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Mechanical Properties of Concrete Using Plastic Waste

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Abstract. This paper presents strength and behaviour of concrete by the addition of percentages recycled waste plastic (polyethylene terephthalate-PET). Almost 60 concrete samples with a cylindrical shape of 100 x 200 mm and a prism of 100 x 100 x 400 mm were prepared. Concrete strength (compressive, indirect tensile and flexural strength) were investigated throughout 7, 14, and 28 days using 10%, 15% and 20% of PET plastic aggregate as a substitute for coarse aggregate. It is found that when the percentages of PET plastic increase in concrete, the slump value and weight of concrete decrease significantly. The compressive strength, indirect tensile strength and modulus of rupture are also found to be decreased with increasing the percentages of PET plastic. The addition of PET plastic more than 10%, the strength dropped drastically more than 40%. The usage of waste plastic in concrete leads to a change in the modes of failure from brittle (rapid) failure to more ductile failure.

1. Introduction

Concrete is the most widely used construction material, obtained by mixing Portland cement, water, aggregates and additives to improve its performance. The use of waste and recycled materials in concrete mixes is the current trend in concrete development. Besides helping to reduce environmental pollution, by utilizing and treating solid waste generated by industrial waste and municipal waste, it also reduces the use of natural resources.

Plastic is one of the most significant innovations of materials in the 20th century. It is not surprising that plastic is widely used. Plastics have many advantages compared to other materials, such as plastic which has a low density, is insulating against electricity, has varying mechanical strength, limited temperature resistance, and chemical resistance varies. In addition, plastic is also lightweight, easy to design and production costs. But behind all the advantages, plastic waste creates problems for the environment. The nature of plastics as non-biodegradable materials causes plastic to take 100-500 years to fully decompose. The use of plastics has increased from time to time, causing the amount of plastic waste also continues to increase. According to the Minister of Environment and Forestry Siti Nurbaya, Indonesia is expected to produce 9 million tons of plastic waste in 2019 [1] and the total plastic waste in 2017 will be 65.8 million tons [2].

To overcome this, environmental experts and scientists from various disciplines have conducted various studies and actions. One of them is by recycling plastic waste. But this method is less effective. Only about 4% can be recycled, the rest is piled up in a landfill. Thus, it is necessary to handle plastic waste more efficiently, by utilizing plastic waste into artificial aggregates in concrete mixtures. The volume of concrete contains 65-80% aggregate and plays an important role in concrete properties such



as workability, strength, dimensional stability and durability, therefore the use of plastic waste in concrete as a substitute for aggregate can reduce the amount of waste significantly.

In civil engineering construction, the use of shredded plastic has increased dramatically as a partial replacement of aggregates. Because it provides environmental benefits and economic value where the use of waste is increasing in concrete [3-4]. Previous studies have shown that partial replacement of aggregate with waste plastic can improve concrete performance such as resistance to abrasion and impact loads, ductility, shock absorption, and thermal conductivity [5]. Some studies also present that the addition of plastic waste to concrete mixes causes a decrease in mechanical properties such as compressive strength, tensile strength and flexural strength [6-7]. Other studies have shown that the addition of steel fibers in normal concrete increases mechanical properties (compressive strength, flexural strength, tensile strength) significantly [8-9].

This study aims to determine the mechanical properties of concrete using PET plastic bottle waste as an artificial coarse aggregate. To increase the strength of plastic waste concrete, 0.5% steel fiber is added to the weight of cement. The crack patterns and the distribution of chopped plastic and steel fibers in concrete will be discussed.

2. Experimental programs

Laboratory studies were carried out to evaluate compressive strength, indirect tensile strength and flexural strength of concrete containing shredded PET plastic and steel fibers.

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. Crushed stone (aggregate maximum size of 30 mm and a fineness modulus 7.54) and river sand (fineness modulus 2.27) 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 characteristics

Characteristics		Crushed stone	Sand river	PET Plastic
Specific gravity	Dry oven	2.56	2.46	-
	Surface dry (SSD)	2.62	2.58	1.26
Water absorption, %		2.17	4.82	-

2.2. Specimens

Three standard cylindrical specimens of 100 x 200 mm are formed for each mix of compressive and indirect tensile test, while bending test used prism of 100 x 100 x 400 mm. There are 4 mix variations with 0%, 10%, 15% and 20% substitution of shredded PET plastic on the coarse aggregate volume and water cement ratio was 0.40, as presented in Table 2. Tests carried out were compressive test (7, 14 and 28 days), indirect tensile test, and bending test (28 days) using Universal Testing Machine (UTM). The specimen is cured in fresh water until the age of testing.

Table 2. Mix design of plastic concrete (PC) in kg/m³

No.	Material	NC	PC-10	PC-15	PC-20
1	Water	182.69	182.69	182.69	182.69
2	Cement	462.50	462.50	462.50	462.50
3	River sand	613.49	613.49	613.49	613.49
4	Crushed stone	1021.63	919.47	868.39	817.33
5	Dramix 3D 80/60	2.31	2.31	2.31	2.31
6	PET Plastic	-	46.38	69.57	92.75
7	Superplasticizer	-	-	-	2.31

The PET plastic used in this study passed $\frac{3}{4}$ " and retained on sieve No. 4. Physical appearance of PET plastic and type of testing are presented in Figures 1.

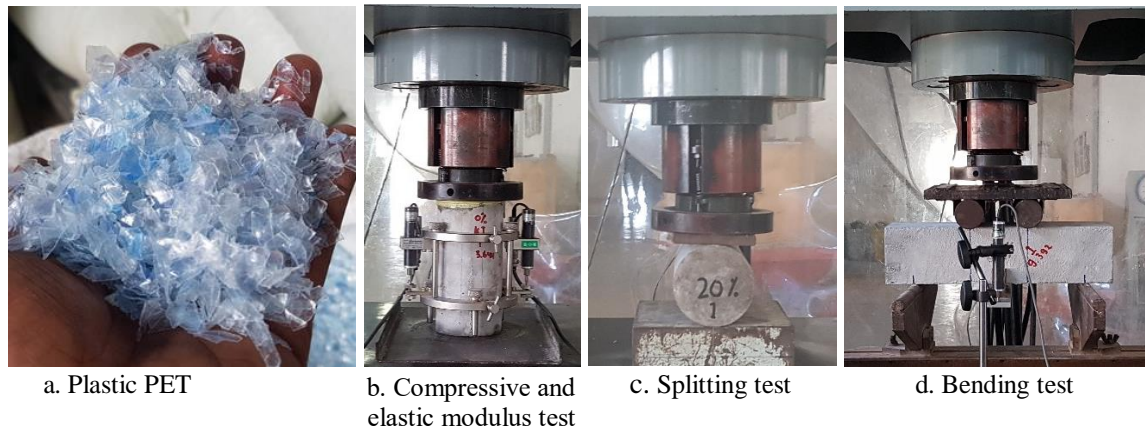


Figure 1. Plastic PET and type of testing

3. Results and Discussion

3.1. Fresh concrete properties

Slump test was performed to determine the consistency 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 consistency of concrete mix should be matched to the requirements for the finished product quality. Slump values decrease with increasing percentage of PET plastic in concrete. Concrete slump values for the addition of 0%, 10%, 15% and 20% PET plastics are 12, 9, 3 and 8 cm, respectively. The addition of 10% PET plastic still meets the target slump value of 8 ± 2 cm. However, when PET plastic is added more than 10%, the slump decreases drastically, causing the concrete is stiff and difficult to stir. The addition of superplasticizer (a water reducing-retarding admixtures type) to the substitution of 20% PET plastic could improve concrete workability, making it easier to compact.

Table 3 describes the reduction in weight of concrete volume to the increase in PET plastic substitution in concrete. The greater the volume of PET plastic added, the greater the weight reduction in concrete volume. However, the substitution of PET plastic up to 20%, it cannot be categorized as lightweight concrete with a weight between $1140 - 1840 \text{ kg/m}^3$ according to SNI 03-2847-2013.

Table 3. Weight of concrete

Name	Volume of PET Plastic (%)	Average weight of concrete (kg/m^3)	Reduction (%)
NC	0	2349.41	-
PC-10	10	2257.95	3.89
PC-15	15	2122.42	9.66
PC-20	20	2051.75	12.67

3.2. Hardened Concrete Properties

Compressive strength testing was carried out according to ASTM C39/C39M-01 at the age of 7, 14, and 28 days using cylinders of 100 mm x 200 mm. Compressive strength is the most important parameter in structural design. Like concrete in general, compressive strength increases with age for all variations of the addition of PET plastic as presented in Figure 2. This means that the hydration process in the cement paste runs well.

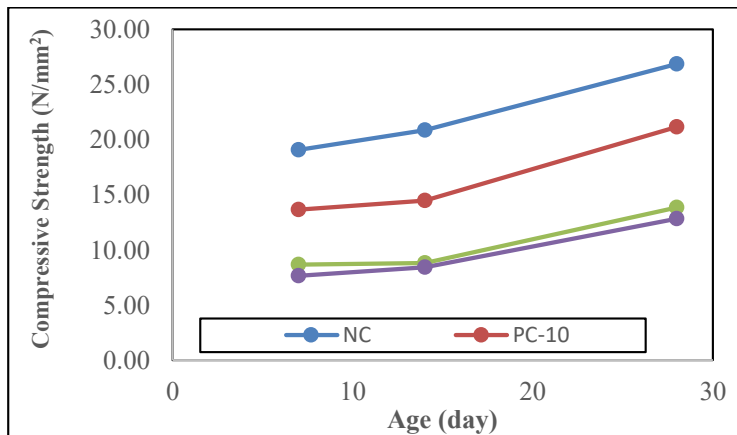


Figure 2. Compressive strength with variations in the addition of PET plastic

It is obvious from Table 4 that the compressive strength of concrete decreases with increasing the percentages of PET plastic. The addition PET plastic more than 10%, the compressive strength dropped drastically to 48%. The loose in strength attributed the plastic aggregate doesn't bond to the cement paste in the material in the same way that a crushed stone particle would. Therefore, substitution of PET plastic is limited to only 10% of the coarse aggregate volume.

Table 4. Compressive strength reduction

Name	Volume of PET Plastic (%)	Compressive strength (MPa)	Reduction (%)
NC	0	26.84	-
PC-10	10	21.14	21.23
PC-15	15	13.86	48.38
PC-20	20	12.84	52.15

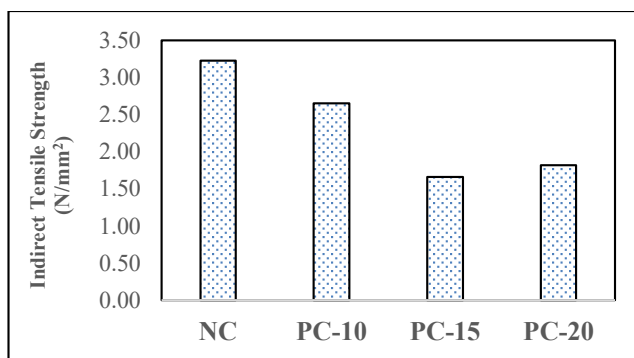


Figure 3. Indirect tensile strength with variations in the addition of PET plastic

Figure 3 indicates the test results of indirect tensile strength of hardened concrete, which was conducted according to ASTM C496-96 at 28-day. The test results showed a decrease in split tensile strength by increasing the volume of PET plastic in concrete. Addition of 10% PET plastic reduced split tensile strength by 17.8%. Then, the addition of 15% and 20% PET plastic, tensile strength dropped dramatically to 48.6% and 43.7% respectively. Therefore, it is not recommended to add more than 10% PET plastic. A large decrease in tensile strength of PN-15 compared to PN-20 due to the low consistency of PN-15 without the addition of superplasticizer, making it difficult to compact and produce less dense concrete. Visually observed the distribution of coarse aggregate, steel fibers and PET plastics on the surface of the specimens that have been split. Overall the specimen shows coarse aggregates, steel fibers and PET plastics evenly distributed, as shown in Figure 4.

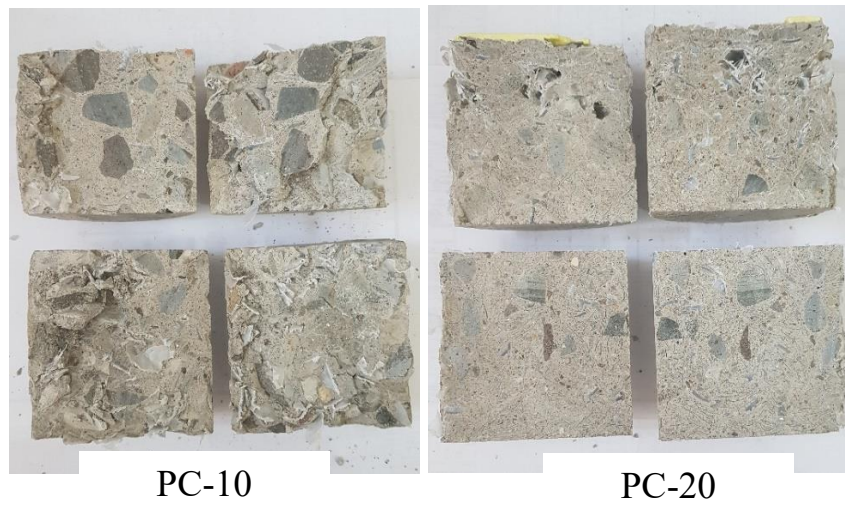


Figure 4. Distribution of aggregate, steel fiber and PET plastic

Flexural strength testing was carried out according to ASTM C78-02T at 28 days old. It is clear from Figure 5 that when the percentage of added PET plastic increases, the bending strength on the contrary decreases. The greatest decrease in strength occurs in PN-15 due to low consistency without superplasticizer, making it difficult to compact and produce less dense concrete.

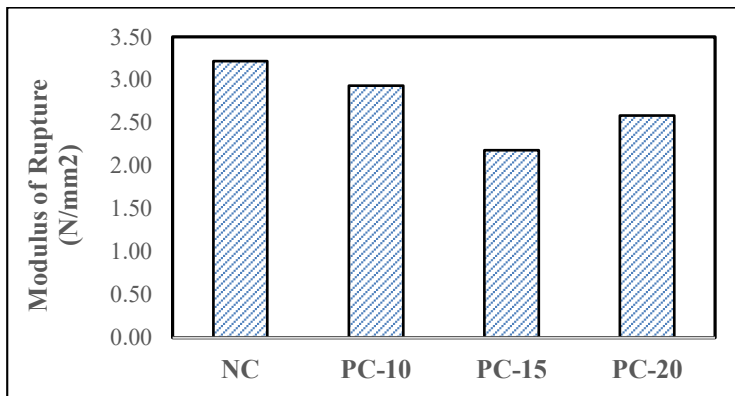
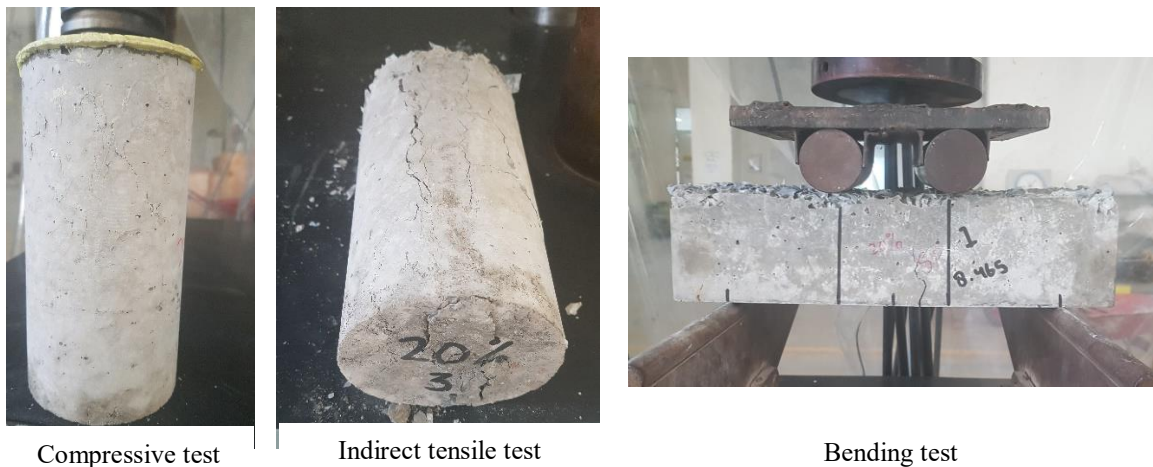


Figure 5. Bending strength with variations in the addition of PET plastic



Compressive test

Indirect tensile test

Bending test

Figure 6. Failure modes

The usage of PET plastic in concrete leads to a change in the modes of failure from brittle (rapid) failure to more ductile failure as shown in Figure 6. This indicates the bridge effect works well due to the use of steel fiber and chopped PET plastic with a size of about 20 mm.

4. Conclusion

From the results and discussion, it can be concluded as follow:

- a. In general, the compressive strength, indirect tensile strength and modules of rupture are found to be decreased with increasing the percentages of PET plastic bottle. The addition PET plastic more than 10%, the compressive strength dropped drastically to 48%. Therefore, substitution of PET plastic is limited to 10% of the coarse aggregate volume.
- b. The usage of waste plastic in concrete leads to a change in the modes of failure from brittle (rapid) failure to more ductile failure.

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