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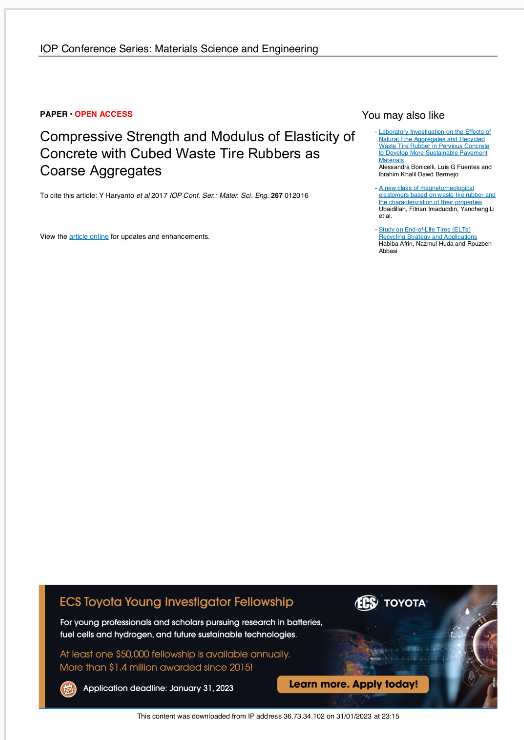
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Compressive Strength and Modulus of Elasticity of Concrete with Cubed Waste Tire Rubbers as Coarse Aggregates

Y Haryanto[1], N I S Hermanto[1], G Pamudji[1] and K P Wardana[1]
[1]Department of Civil Engineering, Faculty of Engineering, Jenderal Soedirman University, Jl. Mayjend Sungkono Km 5, Purbalingga, Indonesia

E-mail: yanuar_haryanto@yahoo.com

Abstract. One feasible solution to overcome the issue of tire disposal waste is the use of waste tire rubber to replace aggregate in concrete**.** We have conducted an experimental investigation on the effect of rubber tire waste aggregate in cuboid form on the compressive strength and modulus of elasticity of concrete. The test was performed on 72 cylindrical specimens with the height of 300 mm and diameter of 150 mm. We found that the workability of concrete with waste tire rubber aggregate has increased. The concrete density with waste tire rubber aggregate was decreased, and so was the compressive strength. The decrease of compressive strength is up to 64.34%. If the content of waste tire rubber aggregate is more than 40%, then the resulting concrete cannot be categorized as structural concrete. The modulus of elasticity decreased to 59.77%. The theoretical equation developed to determine the modulus of elasticity of concrete with rubber tire waste aggregate has an accuracy of 84.27%.

1. Introduction

One industry which has the potential for rapid development in Indonesia is the tire industry. The Indonesian tire industry experienced a 5% increase of tire sales, from 96.57 million units in 2012 to 101.43 million in 2013. This figure comprises car tire sales of 47.26 million units, and motorcycle tire sales of 54.16 million units [1]. This number is predicted to increase continuously and rapidly [2], while only a small portion of waste tire is regularly discarded. Meanwhile, more than 50% of tire waste is disposed of without special treatment [3]. Tire waste disposal has become a major environmental issue in major cities around the world. The easiest and cheapest way to dispose the waste is by burning, but the pollution generated makes it unacceptable and it is prohibited by law in some countries. It is estimated that approximately one billion tires are withdrawn from global use annually [4-6].

One feasible solution to overcome those problems is the use of waste tire rubber to replace aggregate in concrete. Several researchers who have investigated the use of waste tire rubber as an aggregate replacement in concrete reported that it reduces compressive strength [7-9] due to poor adhesion of the waste rubber tire aggregate to cement paste [3]. Treatment with a different method to increase the adhesion of the tire rubber waste aggregate has also been studied [10, 11]. In another study, it was suggested that concrete with waste tire rubber aggregate of a certain size may reach a compressive strength of 20 MPa at a water–cement ratio of 0.35 [12] and it also showed improved

[1] To whom any correspondence should be addressed.

post-cracking behaviour, although its bond strength didn't differ significantly from normal concrete in pull-out test results [13].

As a heterogeneous multiphase material, concrete is a mixture of cement paste and fine and coarse aggregates, with a range of sizes and shapes. With regard to its mechanical behaviour, concrete is often considered to be a three-phase composite structure, consisting of aggregate particles, the cement paste matrix in which they are dispersed, and the interfacial transition zone (ITZ) around the aggregate particles and cement paste [14]. In some applications of concrete, it is demanded that concrete should have low unit weight, high strength, high toughness and high impact resistance. Although concrete is the most commonly used construction material, it does not always fulfil these requirements [15]. One of the ways to improve these properties might be the addition of the rubber into concrete as an aggregate. The objectives of this work are to complement previous studies by discussing the effect of waste tire rubber aggregate in cuboid form on the compressive strength and concrete elasticity modulus.

2. Experimental Work

The materials used for the concrete mixture were cement type 1, fine aggregate such as sand from Mount Merapi in Yogyakarta, and coarse aggregate from local stone crushers in Purbalingga. Fine aggregate should have the specific gravity of 2.62 with a fine modulus of 3.07. The coarse aggregate had a specific gravity of 2.69 with a 20 mm maximum size of aggregate. The waste tire rubber as a replacement for coarse aggregates was made in cuboid form (Figure 1), and had a specific gravity of 1.00 with a size variation of 5 mm, 10 mm, 15 mm and 20 mm. The substitution percentage in each specimen varied between 0%, 20%, 40%, 60%, 80% and 100%. The composition of the concrete mixture was named according to the content of waste tire rubber aggregate, as presented in Table 1.

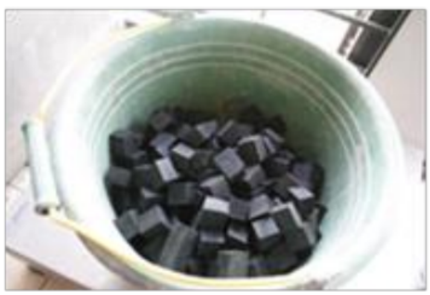

Figure 1. Waste tire rubber aggregate.

Table 1. Composition of concrete mixture.

Code	Aggregate variation	Material Requirement				
		Cement (kg)	Water (kg)	Gravel (kg)	Sand (kg)	Rubber (kg)
A	0%R, 100%C	405	210	1059	706	0
B	20%R, 80%C	405	210	847	706	79
C	40%R, 60%C	405	210	635	706	159
D	60%R, 40%C	405	210	423	706	238
E	80%R, 20%C	405	210	211	706	318
F	100%R, 0%C	405	210	0	706	397

%R: Rubber content, %C: Course aggregate content

To check the concrete-mixture workability, a slump test was used as shown in Figure 2. The slump test was conducted according to SNI 1972: 2008 [16]. The compressive strength test and modulus of

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elasticity test were conducted at 28 days on 72 cylindrical test specimens with the height of 300 mm and diameter of 150 mm in accordance with SNI 1974: 2011 and SNI 03-4169-1996 [17, 18]. The concrete compressive strength was determined with an experiment using (1), while the modulus of elasticity of concrete was determined with an experiment and empirical test [19] based on (2) and (3).

$$f_c^{'} = \frac{P}{A} \tag{1}$$

$$E = \frac{S_2 - S_1}{\varepsilon_s - 0.00005} \tag{2}$$

$$E = W_c^{1.5} \; x \; 0.043\sqrt{f_c^{'}} \tag{3}$$

in which:

$f_c^{'}$ = Compressive strength (MPa)
P = Maximum load (N)
A = Area of specimen (mm^2)
E = Modulus of elasticity (MPa)
S_1 = Stress when the load reaches 40% of the maximum load (MPa)
S_2 = Stress when the contraction reaches 0.00005
ε_1 = Strain corresponding to the stress S_1 (MPa)
W_c = Unit weight of concrete (kg/m^3)

Figure 2. Slump test.

3. Results and Discussion

3.1. Workability

The workability property of the fresh concrete produced from the slump test is shown in Figure 3. Waste tire rubber aggregate has a poor interlocking action with cement paste [20] and causes the concrete mix to become more diluted, hence the slump value for each content of waste tire rubber aggregate increased. The slump values for all the concrete mixtures ranged between 125–151 mm.

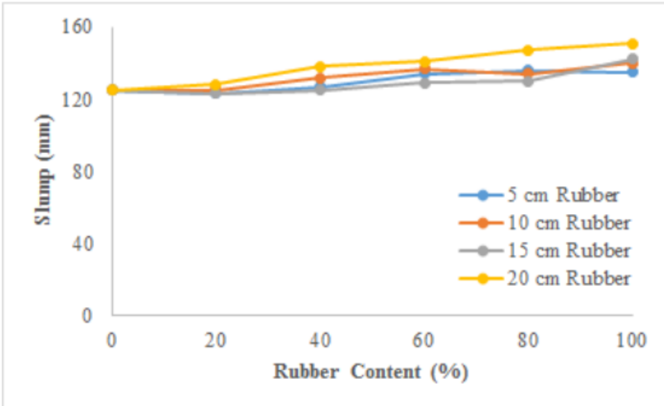

Figure 3. Workability.

3.2. Density

Figure 4 shows the average density at 28 days of the specimens that were prepared for the compressive strength test and modulus of elasticity. As shown in the below figure, the density decreased with the addition of tire rubber waste aggregate. The decrease in density was caused by the low specific gravity of waste tire rubber aggregate [9]. A decrease in density can be expected in the utilization of concrete with waste tire rubber aggregate for architectural applications such as interior construction [21].

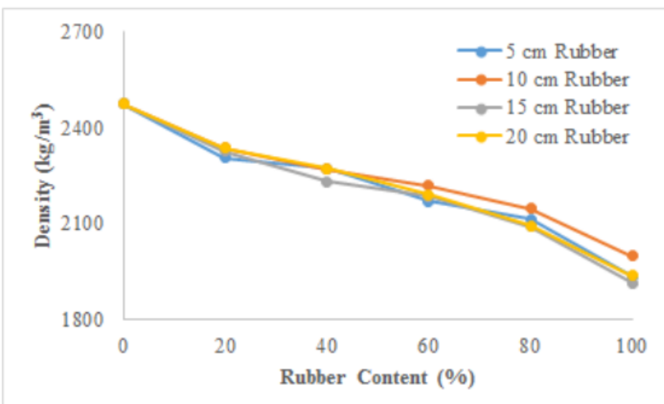

Figure 4. Density.

3.3. Compressive Strength

The increased content of waste tire rubber aggregate caused the compressive strength to decrease as shown in Figure 5. The rubber particles were much softer than the cement matrix around the rubber, so the stress was centered on the part that led to cracks at the rubber and cement interface at the time of loading [10]. The cracks that occurred subsequently spread and caused a loss of strength and eventual failure. Furthermore, the use of softer waste tire rubber aggregate led to decrease strength because the concrete compressive strength was strongly influenced by the aggregate properties. If the content of waste tire rubber aggregate is more than 40%, then the resulting concrete cannot be categorized as structural concrete. The biggest decrease of compressive strength occurred in the concrete with 100% rubber, with the size of 20 mm, i.e. equal to 64.34%.

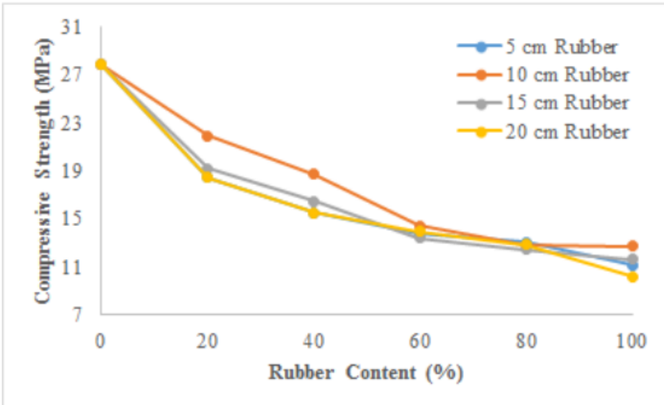

Figure 5. Compressive strength.

3.4. Modulus of Elasticity

Because concrete with waste tire rubber aggregate has a lower compressive strength and there is a relation between the compressive strength and modulus of elasticity, it can be predicted that the concrete will also have a lower modulus of elasticity as shown in Figure 6. The below behaviour can be explained in connection with the lower modulus of elasticity of rubber [22]. The largest decline of modulus of elasticity occurred in concrete with 100% rubber in the form of 5 cm cuboids, i.e. equal to 59.77%. The theoretical modulus of elasticity based on (3) was higher than the modulus of elasticity of the experimental result. The development of (3) resulted in (4) with an accuracy of 84.27% as shown in Figure 7.

$$E = W_c^{1.5} \ x \ 0.0349\sqrt{f_c^{'}} + 1144 \quad (4)$$

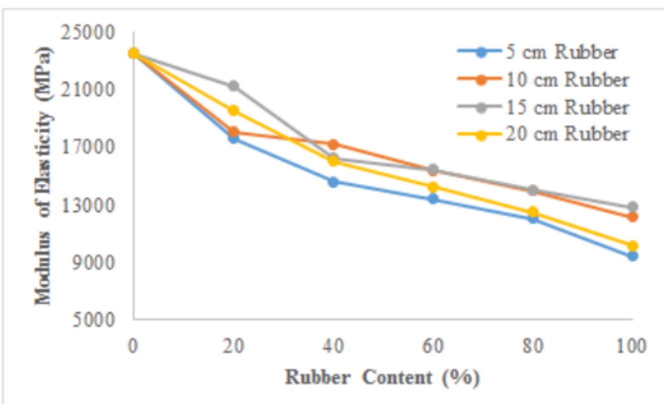

Figure 6. Modulus of elasticity.

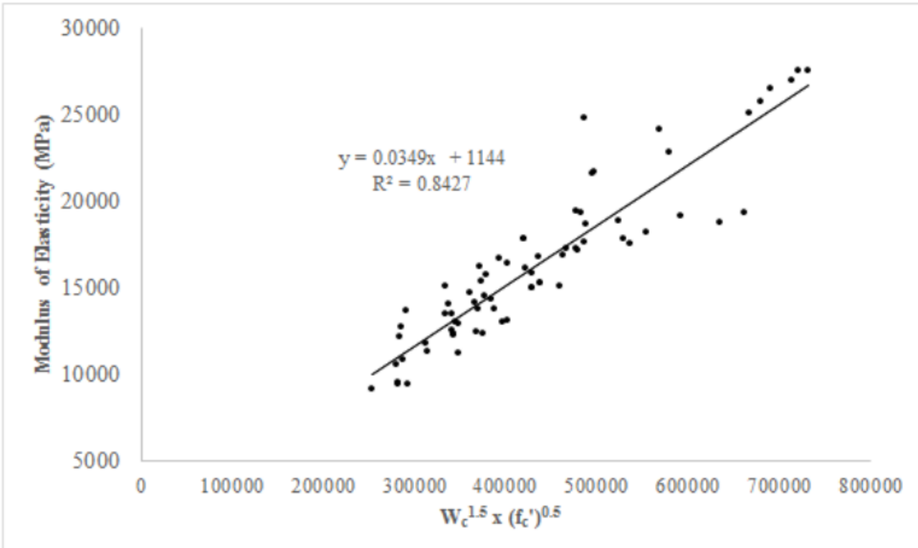

Figure 7. Development of a new theoretical modulus of elasticity equation.

4. Conclusion
Based on the above results, we concluded that:

a. Workability increased with a range of slump values between 125 mm and 151 mm. On the other hand, the density decreased due to the low specific gravity of waste tire rubber aggregate.
b. The compressive strength decreased to 64.34%. If the content of waste rubber tire aggregate is more than 40%, the resulting concrete cannot be categorized as structural concrete.
c. The elasticity modulus decreased to 59.77%. The theoretical equation developed to determine the concrete elasticity modulus with waste rubber tire aggregate had an accuracy of 84.27%.

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