Splitting tensile strength of lightweight concrete using polypropylene coarse aggregate coated with sand

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Abstract. As part of efforts to reduce plastic waste, transformation of it to one concrete component will be good for the environment. The use of plastic waste as coarse aggregate in concrete making can provide lighter concrete but with a lower strength compared to normal concrete. Accordingly, an experimental study of 42 concrete specimens using waste polypropylene coarse aggregates coated with sand was carried out. Splitting tensile tests were conducted to cylinder concrete specimens having diameter of 15 cm and depth of 30 cm respectively. Three mixtures of sand coated polypropylene coarse plastic aggregate, river sand as fine aggregate, water and Portland Composite Cement with a water-cement ratio of 0.29, 0.287 and 0.255 were conducted. The mass proportion of cement and sand are the same but the mass of plastic coarse aggregates coated with sand is specific for each mixture. Splitting tensile strength of the specimens in general shows that higher tensile strength is found for specimens having higher compressive strength. From the test results, two equations of splitting tensile strength are proposed where it is based on three different quality of lightweight concrete at the age of 7 and 28 days. Finally the splitting tensile strength for lightweight concrete using polypropylene coarse aggregate coated with sand is found to be higher than the direct tensile strength for the same lightweight concrete.

1. Introduction

Recent studies confirm the use of plastic aggregates as component of concrete material with satisfactory results \cite{1, 2}. The use of it as one of the component of a construction material could minimize plastic waste problem. As there are many kind of plastic waste from industries, there is lack of mechanical properties information of lightweight concrete using a specific plastic waste aggregate. Beside compressive strength, shear strength, elasticity modulus and Poisson ratio, tensile strength is considered as one of the important mechanical properties in the civil engineering domain. Direct tension, splitting and flexure tests are often used for determining the tensile strengths of normal and lightweight concrete. Flexure and splitting concrete tensile strength are considered higher in values compared to direct tensile strength \cite{3, 4}. Since there are three formulations for concrete tensile strength, appropriate engineering judgement should be used in the design and construction of civil engineering concrete structures. Recent studies of splitting tensile test of concrete could give new perspective in the construction industry. In this regard, Yan K et al \cite{5} have presented a possible applicability of support vector machine (SVM) to predict the splitting tensile strength of concrete from compressive strength of concrete. Another study \cite{6} shows a better understanding of the effects of a construction joint on the splitting tensile strength could reducing the amount of steel reinforcement at the construction joints.
In this study, splitting tensile strength of lightweight concrete using polypropylene waste plastic coarse aggregate which is coated with sand is obtained as function of the compressive strength at age of 7 and 28 days. Finally the splitting tensile strength equation is compared to direct tensile strength from previous study.

2. Experimental program
The main objective of this study is to obtain the splitting tensile strength of the lightweight concrete. A series of trial mix was conducted previously before conducting the compression and splitting tensile tests. The preparation of the material needed for concrete mix design is described in the following paragraph.

2.1 Materials
Portland Cement Composite was used to comply Indonesian Standard (SNI 15-7064-2004) [7] and British Standard (BS EN 197-1:2000) [8]. The coarse aggregate was produced from waste of Polypropylene (PP) plastic. Figure 1 presents the original shapes of uncoated plastic aggregate. The uncoated aggregate shape is similar to the plastic aggregate designed by Pamudji, G et al [9]. The size of the biggest aggregate has generally 10 mm of thickness and, 20 mm of length and 20 mm of width. The coated plastic aggregate was produced by the same method as presented in [10]. In this regard, plastic aggregate was established by heating the plastic up to the melting point, then flowed into the mould by hydraulic pressure. The process itself was conducted using manual injection plastic machine with automatic temperature control. The melting temperature of the plastic is in range of 130±10°C. The plastic aggregate were then cooled after the formation. Afterward it was coated with hot sand by placing the uncoated plastic aggregate into a rotating cylinder. The final shape of plastic aggregate coated with sand is presented in Figure 2. The coating is expected to improve bonding at the interface between coarse aggregate and mortar. Abrasion test was established afterward, and the coarse aggregate abrasion is obtained not more than 10.8%.

![Figure 1. Shape of uncoated plastic aggregate [9]](image1)

![Figure 2. Plastic aggregate coated with sand [10]](image2)

Sand was taken from Cimangkok which is located at West Java Province, Indonesia. It was used as fine aggregate. Size of the fine aggregate is less than 9.5 mm while its bulk specific gravity and fineness modulus of the fine aggregate are found to be 2.588 and 2.316 respectively. The passing percentage of fine aggregate is within the limits as indicated in Indonesian standard SNI 03-2834-2000 [11].

2.2 Mix proportion of concrete
Proportion of materials was determined using mix design formulation that is based on absolute volume. From trial mixes, 3 (three) material mix proportion are denoted by mix design or mixture (MD1, MD2 and MD3) have fulfilled the material mixture for structural purposes. For the 3 mixtures, the results of the sieve analysis of the coarse aggregate are almost the same as shown in Figure 3a and 3b, where the results are slightly outside the lower and upper limit as indicated in Indonesian Standard SNI 03-2834-2000. The sieve analysis of the fine aggregate is presented in Figure 4 where the result is within both limit, upper and lower.
Similar water to cement ratio (W/C) were used for the 2 (three) mixtures, which are 0.290 and 0.287 for mixtures MD1 and MD2 respectively, while mix design MD3 has 0.256 as presented in Table 1. Superplasticizer (SP) was used in order to have better workability to mix all materials of MD1 to MD3.

### Table 1. Concrete mix proportion

| Mixture Type | W/C  | Cement (kg) | Sand (kg) | Coarse Plastic Aggregate (kg) | Water (kg) | SP (kg) |
|--------------|------|-------------|-----------|--------------------------------|------------|-------|
| MD1          | 0.290| 482         | 826.0     | 434.686                        | 139        | 2.90  |
| MD2          | 0.287| 529         | 909.9     | 367.773                        | 152        | 3.70  |
| MD3          | 0.256| 558         | 961.0     | 349.707                        | 143        | 4.46  |

2.3 Density of concrete specimens

The splitting tensile test of concrete specimens was carried out on 150 mm diameter and 300 mm height cylinder specimens where at 7 days 3 (three) specimens, and at 28 days 4 (four) cylinders were tested for each mixture. The density of these 21 cylinders specimens are listed in the Table 2. The densities of other 21 cylinders specimens for compression test are found almost in the similar range as shown in Table 2.
Table 2. Average concrete density

| Age (days) | MD1 (kg/m³) | MD2 (kg/m³) | MD3 (kg/m³) | Number of specimen |
|------------|-------------|-------------|-------------|--------------------|
| 7          | 1780.48     | 1785.47     | 1811.75     | 9                  |
| 28         | 1738.22     | 1779.77     | 1781.27     | 12                 |

2.4 Compression test of concrete specimens

The compression test of concrete specimens was carried out on 150 mm diameter and 300 mm height cylinder specimens where at 7 days 3 (three) specimens were tested, and at 28 days 4 (four) cylinders were compressed for each mixture. Compression test was done by following ASTM C-39 [12]. The compression test was conducted at the 7th and 28th day for a total of 21 specimens tested as shown in the Table 3.

Table 3. Average concrete compressive strength

| Age (days) | MD1 (MPa) | MD2 (MPa) | MD3 (MPa) | Number of specimen |
|------------|-----------|-----------|-----------|--------------------|
| 7          | 17.03     | 19.28     | 20.34     | 9                  |
| 28         | 21.01     | 23.45     | 26.58     | 12                 |

2.5 Splitting tensile test of concrete specimens

The splitting tensile test of concrete specimens was carried out on 150 mm diameter and 300 mm height cylinder specimens where at 7 days 3 (three) specimens were tested, and at 28 days 4 (four) cylinders were examined for each mixture. Splitting tensile test was carried out by following ASTM C-496 [13]. The test was conducted at the 7th and 28th day for a total of 21 specimens tested as shown in the Table 4.

Table 4. Average concrete splitting tensile strength

| Age (days) | MD1 (MPa) | MD2 (MPa) | MD3 (MPa) | Number of specimen |
|------------|-----------|-----------|-----------|--------------------|
| 7          | 1.42      | 2.06      | 2.39      | 9                  |
| 28         | 2.12      | 2.43      | 2.52      | 12                 |

2.6 Splitting tensile and compressive strength relation

Having all the average compressive and splitting tensile strength at age of 7 days and 28 days for all the 3 mixtures as shown in the Table 5 and Table 6, we can find the relation between the concrete splitting tensile $f_{sp}$ and compressive strength $f_{c'}$ for 7 days and 28 days old concrete as presented by the equation (1) and (2).
Table 5. 7 days splitting tensile and compressive strength

| Mixture type | Compressive strength (MPa) | Splitting tensile strength (MPa) | Percentage to compressive strength (%) | Average percentage (%) |
|--------------|-----------------------------|----------------------------------|----------------------------------------|-------------------------|
| MD1          | 17.03                       | 1.42                             | 8.34                                   | 10.256                  |
| MD2          | 19.28                       | 2.06                             | 10.68                                  |                         |
| MD3          | 20.34                       | 2.39                             | 11.75                                  |                         |

\[ f_{sp} = 0.1025 \ f'c' \] for concrete age of 7 days

Table 6. 28 days splitting tensile and compressive strength

| Mixture type | Compressive strength (MPa) | Splitting tensile strength (MPa) | Percentage to compressive strength (%) | Average percentage (%) |
|--------------|-----------------------------|----------------------------------|----------------------------------------|-------------------------|
| MD1          | 21.01                       | 2.12                             | 10.09                                  | 9.977                   |
| MD2          | 23.45                       | 2.43                             | 10.36                                  |                         |
| MD3          | 26.58                       | 2.52                             | 9.48                                   |                         |

\[ f_{sp} = 0.0997 \ f'c' \] for concrete age of 28 days

3. Splitting tensile and direct tensile strengths

Previous study [14] has found the direct tensile strength \( f_t \) as function of the compressive strength from the same type of lightweight concrete, which is presented by the equation (3).

\[ f_t = 0.42 \ \sqrt{f'c'} \] for concrete age of 28 days

By introducing the same compressive strength into the equation (2) and (3), we can obtained a lower value of direct tensile strength compared to that of splitting tensile strength for the same specific lightweight concrete material. Similar situation was also found by Kim and Taha in their study [15].

4. Failure pattern of concrete specimen

From 21 specimens tested, all specimens have experienced failure almost at the middle part of the concrete cylinder specimens. Example of this typical failure is shown in the Figure 5 for concrete specimen at age of 7 days, and Figure 6 represents typical failure from specimen at the age of 28 days.

5. Conclusive remarks

In this study, it is concluded that splitting tensile strength is dependent on the compressive strength of the concrete. The higher the compression strength the higher the splitting tensile strength will be. The splitting tensile strength of lightweight concrete studied is higher compared to that of direct tensile strength obtained from previous study. This study also reveals that polypropylene coarse aggregate coated with sand contributes in fulfilling the lightweight structural concrete criteria. Two equations of splitting tensile strength are proposed where it is based on three different quality of lightweight concrete at the age of 7 and 28 days. The failure pattern of all specimens, are typical where it is located at the middle part of the concrete cylindrical specimen following the direction of the vertical load applied to the specimens. Future work involving flexure tests of beams made of lightweight
concrete using polypropylene coarse aggregate coated with sand are to be conducted to have insight of the tensile strengths from direct tension, splitting and flexure tests.

Figure 5. Typical failure of 7 days old specimen

Figure 6. Typical failure of 28 days old specimen

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