The Effect of Adding Minerals on Plastic Aggregate to Lightweight Concrete

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Abstract. This research was conducted by making several concrete mixtures using artificial aggregates from PET (polyethylene terephthalate) plastic and mineral mixtures. Four types of minerals were used; namely, fine sand, fly ash, rice husk ash, and Portland cement. Each of these powders was added to the plastic melt during the aggregate manufacturing process. Five types of aggregates were produced including one artificial aggregate without any mineral addition. The initial test results showed that for all minerals, the use of artificial aggregates as a substitute for natural coarse aggregates tended to increase the compressive strength of concrete when compared to the reference concrete, i.e. concrete with pure PET aggregate (without added minerals). At this step, it was seen that the addition of cement and rice husk ash to PET aggregates provided the highest concrete compressive strength. In the next stage, by adding cement content to the concrete mixture, artificial aggregates from PET plastic were able to produce concrete that meets the requirements as structural lightweight concrete, both as a substitute for natural coarse aggregates and for the overall natural aggregates (fine and coarse aggregates).

Keywords: plastic aggregates, artificial aggregates, lightweight concrete

1. Introduction
There are almost no objects in the life of modern society today that do not contain plastic. Every day in their activities, humans will always be in contact with plastic. Human’s dependence on plastic had been believed to be of a high level but had not been measured with certainty until research was done on the production, use, and travel of all plastic that have ever been made. Geyer et al. [4] conveyed the results of their research that since plastic materials were discovered until the research was conducted, plastic manufacturers around the world had produced 8,300 million metric tons of original plastic. In the year 2015, 6,300 million metric tons of plastic waste was made, around 9% was recycled, 12% was incinerated using incinerators, and 79% had to be borne by the environment in landfills or was just thrown away. If the trend of plastic production and disposal of plastic waste continues, then by 2050, the world's plastic waste will reach 12,000 million metric tons. Meanwhile, Indonesia is the second-largest country producing plastic waste ending at sea. Data on the amount of plastic waste in the Indonesian sea mentioned it reached 0.48 million-1.29 million tons per year [12].
Seeing the above facts, the reuse of plastic waste through recycling would help reduce environmental problems. Research into the use of plastic waste as an aggregate for concrete is in line with efforts to reduce the environmental burden caused by plastic waste. These long-chain polymers often contain hazardous materials so that the use of plastic in concrete mixes can temporarily prevent the direct contact of plastic with the natural environment since concrete buildings generally have a relatively long service life [9]. Meanwhile, the increasing demand for natural materials as concrete formers or as road pavement can lead to an excessive exploration of natural aggregates that might cause environmental damage and the emergence of potential landslides. Continuous use of natural aggregate deposits would lead to reduced availability, while the quarries are sometimes further away from the construction site so that ultimately the material costs for making concrete would become more expensive [6]. Plastic waste can be recycled into new goods after undergoing a particular process, but it becomes uneconomical because the recycling process would generate recycled plastic products of reduced quality, so that plastic manufacturers prefer to produce new plastic, not products from recycling [8]. Therefore the reuse of unwanted plastic waste can be done by using it as an artificial aggregate.

The use of plastic waste as a concrete mixture has been carried out by researchers from various countries in the world, where plastic can be used in the original or recycled forms and can be used as aggregates or as fibers. Previous studies have shown that the use of plastic as aggregates generates a low ability to absorb water resulting in weak aggregate bonds with cement paste. Therefore, various efforts have been made by researchers to increase aggregate binding capacity such as giving a layer on the aggregate surface [3]; roughening aggregate surfaces [7]; mixing plastic with minerals such as with fly ash [5] or mixing it with red sand [1]. This study uses the same idea as the last method mentioned above, but with a choice of other mineral variations that are more easily found. The minerals used in this study are fine sand, fly ash, rice husk ash, and portland cement. Except for Portland cement, the minerals selected in this study were waste and were easily obtained from around the study site: type F fly ash was taken from coal-fired steam power plants, rice husk ash was obtained from burned rice husk in the process of making clay bricks in a brickyard found in the suburbs, and fine sand was acquired by sieving local sand. The plastic used was a type of colorless PET (polyethylene terephthalate) that came from used mineral water bottles. With the lightweight plastic properties, the artificial aggregate from recycled plastic was used as fine and coarse aggregate to make lightweight concrete.

2. Materials and Method

2.1. Materials

The cement used was Portland Pozzolanic Cement (PPC) in accordance with requirements of Indonesian Standard, SNI 15-7064-2004 [11]. Its specific gravity (SG) was 3.15. This cement was used as a binding agent for lightweight concrete mixtures and also as one of the minerals for plastic aggregate mixtures.

The natural fine aggregate used was pit sand with a fineness modulus (FM) of 2.69 and SG 2.14. Sand grading was arranged so that it met the ideal gradation of zone 2 (Figure 1.) according to Indonesian Standards, SNI 03-1968-1990 [10]. This pit sand was also used as a mixing mineral in plastic aggregates that passed No. 50 sieve and retained No. 100 sieve.

The natural coarse aggregate used was crushed stone gravel that passed No. 3/8 sieve, retained No. 4 sieve according SNI 03-1968-1990 [10], SG 2.68. Type F fly ash (Figure 2a.) originated from a coal-fired steam power plant, Paiton (PLTU Paiton) with SG of 3.07.

Rice husk ash (Figure 2b.) was obtained from burning rice husk in a brickyard with SG of 2.73. PET plastic (clear, colorless) came from chopped mineral water bottles (Figure 2c). SG 1.307.
2.2. Methods
This study was carried out in several stages as can be seen in Figure 3, and explained in the following section.

- Stage 1. The process of making plastic aggregates
At this stage plastic aggregates were made by melting PET plastic on a frying pan, mixing it with minerals, pouring it into molds and cooling, crushing the chunks of cold plastic aggregates, and sieving. The process is shown in Figure 4 and Figure 5. Four types of minerals were mixed with PET plastic namely fine sand, fly ash, rice husk ash, and cement. The four types of aggregates were produced according to the type of mineral. The fifth aggregate, made as a reference, was pure PET aggregate (aggregate without any mineral addition). To find out the weight proportion of the amount of a mineral compared to the amount of PET in a plastic aggregate that would produce the highest compressive strength of lightweight concrete, the proportion of minerals-PET was varied into three ratios (mineral: PET) = 1: 1, 1: 3, and 1: 5. Overall, thirteen variations of artificial aggregates were planned to be made, with differences in the type of mineral, mineral-PET variation, and one artificial aggregate without minerals (pure PET aggregate).
Stage 1
The process of making plastic aggregate

Stage 2
a) Selection of mineral types
b) Selection of mineral-PET proportions

Stage 3
Testing the mechanical characteristics of lightweight concrete

Figure 3. Research stages

Figure 4. Process of making plastic aggregates

- Melting PET on a frying pan
- Mixing with minerals
- Pouring into molds and cooling
- Crushing the chunks of cold plastic aggregates
- Sieving

Figure 5. The process of making aggregates in the laboratory (a) melting PET (b) mixing with minerals (c) temperature measurement (d) pouring into molds (e) the chunks of plastic aggregate (f) crushing with stone crusher (g) crushed plastic aggregate (h) sifting (i) artificial aggregate after sifting

Stage 2. Selection of mineral types and selection of mineral-PET proportions
At this stage, concrete mixtures were made with coarse plastic aggregates that were made in step 1, while fine aggregates used natural sand. Meanwhile, the types of concrete mix were made as many as the types of artificial aggregate that had been produced. The test carried out was a compressive test with cube specimens of 100 mm x 100 mm x 100 mm (Figure 6.) as many as five specimens for each type of concrete. Before being tested, each test object was weighted. In this stage, the mineral types and the proportion of mineral-PET from the artificial aggregate were selected based on the ability to produce concrete compressive strength and concrete density equal to or close to the criteria for structural lightweight concrete, then we proceeded to step 3.
Stage 3. Testing the mechanical characteristics of lightweight concrete
After obtaining the type of material and the proportion of mineral-PET in the aggregate that could produce structural lightweight concrete, then the concrete mixes were remade using the artificial coarse aggregate that had been selected. Also, at this stage, concrete was made utilizing fine plastic aggregate, which was the residual product of coarse artificial aggregate. This fine plastic aggregate was used to replace fine natural aggregate. Thus there were two types of concrete that were both fine and coarse aggregate using artificial aggregates made of plastic. As a reference concrete, concrete composed of coarse and fine natural aggregate (normal weight aggregate) was also made at this stage. Tests carried out on hardened concrete were compression test, split tensile test, flexural tensile test, and modulus elasticity test. For compression test, splitting tensile test, and elastic modulus test, 100 mm diameter x 200 mm height cylindrical specimens were used, while for flexural tensile tests a 100 mm x 100 mm x 300 mm beam was used (Figure 7).

3. Results and discussion

3.1. Stage 1. The process of making plastic aggregates
As described in the method section, the manufacture of plastic aggregates began with melting PET plastic in a frying pan. The heat source was LPG through a set of gas stoves. It should be noted that the weakness of using a gas stove for melting PET plastic is the difficulty in temperature regulation, while PET plastic has a melting temperature ranging between 245°C and 265°C (http://www.precious plastic.com), or has a melting temperature range of only around 20°C. If the heating temperature exceeds the melting point range, PET plastic becomes too liquid which results in the plastic formed being brittle and hollow. On the contrary, if the heating temperature is then lowered to below the melting point range, it will make PET plastic dough quickly begin to thicken, become stiff, and difficult to stir. Therefore at the time of PET plastic melt supervision must be strict. Once some of the
plastic has begun to melt, the plastic in the pan should be stirred immediately to avoid reaching temperatures that are far above the melting point. After the PET plastic had melted, a mixture of minerals were added, and the mixture continued to be stirred. The stirring of PET plastic in the pan was complete when the dough became homogeneous (no more plastic lumps that had not melted), and the minerals were mixed evenly. After being completely homogeneous, the mixture was then poured into a mold and allowed to cool. The cooled PET-mineral mixture became a large chunk of artificial aggregate, which was then reduced in size by breaking it down with a hammer, then put into a stone crusher to get the aggregate fraction as planned. By sifting the results of the stone crusher, finally the desired aggregate size was obtained. And the process of making plastic aggregate was continued until it reached the overall aggregate requirement, with all types of minerals and all planned mineral-PET variations. Based on the previously planned aggregate differences, 13 types of plastic aggregates were made including pure PET aggregate, but based on the results of the implementation in the laboratory only 11 types could be produced, because aggregates with a mixture of rice husk ash - PET with a proportion of 1: 1 and 1: 3 would not form properly. Figure 8 shows three types of coarse plastic aggregates that were successfully made. Table 1 shows the characteristics of artificial aggregates from recycled plastic.

Figure 8. (a) Coarse artificial aggregate made of PET plastic, and in close-up: (b) Pure PET aggregate (c) cement-PET aggregate, in proportion of 1:3 (d) rice husk ash-PET aggregate, in proportion of 1:5

In Figure 8, Pure PET aggregate (b), which is an aggregate without mineral mixture, shows a smooth aggregate surface and is not too porous, whereas in cement-PET aggregate (c) and rice husk
ash-PET aggregate (d), aggregate surface texture looks rough and porous, so it was hoped that the cement paste would be absorbed and form a stronger bond with the plastic aggregate.

Table 1. Specific gravity and density of artificial coarse aggregates in various treatments.

| Type of coarse aggregate | Weight proportion of mineral:PET | Aggregate specific gravity | Aggregate density (kg/m$^3$) |
|--------------------------|----------------------------------|---------------------------|-----------------------------|
| Natural aggregate        | -                                | 2.68                      | 1354.83                     |
| Pure PET                 | 1:1                              | 1.72                      | 625.26                      |
| Fly ash-PET              | 1:1                              | 2.19                      | 752.74                      |
| Fly ash-PET              | 1:3                              | 1.31                      | 720.18                      |
| Fly ash-PET              | 1:5                              | 1.2                       | 717.03                      |
| Rice husk ash-PET        | 1:1*                             | -                         | -                           |
| Rice husk ash-PET        | 1:3*                             | -                         | -                           |
| Rice husk ash-PET        | 1:5                              | 1.16                      | 669.70                      |
| Cement-PET               | 1:1                              | 2.23                      | 772.08                      |
| Cement-PET               | 1:3                              | 1.32                      | 738.10                      |
| Cement-PET               | 1:5                              | 1.21                      | 735.86                      |

Table 1 shows the specific gravity and the density of artificial aggregates derived from PET plastic mixtures with various types of minerals and their proportional variations. In the proportion of 1: 1 and 1: 3 (marked with an asterisk in the table) rice husk ash and PET could not mix, hence the artificial aggregate could not be formed, which was due to too much mineral content. Figure 9 shows a graph of the two types of coarse aggregates made from a mineral-PET mixture. The curve shows that with greater proportion of PET values from minerals, the density of artificial coarse aggregates would be smaller. A similar pattern was observed regarding the effect on aggregate density, i.e. more PET plastic content would reduce the value of artificial aggregate density, as shown in Figure 10.

![Figure 9](image_url)

**Figure 9.** Effect of mineral-PET ratio on specific gravity: (a) Coarse aggregate of fine sand-PET mixture (b) Coarse aggregate of fly ash-PET mixture
3.2. Stage 2. Selection of mineral types and selection of mineral-PET proportions

At this stage each plastic aggregate that had been made functioned as a coarse aggregate, while the fine aggregate used was natural sand. Eleven concrete mixes were made according to the type of aggregate that had been produced. The proportions of the mixture and test results in the form of slump value, density, and compressive strength of concrete are listed in Table 2.

According to ACI 213R-87 (1999) [1], structural lightweight concrete is concrete composed of lightweight aggregates with heavy dry concrete conditions under air conditions at 28 days ranging from 1440 to 1850 kg/m$^3$ and with compressive strength of more than 17.24 MPa.

Referring to the ACI regulations above and seeing the results of the overall test, it could be seen that the artificial aggregate with a cement mixture: PET = 1: 3 and a mixture of rice husk ash: PET = 1: 5 produced lightweight concrete with the highest compressive strength and meets the criteria as structural lightweight concrete (Aggregate No. 9 and No. 11 In Table 2. and printed in bold). Then the two types of concrete were selected to be further processed in the research phase 3. The density and compressive strength of concrete with aggregate cement-PET mixture were 1852.35 kg/m$^3$ and 23.5 MPa, while concrete with aggregate of rice-PET husk: 1811.95 kg/m$^3$ and 22,098 MPa, lightweight concrete with pure PET aggregates: 1723.44 kg/m$^3$ and 14.126 MPa. It can be seen here that the addition of minerals to plastic aggregates increased the compressive strength of concrete.

Table 2. Mixtures composition, slump, density, and compressive strength of concrete in stage 2

| No. | Coarse aggregate name | Mixtures composition per m$^3$ | Slump value (mm) | Concrete density (kg/m$^3$) | Compressive strength (MPa) |
|-----|-----------------------|-------------------------------|------------------|----------------------------|--------------------------|
|     |                       | cement (kg) | natural fine agg. (kg) | plastic coarse agg. (kg) |                           |                          |
| 1   | Pure PET              | 460         | 966               | 474.39                | 110                      | 1723.44                  | 14.13                     |
| 2   | Fine sand:PET=1:1    | 460         | 966               | 427.57                | 90                       | 1786.45                  | 19.31                     |
| 3   | Fine sand:PET=1:3    | 460         | 966               | 421.45                | 100                      | 1755.15                  | 19.28                     |
| 4   | Fine sand:PET=1:5    | 460         | 966               | 417.46                | 110                      | 1744.2                   | 16.21                     |
| 5   | Fly ash:PET=1:1      | 460         | 966               | 514.75                | 120                      | 1930.1                   | 13.54                     |
| 6   | Fly ash:PET=1:3      | 460         | 966               | 492.48                | 90                       | 1836.25                  | 11.44                     |
3.3. Testing the mechanical characteristics of lightweight concrete
At this stage, a concrete mixture was made using two types of artificial aggregates selected in stage 2, which were aggregates with a combination of cement-PET (1:3) and rice husk ash-PET(1:5). Each artificial aggregate was used for two types of concrete mixtures. The first concrete mixture used artificial aggregate as a substitute for natural coarse aggregate and the second mixture functioned to replace the whole natural (coarse and fine) aggregate fraction. Another concrete mixture made as a reference used the entire natural aggregate. Five types of concrete mixtures were produced with details of the proportions and the results of the tests can be seen in Table 3 below. Improvement of the proportion of the mixture was done by increasing the ratio of cement material, with the aim that all kinds of mixtures that were made really can be included in the category of structural lightweight concrete.

Table 3. Test results for mechanical characteristics and mixture composition for each type of concrete

| No. | Concrete mix name | Mixtures composition | density (kg/m³) | compressive strength (MPa) | splitting tensile strength (MPa) | flexural tensile strength (MPa) | modulus of elasticity (GPa) |
|-----|-------------------|----------------------|----------------|--------------------------|-------------------------------|-------------------------------|---------------------------|
| 1   | SC-N              | 460 773.24 713.76    | 2170.60        | 37.303                   | 2.341                         | 3.5                           | 24.7865                   |
| 2   | SN-CPCm           | 460 773.24 407.64    | 1821.46        | 33.832                   | 1.505                         | 3.0                           | 23.6425                   |
| 3   | SN-CPRha          | 460 773.24 353.50    | 1785.03        | 27.351                   | 1.453                         | 2.87                          | 19.3459                   |
| 4   | SC-PCm            | 460 523.91 407.64    | 1662.61        | 23.252                   | 0.969                         | 2.05                          | 17.9885                   |
| 5   | SC-PRha           | 460 466.71 353.50    | 1546.48        | 21.801                   | 0.962                         | 1.6                           | 17.5373                   |

Note:
S=sand, C=coarse, N=natural, P=PET, Cm=cement, Rha=rice husk ash
SC-N = sand & coarse → natural aggregate
SN-CPCm = Sand → natural; Coarse → PET-cement
SN-CPRha = Sand → natural; Coarse → PET-rice husk ash
SC-PCm = Sand & coarse → PET-cement
SC-PRha = Sand & coarse → PET-rice husk ash

According to Table 3 above, it can be seen that all concrete mixtures that used artificial aggregates were in accordance with the structural lightweight concrete criteria. Figure 11 shows the surface of specimen fragments of several types of concrete after compressive testing. In concrete that used fine aggregate in the form of natural sand, the form of coarse aggregate made of plastic was clearly visible (11 a.), but in concrete where all the fractions (fine and coarse aggregate) used artificial aggregates the difference between gravel and sand was not clearly visible, and it looked like a homogeneous mixture (11 b. and 11 c.).
4. Conclusions
This paper studies the effects of adding minerals on plastic aggregates for lightweight concrete which yielded the following conclusions:
1. Artificial aggregates from recycled PET plastic with a mineral mixture can be used as a substitute for natural aggregates.
2. Adding minerals to PET aggregates can make the surface of plastic aggregates more rough and porous.
3. The compressive strength of concrete using aggregate PET mixed with minerals would be higher than that of concrete with pure PET aggregate.
4. The proportion of minerals with PET plastic affects the density of the concrete formed, the more mineral content the higher the density of the concrete.
5. Rice husk ash and cement as added material on plastic aggregates can make concrete reach the structural lightweight concrete criteria.
6. The use of plastic aggregates would reduce the mechanical characteristics of concrete; this is compared to reference concrete, which is concrete with natural aggregates.

References
[1] ACI 213 R-87 1999 Guide for Structural Lightweight-Aggregate Concrete.
[2] Alqahtani, F. K., Ghataora, G., Khan, M. I., Dirar, S., Kioul, A., and Al-Otaibi, M. 2015 Lightweight Concrete Containing Recycled Plastic Aggregates International Conference On Electromechanical Control Technology and Transportation (ICECTT 2015), (Icectt) pp 527–533.
[3] Choi, Y. W., Moon, D. J., Chung, J. S., and Cho, S. K. 2005 Effects of waste PET bottles aggregate on the properties of concrete. Cement and Concrete Research.
[4] Geyer, R., Jambeck, J. R., and Law, K. L. 2017 Production, uses, and fate of all plastics ever made. Science Advances 3 7 p 5
[5] Jansen, D. C., Kiggins, M. L., Swan, C. W., Malloy, R. A., Kashi, M. G., Chan, R. A., Javdekar, C., Siegall, C., and Weingram, J. 2001 Lightweight fly ash-plastic aggregates in concrete. Transportation Research Record, 1775 1 pp 44–52.
[6] Kan, A., and Demirboga, R. 2009 A novel material for lightweight concrete production Cement & Concrete Composites 31 pp 489–495.
[7] Rumšys, D., Bačinskas, D., Spudulis, E., and Meškenas, A. 2017 Comparison of Material Properties of Lightweight Concrete with Recycled Polyethylene and Expanded Clay Aggregates Procedia Engineering 172 pp 937–944.
[8] Saikia, N., and De Brito, J. 2012 Use of plastic waste as aggregate in cement mortar and concrete preparation: A review *Construction and Building Materials* **34** pp 385–401.

[9] Sharma, R., and Bansal, P. P. 2016 Use of different forms of waste plastic in concrete - A review *Journal of Cleaner Production* **112** pp 473–482.

[10] Standart Nasional Indonesia 03-1968-1990 *Metode Pengujian Tentang Analisis Saringan Agregat Halus Dan Kasar* (Jakarta: Badan Standarisasi Nasional Jakarta).

[11] Standart Nasional Indonesia 15-7064-2004 *Semen Portland Komposit* (Jakarta: Badan Standarisasi Nasional Jakarta).

[12] W, K. Aswatama., Suyoso, H., Utami, N. M., and Pranadiarso, T. 2018 The Effect of Adding PET (Polyethylen Terephthalate) Plastic Waste on SCC (Self-Compacting Concrete) to Fresh Concrete Behavior and Mechanical Characteristics *Journal of Physics: Conference Series* **953** 012023.

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