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Feasibility of crumb rubber as fine aggregate in concrete

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Abstract. Production of tires in Indonesia increase steadily, however, utilization of waste tires is very limited. Thus, it is necessary to look for an alternative using waste tires for concrete construction. The objectives focus on using crumb rubber as a waste tire with variations in substitution of crumb rubber to fine aggregate in the concrete of 0%, 10%, 20%, and 30%. In addition, to improve crumb rubber bonding to the concrete mixture, 10% NaOH solution was used. This research is true experimental by making a concrete mixture with a target strength of 20 MPa. The compressive strength testing was conducted at 3, 14, and 28 days, while for splitting test and modulus of elasticity at 28 days. The result showed that each addition 10% of crumb rubber, the weight of concrete volume decreased by 3 %. Compressive strength and splitting strength also decreased with increasing crumb rubber volume. Every 20% addition of crumb rubber, the compressive strength decreased of 26%, while the splitting strength decreased by 10%. The substitution of crumb rubber more than 20% of the volume of fine aggregate is not recommended.

1. Introduction

The use of solid waste as a material substitution in the concrete industry is not new. However, the use of solid waste as an aggregate substitute for concrete in recent years has been increasing as a promising solution to reduce inorganic solid waste. One example of inorganic waste is rubber tire waste from used truck tires.

Crumb rubber is a material produced from scrap or small pieces of used truck tires. From its size distribution, crumb rubber can be categorized as fine aggregate. In Indonesia, research related to rubberized concrete that utilizes tire waste as an aggregate substitute has not been widely used. But in developed countries, a lot of research has been done to utilize the waste.

Grinys et al. (2012) explained that the effect of adding crumb rubber on concrete reduced the compressive strength, bending and tensile strength of the concrete when the substitution of crumb rubber was more than 30% even though crumb rubber possessed elastic, easily formed, and flexible properties. The testing of flexural strength on crumb rubber concrete 7% increased but when the crumb rubber used was more than 30% it greatly reduced the flexural strength of the concrete compared to its compressive strength.

Eldin et al. (1993) tested the compressive strength and flexural strength of a rubberized concrete mixture. Use two types of gradations with different rubber volumes. The results showed that there was a decrease in compressive strength of 85%, while the flexural strength of 50% when coarse aggregate was completely replaced by a tire chip. The decrease in compressive strength is smaller (65%) when the



fine aggregate is completely replaced by crumb rubber. Concrete containing rubber does not show brittle failure when compressive testing 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, it takes a mix design that can optimize the volume of rubber in the mixture.

Research conducted by Segre et al. (2000) 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. It is assumed that by doing this, sodium hydroxide will hydrolyze the acid and / or carboxyl groups that are on the rubber surface (Smith, et al, 1995). Samples were tested after 28 days of curing. To determine the bond between the surface of the rubber and cement, the micrograph of the sample was obtained using 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. The study also noted that with immersing in NaOH, rubber particles were less attractive than rubber which 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 in 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 behaviour of concrete crumb rubber using local materials and a maximum volume that can be used in concrete. It will also be explored the possibility of the practical application of rubber concrete using local materials.

2. Experimental programs

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

2.1. Materials

Portland Composite Cement (PCC) that meets SNI 15-7064-2004 Indonesian cement production and is available in the market is used as a binding material. Some of the oxide components used in this study are presented in table 1.

Table 1. Components of PCC cement oxide.

Oxide Component	SNI 15-7064-2004	PCC
	Standard	Interval
MgO	6.0 max	0.97
SO ₃	4.0 max	2.16
Loss of Ignition	5.0 max	1.98

Crushed stone (MSA 20 mm and modulus roughness of 6.72) and river sand (fineness modulus of 2.56) meet SNI 03-1968-1990 standards for coarse and fine aggregate. An aggregate sourced from the Jeneberang river, Bili-Bili. Table 2 illustrates the physical properties of aggregates.

Table 2. Aggregate physical characteristics.

Characteristics	Crushed stone	Sand river
Specific gravity	Dry oven	2.49
	Surface dry (SSD)	2.58
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 mixture with crumb rubber substitution of 0%, 10%, 20% and 30% to the fine aggregate volume, as presented in table 3. Crumb rubber before being mixed into the concrete immersed for ± 30 minutes in 10% NaOH solution. Tests carried out were compressive strength (3, 14 and 28 days), split tensile strength, elastic modulus and flexural strength (28 days). The specimens are cured in tap water until the age of testing.

Table 3. Mix design of concrete (kg/m³).

No.	Materials	NC	NCR-10	NCR-20	NCR-30
1	Water	230	230	230	230
2	Cement	450	450	450	450
3	Sand	547	492	437	383
4	Crushed stone	931	931	931	931
5	Crumb rubber	-	21	42	63

Crumb rubber, in general, has a modulus of elasticity ranging from 0.77 - 1.33 MPa and a low density of 1.08 - 1.27 t / m³. The crumb rubber used in this study passed No. 4. The physical appearance of the crumb rubber is shown in figure 1.

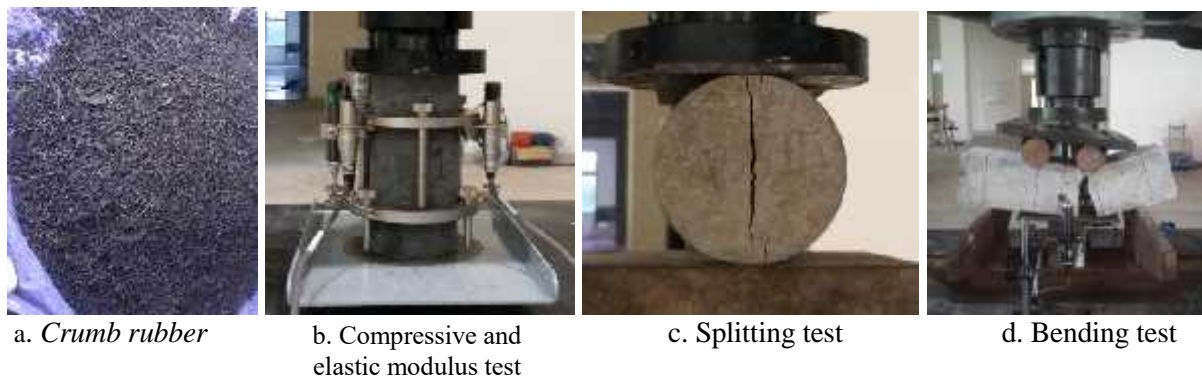


Figure 1. Crumb rubber and type of testing.

3. Results and discussion

3.1. Fresh concrete properties

Workability of fresh concrete was tested by slump tests and the results can be seen in table 4. Slump values decreased with an increasing percentage of crumb rubber in concrete, but still met the slump test target of 10 ± 2 cm.

Table 4. Slump value.

Name	Volume of Crumb Rubber (%)	Slump (cm)
NC	0	10
NCR-10	10	10
NCR-20	20	9,5
NCR-30	30	8

Table 5 shows the weight of concrete, which decreases with the increasing volume of crumb rubber in concrete. However, the substitution of crumb rubber up to 30%, it cannot be categorized as lightweight concrete with a weight between 1140 - 1840 kg/m³ (SNI 03-2847-2013).

Table 5. Weight of concrete.

Name	Average weight (kg/m ³)	Reduction (%)
NC	2299.36	-
NCR-10	2283.44	0.69
NCR-20	2228.24	3.09
NCR-30	2141.19	6.88

3.2. Hardened concrete properties

The strength of concrete is generally represented by compressive strength. Compressive strength testing aims to determine the strength of concrete at ages 3, 14, and 28 days with the substitution of crumb rubber. Testing is done by Universal Testing Machine (UTM) with a capacity of 1000 kN. Compressive strength increases day by day for all variations of crumb rubber substitution, as shown in figure 2. Increasing compressive strength occurs as a result of the hydration process that runs well where the concrete is cured in water until the age of testing.

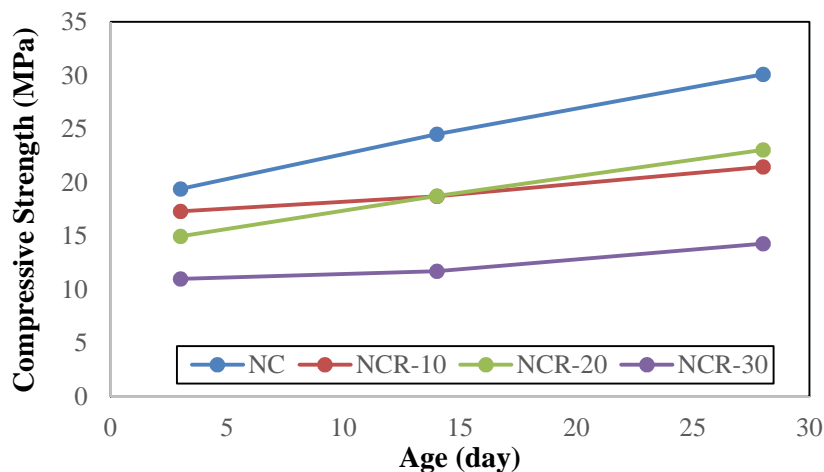


Figure 2. Compressive strength with variations of crumb rubber substitution.

On the other hand, the higher the substitution of crumb rubber, the lower the value of concrete compressive strength. The average compressive strength decreased by 26% with the substitution of crumb rubber up to 20%. If crumb rubber substitution is more than 20%, the compressive strength drops dramatically to 52%. Thus, the substitution of crumb rubber is limited to 20% of the volume of sand. Decreased compressive strength may be caused by a lack of coherence between the rubber surface with cement paste and the elasticity of rubber.

Indirect tensile strength is carried out after the specimen 28 days. The test results show a decrease in split tensile strength as the volume of crumb rubber in concrete increases, as shown in figure 3. Addition of crumb rubber 10% and 20% reduces split tensile strength by 10%. But the addition of 30% crumb rubber, tensile strength decreased by 34%. Thus it is not recommended to add more than 20% crumb rubber.

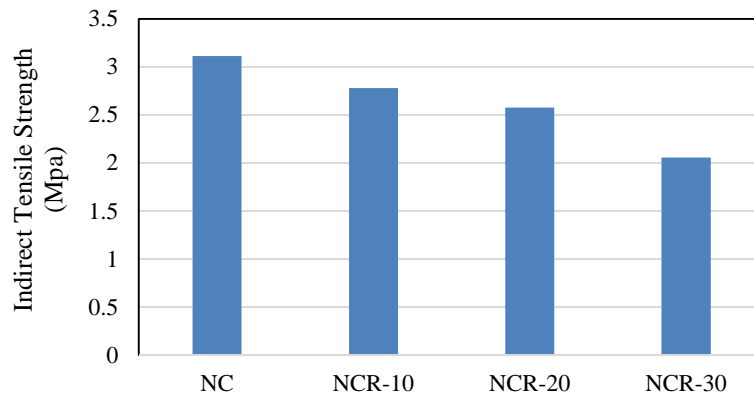


Figure 3. Indirect tensile strength with variations of crumb rubber substitution.

The modulus of elasticity follows the trend of concrete compressive strength, where the higher the substitution of crumb rubber, the lower the modulus of elasticity of concrete. Theoretically, the modulus of elasticity can be calculated based on concrete weight and compressive strength. The results show that the modulus of elasticity from experimental and theoretical is almost the same, as presented in table 6.

Table 6. Modulus of elasticity of crumb rubber concrete.

Name	Volume of <i>Crumb Rubber</i> (%)	Modulus of Elasticity (MPa)	
		Experimental	Theoretical
NC	0	23341.856	26011.091
NCR-10	10	19710.981	21734.551
NCR-20	20	19301.876	21716.262
NCR-30	30	15179.139	16102.838

Figure 4 shows that the higher the volume of crumb rubber in concrete, the flexural strength decreases. However, with 10% crumb rubber substitution (NCR-10), the flexural strength is higher than NC. Observations were also conducted on the deflection during loading. The largest deflection was experienced by NCR-10 of 1,012 mm greater than the deflection experienced by NC (0.778 mm), NCR-20 (0.616 mm) and NCR-30 (0.608 mm). Observation of the collapse pattern shows a collapse occurring in 1/3 of the span. This indicates that the presence of crumb rubber in concrete can develop resistance to bending, and does not occur in shear failure. Also, concrete containing crumb rubber does not show brittle collapse when compressive testing strength and flexural strength is carried out.

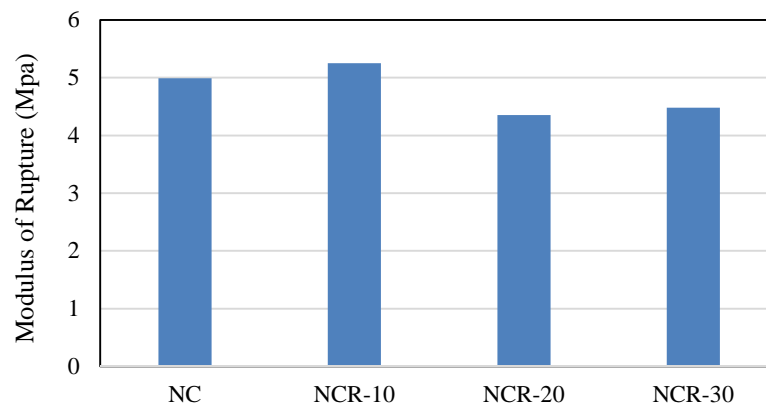


Figure 4. Flexural strength with variations of crumb rubber substitution.

4. Conclusion

Based on the results and discussion, it can be concluded that the weight of the concrete decreased by 3% in each addition of 10% crumb rubber. Compressive strength, split tensile strength, and modulus of elasticity also decreased with the increasing volume of crumb rubber in concrete. The decrease in compressive strength was 26% with substitution of 20% crumb rubber, while split tensile strength decreased by 10%. The modulus of rupture above 4 MPa for all specimens shows high bending ability. Overall, crumb rubber concrete is feasible to develop, especially for flexible loads with 20% substitution of the fine aggregate volume.

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