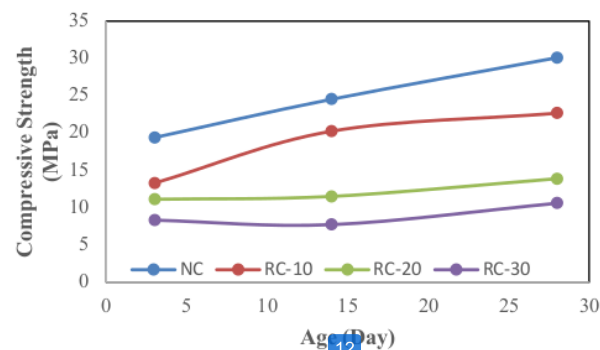
table 4 shows the weight of concrete which reduced by increasing the volume of crumb rubber + tire chips in concrete. However, the addition of crumb rubber and tire chips up to 30% does not change the type of concrete into lightweight concrete (weight between 1140 - 1840 kg/m<sup>3</sup> according to SNI 03-2847-2013).

**Table 4.** Weight of concrete.

Name	Volume of rubber (%)	Average weight of concrete (kg/m <sup>3</sup> )	Reduction (%)
NC	0	2299.36	-
RC-10	10	2255.84	1.89
RC-20	20	2158.17	6.14
RC-30	30	2094.48	8.91

### 3.2. Hardened concrete properties

Compressive strength testing was carried out at the age of 3 days, 14 days and 28 days using cylinders of size 100 mm x 200 mm. Every age of testing consists of 3 samples. The average compressive strength of all mixes is presented in figure 2. Compressive strength increases with age for all variations in the addition of crumb rubber + tire chips.



**Figure 2.** Compressive strength with variations in the addition of crumb rubber + tire chips.

In addition, the greater the addition of crumb rubber and tire chips in concrete, the lower the compressive strength of the concrete. Compressive strength decreased by an average of 24% with the addition of up to 10% crumb rubber + tire chips. If the addition of crumb rubber + tire chips is more than 20%, the compressive strength drops dramatically to 53%. Thus the addition of crumb rubber + tire chips is limited to 10% of the volume of sand and gravel. Decreased compressive strength may be caused by a lack of cohesion between the rubber surface with cement paste and bending properties of

the rubber. This can be seen in table 5 which illustrates the reduction of compressive strength at 28 days with variations in crumb rubber and tire chips.

**Table 5.** Compressive strength reduction with variations of rubber.

Name	Volume of rubber (%)	Compressive strength (MPa)	Reduction (%)
NC	0	30.099	-
RC-10	10	22.655	24.73
RC-20	20	13.878	53.89
RC-30	30	10.585	64.83

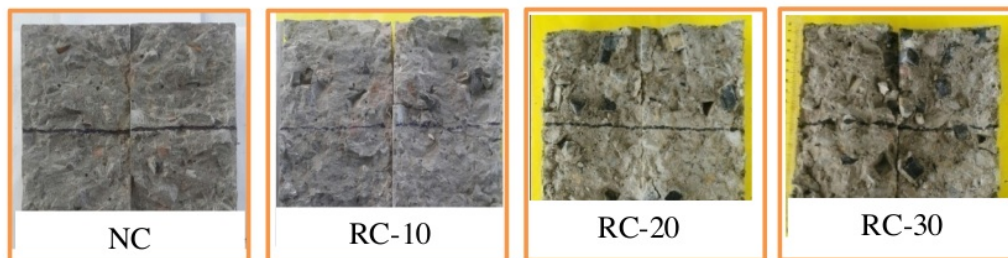
Rubber has a higher elasticity than hardened cement paste surrounding it, thus cracks will start from the interface between the rubber and cement paste, and then propagate. The higher the percentage of rubber in the concrete, the more cracks occurred and were interconnected, thereby reducing the concrete strength drastically.

The test of split tensile strength aims to determine the indirect tensile strength, carried out on 28-day-old specimens. The test results showed a decrease in split tensile strength by increasing the volume of crumb rubber and tire chips in concrete as shown in table 6. Addition of 10% crumb rubber + tire chips reduced split tensile strength by 16%. In addition, the addition of 20% crumb rubber and tire chips, tensile strength dropped dramatically to 40%, therefore it is not recommended to add more than 10% rubber.

**Table 6.** Indirect tensile strength reduction with variations of rubber.

Name	Volume of rubber (%)	Indirect tensile strength (MPa)	Reduction (%)
NC	0	3.115	-
RC-10	10	2.602	16.49
RC-20	20	1.842	40.87
RC-30	30	1.598	48.71

Visually observed the distribution of coarse aggregate on the surface of the specimens that have been split. Overall the specimen shows coarse aggregate and the tire chips spread evenly, as presented in figure 3.

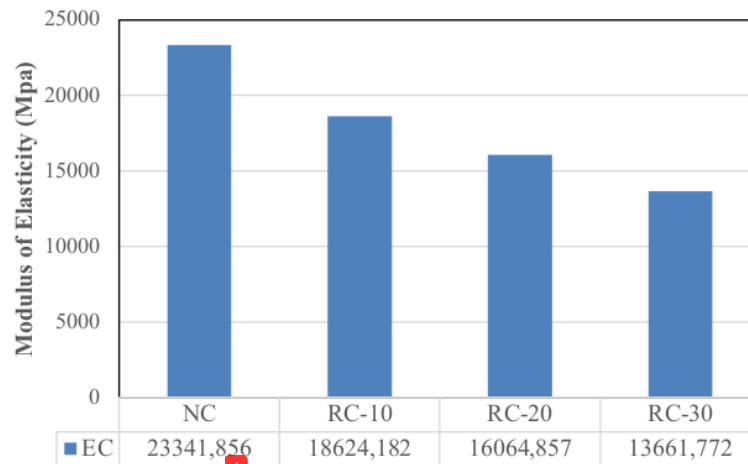


**Figure 3.** Spread of coarse aggregate and tire chips on concrete.

In addition, visually, the split surface of the concrete shows that no rubber is torn after splitting. If the rubber contributes to improve the strength of the concrete, then strength of bond between rubber and cement paste must be quite large. From the results of the observation, it was seen that rubber was released from the mortar bond when the specimen was cracked. It confirms that the surface of the rubber can easily be removed from the concrete paste and visible through the crushed concrete surface.

The interface between rubber and low concrete paste is low, when the concrete is split, the rubber are released from the concrete paste as seen in figure 3. Thus, concrete tire chips have lower tensile strength than normal concrete.

Modulus of elasticity decreased significantly along with the addition of the volume of crumb rubber and tire chips in the concrete mixture, as presented in figure 4.



**Figure 4.** The volume of crumb rubber and tire chips in the concrete mixture.

From the evaluation of mechanical behavior, overall, the addition of crumb rubber and tire chips is limited to 10% in concrete. Greater rubber addition, resulting in a significant reduction in strength.

#### 4. Conclusion

Based on the results and discussion, it can be concluded that the weight of the concrete volume decreased by 3% in each addition of 10% crumb rubber and tire chips. In addition, compressive strength, split tensile strength and elastic modulus also decreased with increasing volume of crumb rubber and tire chips. The reduction in compressive strength averaged 24% on the addition of 30% crumb rubber and tire chips, while the split tensile strength decreased by 16%. This is caused by the weak bond between the rubber surface and cement paste. Thus the addition of crumb rubber and tire chips more than 10% from aggregate volume is not recommended because it drastically reduces the strength of concrete.

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