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Utilization of tire chips as a substitute for coarse aggregate in concrete

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Abstract. Tire chips are produced from the material shred or small pieces of truck tires into a size 0.5 - 3 in. Waste tires increase and are not easily biodegradable in environmental pollution, therefore it is necessary to pay special attention to the environment by using waste tires as an aggregate substitute in concrete. The objectives of this research are to determine the mechanical properties (compressive strength, splitting tensile strength and modulus of elasticity) of concrete by use tire chips of 0%, 10%, 20% and 30% as a substitute of coarse aggregate. Cylinder specimens with a diameter of 100 mm and a height of 200 mm. Compressive strength testing was conducted at 3, 14 and 28 days. While the modulus of elasticity and splitting tensile strength was conducted at only 28 days. The results show that the weight of concrete volume decreases 3% on each additional 10% of tire chips. Compressive strength and splitting tensile strength also decreased with increasing content of tire chips. A decrease in the average compressive strength of 18% in addition to 10% of tire chips, while the splitting tensile strength decreased by 26%. Modulus of elasticity follows the trend of concrete compressive strength and its value is almost equal between experimental and theoretical. The substitutions of tire chips more than 10% of the volume of coarse aggregate is not recommended.

1. Introduction

Used truck tires cause serious environmental problems and the number continues to increase every year. Although most of it is recycled into furniture, but cannot cope with the number of stacking tires continues to increase. Stacking of used truck tires can be a place for mosquitoes to breed that causes health problems. In addition, tire waste cannot biodegrade easily biologically.

The use of natural aggregate as a mixture of concrete material has begun to be significantly limited to maintaining the balance and exploitation of non-renewable natural resources. Making use of waste tires as a substitute material coarse aggregate in the concrete mix can be considered, in addition to reducing environmental pollution caused by the disposal of waste tires.

Tire chips are produced from the material snag or small pieces of used truck tires into a size 0.5 - 3 in. From its size distribution, the tire chip can be categorized as coarse aggregate. In Indonesia, research related to rubberized concrete that utilizes tire waste as an aggregate replacement has not been done well. But in developed countries, a lot of research has been done to utilize the waste.

The research conducted by Eldin, et al. (1993) used tire waste as a chip and crumb rubber as an alternative aggregate to investigate the compressive strength and tensile strength of concrete. The results show that there is an 85% decrease in compressive strength and 15% in tensile strength when the volume of coarse aggregate is completely replaced by the equivalent volume of the chip tire; but by replacing fine aggregates with crumb rubber with the same volume, there will be a reduction of up to 65% in compressive strength and 50% in tensile strength. Concrete containing rubber does not show brittle collapse 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, mix design is needed that can optimize the volume of rubber in the mixture.

Khatib et al. (1999) studied the effect of adding two types of rubber, Crumb (for substitute sand) and Chip (at sizes 10-50 mm for a substitute for gravel). The results show that rubber concrete made with a tire chip has a lower strength than concrete made with crumb rubber.

Segre et al. (2000) added rubber particles to cement paste (rubber particles have a size of maximum 50 µm). To reduce hydrophobicity on the rubber surface, a solution of sodium hydroxide (NaOH) is used to immersed rubber particles. Assuming that sodium hydroxide will hydrolyze carboxyl and/or acid groups on the rubber surface (Smith, et al, 1995). 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 the study also noted that with NaOH immersion, the rubber particles have less traction than the rubber that is 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.

Most of the previous research was carried out analytically and experimentally in the laboratory. The main finding is that the tire chip has decreased in compressive strength even though it can increase ductility. This study aims to see the opportunity to use tire chips as a substitute for coarse aggregate and maximum volume that can be used in concrete. Whether the tire chip is suitable for a variety of practical applications will still be explored using local materials.

2. Experimental programs

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

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 fineness modulus 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	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. Four variations of the mixture with tire chips substitution of 0%, 10%, 20% and 30% to the coarse aggregate volume, as presented in table 3. Tire chips 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) using Universal Testing Machine (UTM) 1000 KN capacity. The specimens are cured in tap water until the age of testing.

Table 3. Mix design of concrete (kg/m^3).

Materials	NC	NTC-10	NTC-20	NTC-30
Water	230	230	230	230
Cement	450	450	450	450
Sand	547	547	547	547
Crushed stone	931	838	745	652
Tire Chips	-	42.5	85.0	127.5

Tire chips generally have a modulus of elasticity ranging from 0.77 - 1.33 MPa and a low density of 1.08 - 1.27 t/m^3. Tire chips are used in this study passed the sieve ¾ "and retain in sieve No. 4. The physical appearance of the chip tire and type of testing is shown in figure 1.

a. *Tire Chips* b. Compressive and elastic modulus test c. Splitting test d. Bending test

Figure 1. Tire chips and type of testing.

3. Results and discussion

3.1. Fresh concrete properties
Slump test was performed to determine the level of viscosity of the concrete, which can describe the ease of workmanship (workability) of concrete without causing segregation in concrete. The greater the addition of tire chips to the concrete mixture, the lower the workability of the concrete. But overall, it still meets the slump test value limit for concrete, which is 10 ± 2 cm, as shown in table 4.

Table 4. Slump value.

Name	Volume of Tire Chips (%)	*Slump* (cm)
NC	0	10
NTC-10	10	10
NTC-20	20	9,5
NTC-30	30	8

Table 5 shows the weight of concrete, which decreases with the increasing volume of tire chips in concrete. However, the substitution of tire chips up to 30%, it cannot be categorized as lightweight concrete with a weight between 1140 - 1840 kg/m^3 (SNI 03-2847-2013).

Table 5. Weight of concrete.

Name	Average weight (kg/m^3)	Reduction (%)
NC	2309.271	-
NTC-10	2218.33	3.94
NTC-20	2162.774	6.34
NTC-30	2098.018	9.15

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 (compressive strength) at the age of 3, 14, and 28 days with the addition of tire chips. Compressive strength increases with increasing age for all variations in chip tire substitution. This is due to the hydration process in the cement paste, which runs well and strengthens the bond between the materials. But the addition of the volume of the chip tire will significantly reduce the compressive strength of the concrete as presented in table 6. The addition tire chips more than 10%, the compressive strength dropped dramatically to 49%. Therefore, the substitution of tire chips is limited to only 10% of the coarse aggregate volume.

Table 6. Compressive strength with variations in substitution of tire chips.

Name	Volume *tire chips* (%)	Compressive Strength at 28 days (MPa)	Reduction (%)
NC	0	33.380	-
NTC-10	10	27.086	18.39
NTC-20	20	16.743	49.64
NTC-30	30	16.338	52.49

Rubber has a higher elasticity than hardened cement paste surrounding it. Thus cracks starts from the interface between the rubber and cement paste, and then propagate. Due to the lack of cohesion between rubber and cement paste, soft rubber particles will be considered as a void in concrete. The higher the percentage of rubber as a coarse aggregate substitute, the higher the pore produced.

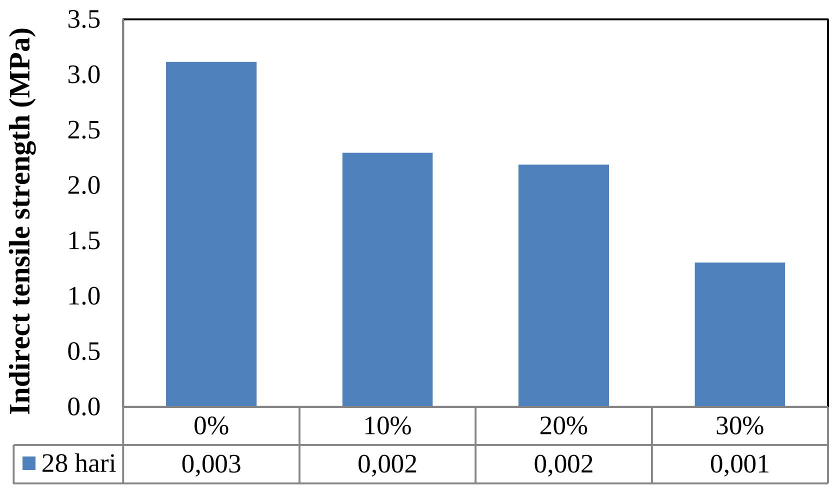

Figure 2. Indirect tensile strength with variations of tire chips substitution.

The test of split tensile strength aims to determine the tensile strength of concrete indirectly. The test results showed a decrease in split tensile strength along with the increase in the volume of tire chip in concrete, as shown in figure 2. Addition of 10% and 20% tire chips reduced split tensile strength by 26% and 29% respectively. However, the tensile strength dropped dramatically to 58% when 30% tire chip was added, thus it was not recommended to add more than 20% tire chips.

The rubber acts as a soft material and can behave as a resistance to crack propagation. Therefore, the concrete tire chip must have a higher tensile strength than normal concrete. But in reality, the increase in the volume of the tire chip will reduce the tensile strength of the concrete.

Visually, the cracked concrete surface shows that no rubber is torn after cracking. If the rubber has a positive role in improving the strength of concrete, the strength of the bond between the rubber and cement paste should be large enough. If not, then the crack propagation was met with rubber particles as well as the pressure exerted causes surface segregation between rubber and cement. Therefore, it can be said that the rubber acts only as a pore and concentration points that accelerate the destruction of the concrete. This theory confirms that the surface of the rubber can easily be detached from the concrete paste and visible through the crushed concrete surface. The interface between the tire chips and the concrete paste is low, seen when the concrete was split, the chip tire was released from the concrete paste (see figure 3). Thus, the concrete tire chip has a lower tensile strength than normal concrete.

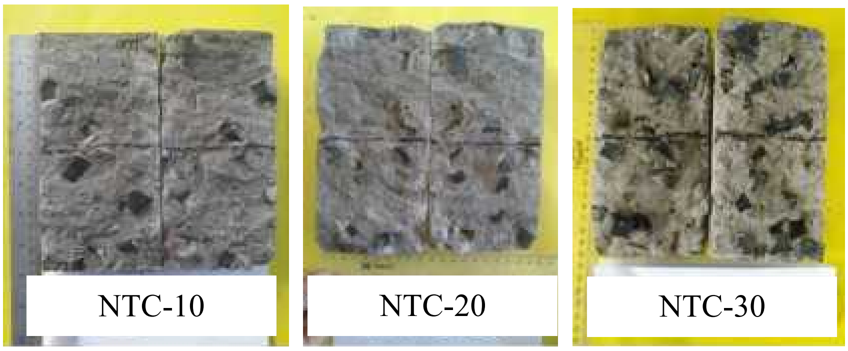

Figure 3. Tire chip detached from concrete paste.

The modulus of elasticity follows the trend of concrete compressive strength, where the greater the substitution of tire chips, the lower the modulus of elasticity of concrete, as presented in figure 4.

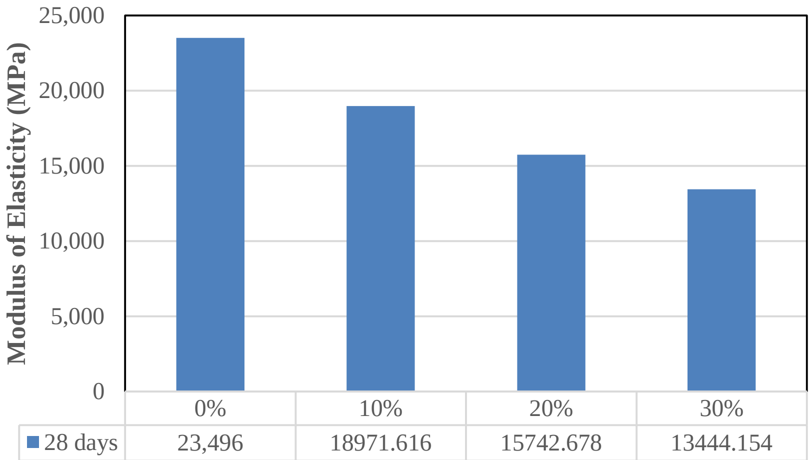

Figure 4. Modulus of elasticity to the percentage increment of tire chips.

Figure 5 shows that the greater the volume of tire chips in concrete, the modulus of rupture decreases. However, with 10% tire chips substitution (NTC-10), the modulus of rupture is higher than NC. Observations were also conducted on the deflection during loading. The largest deflection was experienced by NTC-10 of 0.938 mm greater than the deflection experienced by NC (0.778 mm), NTC-20 (0.677 mm) and NTC-30 (0.652 mm). Observation of the collapse pattern shows a collapse occurring in 1/3 of the span. This indicates that the presence of tire chips in concrete is able to develop resistance to bending, and does not occur in shear failure. Also, concrete containing tire chips does not show brittle collapse when compressive testing strength and flexural strength is carried out.

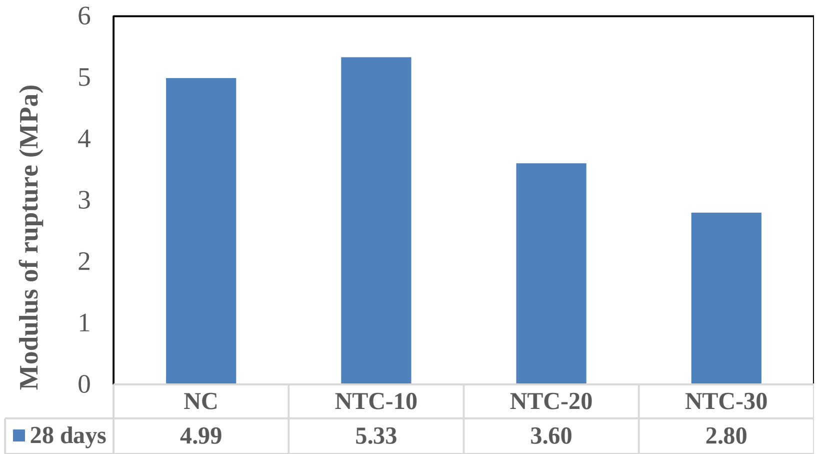

Figure 5. Modulus of rupture with variations of tire chips substitution.

4. Conclusion

From the results and discussion, it can be concluded that the weight of the concrete decreased by about 3% in every 10% increase in the chip tire. Compressive strength and elastic modulus, indirect tensile strength and flexural strength also decreased with increasing substitution of chip tire. The reduction in compressive strength averaged 18% in the addition of up to 10% of the tire chip, while the split tensile strength decreased by 26%. Modulus of rupture shows a value of more than 5 MPa with the addition of 10% tire chips, but decreases significantly if more than 10% tire chips are added.

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