The Effect of Adding PET (Polyethylen Terephthalate) Plastic Waste on SCC (Self-Compacting Concrete) to Fresh Concrete Behavior and Mechanical Characteristics

K Aswatama W¹, H Suyoso², N Meyfa U³ and Tedy P⁴
¹,²,³,⁴Departement of Civil Engineering, University of Jember
Jl. Kalimantan No. 37, Jember, Indonesia

¹ketut.teknik@unej.ac.id

Abstract. To study the effect PET waste plastics on SCC then PET plastic waste content for SCC is made into 2.5%; 5%; 7.5%; and 10%. As reference concrete is made SCC with 0% PET level. The results on all fresh concrete test items indicate that for all PET waste levels made are meeting the criteria as SCC. The effect of adding PET to fresh concrete behavior on all test items shows that the filling ability and passing ability of concrete work increases with increasing of PET. However, the increase in PET will decrease its mechanical properties. The result of heat test shows that the mechanical properties of concrete (compressive strength, splitting, and elastic modulus) after heating at 250°C temperature has not changed, while at 600°C has significant capacity decline. To clarify the differences between SCC before and after heating, microstructure analysis was done in the form of photo magnification of specimen using SEM (Scanning Electron Microscope).

Keywords: plastic waste, PET, SCC, fresh concrete

1. Introduction

Research on concrete using plastic waste as one of its constituent materials can support government and society efforts in overcoming the amount of plastic waste that has become the environmental problem that is environmental pollution in all places around the world. The presence of plastics in the ocean will be very threatening to the lives of marine animals, while the presence of plastic on land will be able to contaminate the soil, when scattered in the body of water will be able to clog the flow, while the burning plastic will cause health problems. Various efforts were made to overcome the problem of this plastic waste by 3R, namely Reduce, Reuse, and Recycle, but the rate of increase of plastic goods and also the resulting waste has not been balanced with the efforts of 3R above. As an illustration, according to the Indonesian Institute of Sciences, Indonesia is the 2nd largest country in the world that dumps plastic waste into the oceans. Plastic consumption in Indonesia per capita reaches 17 kilograms per year with consumption growth reach 6-7 percent per year. Therefore, no matter how small a business is done in the handling of waste plastic, it means to help solve environmental problems, especially environmental pollution due to waste plastic.

Polyethylene terephthalate (PET) is one type of plastic generally made for mineral water bottles. The first step of recycling is done by chopping the plastic bottle into the crusher and then sieved and separated into various sizes of chopped. Furthermore, the result of the chopping is sent to the
manufacturer of plastic rope. Not all of the chopped plastics will be recycled, but the finely shredded grain will be discarded, as it contains many impurities such as soil and sand. This research will take the discarded chopped result as a mixture for SCC (Self-Compacting Concrete).

Self-Compacting Concrete is a self-compacted concrete (without mechanical vibrator), and able to flow with its own weight to fill all parts of the formwork without segregation. Generally, the proportion of SCC is different from conventional concrete. The difference lies in the addition of powder materials, the reduction of the amount of coarse aggregate, and the use of HRWR (High Range Water Reducer) is a superplasticizer in large quantities. Another thing that is a major requirement on SCC is fresh concrete behavior, that fresh concrete must be able to flow well in all obstacles while casting. To ensure that SCC can flow on its own, fresh SCC behavior must fit within the standard test limits on flowing ability, filling ability, and passing ability.

Some research on concrete using plastic waste has been done. Plastic bag waste can replace conventional aggregates well and produce acceptable compressive strength of concrete [7]. Meanwhile, the investigation of physical and mechanical properties in Self-Compacting Mortar (SCM) using PET plastic waste resulted in the conclusion that the level of plastic waste up to 50% of sand will produce maximum density. The mortar has a mechanical strength that is still acceptable as a concrete belonging to a lightweight concrete group. In addition, with the addition of PET plastic waste mixture, the level of concrete flowability will rise. However, the compressive strength of concrete has decreased to 33% of the control concrete [15]. Albano et al [1] investigated the behavior of concrete using PET plastic waste aggregate at various w/c ratios, with PET levels of 10% to 20% by volume of concrete. The study concludes that when the proportion and size of PET aggregate increases, concrete strength, split strength, elastic modulus, and ultrasonic velocity will decrease. The study also concluded that the flexural strength of concrete with PET aggregate is influenced by concrete temperature, w/c ratio, grade and aggregate size of PET plastic. Yang et al [16], led to a study that led to the conclusion that the compressive strength, tensile strength and flexural strength of Self-Compacting Lightweight Concrete (SCLC) increased to a degree of sand replacement of up to 15%. However, after passing these figures shows a tendency of decline, it is due to the presence of excess free water that weakens the interface between plastic and cement paste. Another SCC study has been done by Sadrmortazi et al [14] by combining PET plastic waste with silica fume and fly ash. In the study, it was observed that at 15% PET levels, SCC began to segregate. The results of this study also show that the addition of PET particles will decrease the value of its mechanical properties, this is due to the weak bond between cement and PET particles.

Differently, from previous studies mentioned above, this study focuses solely on the effect of PET plastic waste on SCC. SCC is made without the use of powder. Another thing that makes it different is that in this study the cement used is Portland Pozzolan Cement (PCC). The use of PET plastic waste in SCC in this study is expected to make it easier for the fresh concrete to flow by itself, this is related to the texture of smooth and slippery plastic surfaces when exposed to water. The behavior of fresh concrete and mechanical properties of hardened concrete after heating should be known as well.

2. Experimental program

2.1. Materials

- The cement used is Portland Pozzolan Cement in accordance with the requirements of Indonesian Standard, SNI 15-3500-2004 [12]. Specific gravity 3.15.
- The fine aggregate used is sand with a fineness modulus of 2.73, specific gravity of 2.69. The result of sieve analysis can be seen in Table 1.
- Coarse aggregates use gravel with a maximum size of 1 cm with a fineness modulus of 6.2 and specific gravity of 2.65. The result of sieve analysis can be seen in Table 1.
- PET plastic with fineness modulus 3.2, specific gravity of 1.307 (Figure 1.)
- HRWR is superplasticizer produced by Sika.
2.2. Mixtures preparation

The design mixture (SCC) used is guided by the Indonesian Standard, SNI 03-2834-2000 [10], with the addition of superplasticizer of 1% of the weight of cement. The aggregate condition is SSD (saturated surface dry). Added PET of 2.5% (to the volume of sand) to a level of 10%. As reference concrete is created SCC without PET (0% PET). The proportions of the material are shown in Table 2.

| Table 1. Characterization of aggregates. |
|------------------------------------------|
| Sieve (mm) | Retained in weight (%) |
| Sand | PET | Coarse |
| 19.00 | 100.00 | 100.00 | 100.00 |
| 9.50 | 100.00 | 100.00 | 384.60 |
| 4.76 | 0.05 | 0.58 | 1040.80 |
| 2.38 | 10.22 | 3.86 | - |
| 2.19 | 15.93 | 42.22 | - |
| 0.59 | 31.26 | 28.48 | - |
| 0.297 | 10.26 | 19.72 | - |
| <0.149 | 4.62 | 1.68 | 2.65 |
| Specific gravity | 2.69 | 1.31 | - |
| Bulk density (kg/m³) | 1300.00 | 410.00 | 1423.00 |
| Fineness modulus | 2.73 | 3.20 | 6.20 |

| Table 2. Mixtures composition. |
|-------------------------------|
| Mix | Cement (kg/m³) | Coarse (kg/m³) | Sand (kg/m³) | PET (kg/m³) | w/c | water (ltr) | SP (ltr) |
| 0% PET | 777 | 708 | 640 | 0 | 0.3 | 233 | 7.8 |
| 2.5% PET | 777 | 708 | 635 | 5 | 0.3 | 233 | 7.8 |
| 5% PET | 777 | 708 | 630 | 10 | 0.3 | 233 | 7.8 |
| 7.5% PET | 777 | 708 | 625 | 15 | 0.3 | 233 | 7.8 |
| 10% PET | 777 | 708 | 620 | 20 | 0.3 | 233 | 7.8 |

2.3. Test methods

SCC testing in this study consisted of the fresh concrete test and harden concrete test. Fresh concrete testing includes: slump flow test, L-shaped box test, and V-Funnel test, referring to testing standard from EFNARC 2005 [5]. SCC fresh concrete testing equipment can be seen in Figure 4. Meanwhile, testing of mechanical characteristics of concrete includes compressive strength, tensile strength, and modulus of elasticity. Due to the existing PET plastic content, the post-heating mechanical characteristics will be tested as well. Three types of heat treatment specimens were made for post-heating mechanical characteristics, i.e. non-heating specimens (with a room temperature of about 30°C), specimens after heating at a temperature of 250°C for 2 hours and specimens after heating at 600°C for 2 hours. Guidance on testing of mechanical characteristics of concrete refers to Indonesian Standard, SNI [11,13]. All specimens were tested at 28 days. The heating of the specimens was carried out using an oven (Figure 2.) The shape of the specimen consists of two types, namely the cylinder with the diameter of 10 cm and the height of 20 cm (for compressive strength test), and the cylinder with the diameter of 15 cm and the height of 30 cm (for splitting tensile strength test and elastic modulus test).

3. Result and discussion

3.1. Fresh concrete behavior

The results of fresh concrete testing show that almost all mixed designs made i.e. 0% PET (reference SCC), 2.5% PET, 5% PET, 7.5% PET, and 10% PET meet the requirements as SCC mix. The T⁵₀₀ test shows that the fastest time for fresh concrete to reach 500 mm diameter is 5 seconds (10% PET) and the
longest is 10.6 seconds (by Mix Ref). While the time range limits for standard T500 testing are 3 to 15 seconds. The results also show that the more PET content, the faster it will take SCC to reach a diameter of 500 mm. Meanwhile, the slump flow test shows that the maximum diameter of concrete distribution that can be achieved is 815 mm (10% PET), and visually visible without segregation. In the slump flow test, it is seen that the more PET content, the greater the diameter that can be achieved. The test results can be seen on the slump flow test graph in Fig. 3. In the V-funnel test shows the same thing, namely that the more PET content, the faster the fresh concrete can pass through the V-funnel. But only 10% PET mix meets the requirements (in range 6sec to 12sec), another mixture takes more than 12 seconds. Meanwhile, the L-box test results show that all the mixtures made have an L-box ratio (H2 / H1) above 0.8 and below 1. The complete test results value are presented in Table 3.

Looking at the graph of the fresh concrete test results in Fig. 3 shows that the replacement of sand with PET plastic waste up to 10% (of sand volume) will increase the filling ability and passing ability of SCC, this corresponds to the initial hypothesis of the slippery surface of the plastic to be helping other materials on fresh concrete to flow more easily. These results are also consistent with research from Ghernouti [7] and Safi [15] which conclude that the addition of plastic will improve the workability of concrete.

Table 3. Fresh concrete test value.

| PET content | T500 (sec.) | Slump flow (mm) | V-funnel (mm) | L-box (H2/H1) |
|-------------|-------------|-----------------|---------------|---------------|
| 0%          | 10.6        | 760             | 13.4          | 0.93          |
| 2.5%        | 7.0         | 765             | 12.9          | 0.97          |
| 5%          | 6.6         | 770             | 12.5          | 0.98          |
| 7.5%        | 5.5         | 810             | 12.0          | 0.96          |
| 10%         | 5.0         | 815             | 9.5           | 0.96          |

Fig. 1. View of shredded PET.  
Fig. 2. Oven equipment.
3.2. Mechanical characteristics
Tests of mechanical characteristics are performed when the concrete reaches the age of 28 days. For 3 heating treatments, the ID name was as follows: unheated treatment (as reference) was named ID = T30, heated treatment at 250°C for 2 hours (ID = T250), and heated treatment at 600°C for 2 hours (ID = T600). Each heat treatment is made for all SCC mix, i.e. 0% PET, 2.5% PET, 5% PET, 7.5% PET and 10% PET. The temperature of 250°C was chosen because of the temperature around the PET plastic begins to melt, while at 600°C PET plastic temperature has exceeded its melting point and will decompose [4], as the reference is a non-heated test object. Furthermore, the three heating treatments will be compared to each of its mechanical characteristics.

Figure 3. Fresh concrete test graph: (a) T500 (b) Slump flow (c) V-funnel (d) L-box.

Figure 4. (a) Slump flow test (b) V-funnel test (c) L-box test.
3.2.1. Compressive strength

Fifteen cylindrical test specimens of 10 cm in diameter and 20 cm in height were made for each SCC mix design which was further divided into five cylinders for T30 treatment, five cylinders for T250, and five more cylinders for the T600. Compression test using the universal testing machine and refer to Indonesian Standard, SNI 03-1974-2011 [13], on the procedure of concrete compressive strength test with the cylindrical test object. Compression test after heating is done after the specimen in room temperature condition. Test results can be seen in Table 4.

Figure 6. shows a bar chart of the compressive strength of each design mix and at each temperature treatment. The more PET levels will decrease the compressive strength of the concrete. This is because PET plastics have lower elastic modulus than other materials such as sand, gravel, and also harden cement paste [6]. In addition, a smooth plastic surface causes the cement to not bind the plastic itself and can easily pull out from its cement matrix [8,9], so with more PET levels the more weak part of the concrete will affect the overall strength of the concrete. The addition of PET content of 2.5%, 5%, 7.5% and 10% to the volume of sand will decrease the compressive strength of concrete by 0%, 18.6%, 32.8% and 34.3%, compared to reference mixture.

In the treatment of temperature T250 for SCC without PET and SCC with PET at all levels showed that the compressive strength of concrete is relatively the same when compared with each compressive strength of the reference concrete (T30). From these results, it can be concluded that the compressive strength of concrete does not change when heated to 250°C and this corresponds to the results of research from Chan et al [3] which states that up to heating temperature of 400°C only a small part of the concrete decreased its compressive strength. On the other hand, at a temperature of 250°C the temperature at which PET plastic begins to melt and changes from a solid plastic to a liquid, but in this study the compression test is carried out after the heating is completed and the temperature of the specimen has dropped back to the room temperature so that the PET plastic again turned into solid, therefore the test on this condition can be said the same condition with the test object that does not undergo heat treatment.

At the temperature treatment of T600, the compressive strength of concrete has decreased significantly. This occurs in all types of mixtures made including concrete without PET plastic waste. The decrease in compressive strength in the SCC without PET is 40% compared to the reference SCC. According to Chan et al [3], at high temperatures, concrete decreased compression capacity due to dehydration of hard cement paste; which is the backbone of concrete strength; so the C-S-H gel in this condition becomes a loss of binding ability. Meanwhile, the compressive strength of SCC with PET had a mean decrease of 43%, and this decrease was greater than the decrease in compressive strength with SCC without PET. This can happen because, in addition to dehydration of C-S-H gel, PET plastic in concrete decomposes [4], then evaporates and leaves empty spaces in concrete, resulting in reduced concrete density, the higher porosity of concrete and voids, finally reducing the strength of the concrete. The concrete void originally occupied by PET plastic can be seen in the photo of the SEM result seen in Fig. 9 and Fig.10.

3.2.2. Splitting tensile strength

Fifteen cylindrical test specimens of 15 cm in diameter and 30 cm in height were made for tensile strength testing, and divided into 3 heating treatments such as compression testing. Testing using the universal testing machine and referring to Indonesian Standard, SNI 03-2491-2002 on concrete tensile strength testing method [11]. In Figure 7., PET addition will decrease the value of tensile strength compared to the reference of SCC without PET. For the T250 temperature treatment, there is no change in the tensile strength, whereas in the T600 temperature treatment the results show that the greater the PET content the greater the percentage decrease of the tensile strength. In the T600 treatment, the percentage decrease of SCC without PET tensile strength was 52.6% while the mean decrease of SCC with PET tensile strength was 53.3%. Test results can be seen in Table 4.
3.2.3. **Modulus of elasticity**

Nine cylinders with a diameter of 15 and a height of 30 cm were made for T30, T300, and T600 tests and applied to all SCC mix designs. The elastic modulus test refers to ASTM C 469-2 [2]. In Figure 8., it appears that the greater the addition of PET content will further decrease the modulus of elasticity of concrete. The elasticity modulus value in the T250 treatment was not different from the T30 treatment, but in T600 heating showed that the greater the PET level, the greater the decrease in the modulus of elasticity. In the T600 treatment, the percentage decrease in elastic modulus of SCC without PET is 40.9% while mean decrease of the elastic modulus of SCC with PET is 45.8%. The test results can be seen in Table 4.

**Table 4. Mechanical characteristics test value.**

| Mix  | Compressive strength (MPa) | Splitting tensile strength (MPa) | Modulus of elasticity (MPa) |
|------|---------------------------|---------------------------------|-----------------------------|
|      | T30 | T250 | T600 | T30 | T250 | T600 | T30 | T250 | T600 |
| 0%   | PET | 61.83 | 60.53 | 37.10 | 6.22 | 6.02 | 2.95 | 38.46 | 36.67 | 22.71 |
| 2.5% | PET | 62.27 | 60.54 | 32.24 | 4.88 | 4.55 | 2.67 | 34.88 | 35.68 | 21.36 |
| 5%   | PET | 50.34 | 52.88 | 30.03 | 4.56 | 4.41 | 2.36 | 34.33 | 36.12 | 19.25 |
| 7.5% | PET | 41.51 | 40.55 | 24.73 | 5.41 | 4.80 | 2.22 | 34.77 | 34.34 | 17.30 |
| 10%  | PET | 40.63 | 42.47 | 22.52 | 5.23 | 4.84 | 2.05 | 33.18 | 32.25 | 16.50 |

**Figure 5.** (a) Compression test (b) Splitting tensile test (c) Elastic modulus test.
Figure 6. Compressive strength of heat treatment T30, T250, and T600.

Figure 7. Splitting tensile strength of heat treatment T30, T250, and T600.
3.3. Microstructure analysis

After completion of compressive strength test, tensile strength test and elasticity modulus test, then part of cylindrical concrete is taken as a sample for SEM (Scanning Electron Microscope) test using Tabletop Microscope 3030plus. A sampling includes 2 types, i.e. samples from T30 (hard concrete SCC without heating) and T600 (hard concrete SCC with 600°C treatment). The result of the SEM photo can be seen in Figure 9. and Figure 10. The magnification photo of 80X (Fig. 9.a) on T30 specimen (without heating) indicates that the particle of PET is visibly attached to a surface of mortar paste and seen as a fine plane at the PET-mortar, and if the same location is enlarged to 1500X (Fig. 9.b) the fine field is seen as a flat surface compared to the rough side of which there is no PET, this means the friction between the particles will decrease when there is PET between the material, the friction force between these particles will further reduce the capacity of the mechanical characteristics of the concrete, in addition to individual plastics themselves which have the weakest strength of other materials.

Photographs of samples with T600 temperature treatments (Fig. 10.) show that there are voids originating from the chamber where the preceding PET has been decomposed and vaporized due to the high temperature received. The voids will add to the weaker part of the concrete that the void is absent in the unburned concrete. Therefore, SCC containing PET and high heating will experience twice the weakening, which is due to loss of binding properties of CSH gel due to high temperature [3], also due to the voids arising from the evaporation of PET plastic due to decomposition process [4].

![Figure 8. Modulus of elasticity of heat treatment T30, T250, and T600.](image-url)
4. Conclusion
This paper is a study of the effect of the addition of PET plastic waste on SCC to fresh concrete behavior and mechanical characteristics resulting in the following conclusions:

1) Replacement of sand with PET plastic waste up to 10% level will increase the filling ability and passing ability of fresh concrete SCC.

2) SCC mechanical characteristics are: compressive strength, tensile strength, and elastic modulus will decrease with increasing PET level. The higher the PET level will be the greater the decrease in mechanical characteristics.

3) At temperatures of 250°C, the mechanical characteristics of harden concrete have not shown any change, while at 600 °C it decreases significantly and occurs in both SCC types i.e. SCC without PET and SCC with PET.

4) At a temperature treatment of 600°C, the decrease in mechanical characteristics of SCC with PET will be greater than that of SCC without PET because in addition to dehydration of C-S-H gel, but also the emergence of voids in the concrete that weakens its strength. These voids arise as a result of the decomposition and evaporation of PET plastic.

Figure 9. SEM of PET particle on SCC unheated treatment T30. (a) X80 enlargement (b) X1.5k enlargement.

Figure 10. SEM of SCC heated treatment T600. (a) X30 enlargement (b) X250 enlargement.
The SEM results show that smooth and flat plastic surfaces of PET plastics give rise to fine planes at the interfacial encounters of the cement matrix and this reduces internal friction on the concrete, which in turn reduces the capacity of mechanical characteristics of the concrete.

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