Mechanical properties of normal concrete for local road pavement using plastic waste substitution as course aggregate

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Abstract. Plastic waste can decrease the carrying capacity of the environment, only about 4% can be recycled. Through research, it is expected to be one of the solutions to the use of plastic waste to reduce environmental impacts. The use of substitution of plastic waste as coarse aggregate in the weight-volume mixture with proportion of 2%, 4%, 6%, 8% and 10% in normal concrete used for local roads and determining the mechanical properties are the aims of this research. The results showed that the compressive strength for reference concrete was 21.268 MPa greater than designed (fc = 19.3 MPa) and with a mixture of plastic waste respectively 13.298 MPa, 14.430 MPa, 11.506 MPa, 6.602 MPa, 6.602 MPa and 5.753 MPa. The tensile strength of the reference concrete is 2.853 MPa, and compared with substitution of 1.981 MPa, 2.216 MPa, 1.863 MPa, 1.155 MPa and 1.179 MPa. The flexural strength test below and do not meet the criteria for the local roads (3 MPa). Plastic waste up to 10% substitution shows the lowest decrease with 4% plastic waste resulting in 19.5% decrease in flexural strength compared to reference concrete and every 2% increase plastic was 10-20% flexural strength decreases.

1. Introduction
Manufacturing processes, service industries and municipal solid waste generally produce waste materials. Increased environmental awareness and concerns related to the disposal of generated waste increase research on this issue. Reuse of wastes is considered the best environmental alternative for solving the problem of disposal. Results search of publications during 2015 for the use of plastic waste in concrete mixes with a total of 84 studies publications for plastic as an aggregate or fiber show that the use of virgin plastic materials (polyethylene terephthalate/PET) is better than recycled results for concrete mixes [1].

Previous studies state that reuse plastic waste PET as an aggregate of sand substitution in concrete provides a good approach to reducing material costs and solving some of the problems of solid waste caused by plastic [2]. Proportion 20% PET as coarse aggregate in concrete with 0.42 w/c ratio and high workability can be used for structural concrete member [3]. The combination of Silica Fume (SF) and Recycled PET fiber increased 3.6–9% compressive strength, 16.9–21.5% elastic modulus, 11.8–20.3% splitting tensile strength [4]. Experimental study on use of coarse aggregate ranging from 0 to 12.5% with E-waste plastic for M 20 grade concrete using manufacturing sand. Its shown the compressive strength of concrete replacing e-waste is high compared to conventional concrete with 10% of
replacement, flexural strength is high compared to conventional concrete with 10% of replacement and the split tensile test is high compared to conventional concrete with 12.5% replacement [5]. Addition of coarse aggregate 15% E-waste displayed a decremental trend in the case of structural strength for M 20 grade concrete [6] and M 60 grade concrete with 20% limited substitution of coarse aggregate [7]. The compressive strength for optimum cement content and 10% E-plastic in the mixture produces weakness and is very good in compressive strength of grade 53 cement [8].

In general, plastics have a low density, are electrically insulating, have varying mechanical strength, limited temperature resistance, and vary chemical resistance. Plastic is also lightweight, easy to design and cheap to manufacture. Plastic waste creates problems for the environment and can decrease the carrying capacity of the environment, only about 4% can be recycled [9]. The use of plastic waste in the production of concrete and mortar normally results in a decline in almost all properties, as a result of their greater deformability and impervious nature, which prevent adequate compatibility with the cement matrix. However, the use of plastic waste has been found to improve the shrinkage behavior, resistance to chloride ion penetration, and to abrasion wear [10].

The abrasion wear on the wearing course of the rigid pavement that receives the most weight, therefore the material making up this layer must be material that is strong enough. A rigid pavement is constructed from cement concrete or reinforced concrete slabs. The materials and design and implementation methods used are the same as concrete in general. The use of sustainable materials (green material) in concrete mixes is an important issue in sustainable pavement such as the use of waste in concrete mixtures [11].

Pavement layers planning needs to be considered several factors that can affect the function of the pavement construction services, including road functions, pavement performance, life service, traffic which is the burden of pavement, soil properties, environmental conditions, properties and materials available at the location to be used for pavement, and geometric shapes of pavement layers.

Based on the description above to minimize the environmental pollution by reusing the plastics waste in the required shape and to understand the behavior of concrete in pavement for local road by conducting mechanical tests with experimental study. Plastics waste were obtained from PET bottle waste is used in this study as replacement for coarse aggregate. The major objective of this task is to reduce as far as possible the accumulation of used and discarded plastic waste into socially and industrially beneficial raw material using simple, low cost and environmental friendly technology [10]. The coarse aggregate was partially replaced with different percentages of plastic by volume ranging from 0 to 10% as most of the previous studies for concrete structural were concentrated on 0–20% plastic waste [8,12]. In this study plastic waste with the proportion of 0-10% with an interval of 2% for local road pavement layers which require 3 MPa concrete flexural strength. Previous study state, the flexural strength with 10% plastic waste M20 concrete (20 MPa) increased 12.5% compared to conventional [5], 1% PET increases flexural strength 23.11% [12].

1.1. Concrete
Concrete is a function of its constituent material consisting of hydraulic cement, coarse aggregate, fine aggregate, water and with or without admixtures or additive [13]. Definition by ACI CT-13 is mixtures of Portland cement or mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials [14]. Air content in normal concrete mixed by weight-volume approximately 1% - 3% for non air-entrained and 4% -8% for air-entrained concrete, cement paste is 25% - 40%, and aggregates about 60% - 75% [15].

The concrete compressive strength characteristics are influenced by the properties constituent materials. The most important parameters affect the strength of concrete, among others: [9,12,13]; 1) cement quality, 2) the proportion of cement in the mixture [16]. 3) aggregate quality, 4) interaction or adhesion between cement paste and aggregate, 5) adequate mixing of concrete materials, 6) concrete casting, compacting, and finishing 7) concrete curing [17], dan 8) the chloride content does not exceed 0.15% in exposed concrete and 1% for unexposed concrete. Most of the concrete material uses local materials except portland cement or chemical admixtures, so when viewed from an economic standpoint
it is very profitable [16,18]. The understanding of the characteristics of the concrete materials and concrete mixture are important according to the behavior of the structure to be made [9,12].

1.2. Mechanical properties

Concrete compressive strength — the measured maximum resistance of a concrete specimen to axial compressive loading and expressed as force per unit cross sectional area [14]. Determination of compressive strength can be done by using a compressive test instrument with a cylindrical specimen in accordance with ASTM C-39 test procedures or cubes according to BS-1881 Part 115; Part 116 at 28 days. The concrete structure design used in buildings according to Indonesian Standard (SNI 2847:2013) article 5.1.1 must not be less than 17 MPa based on cylinder test and test stated in MPa or kg/m². The calculated according to Equation Eq. 1, where: \( f'_c \) is concrete compressive strength, MPa; \( P \) is maximum load (kN); and \( A \) is cross sectional area (mm²).

\[
f'_c = \frac{P}{A}
\]

(1)

Splitting tensile strength, \( (f_{cr}) \) is tensile strength of concrete determined by a splitting tensile test (also called indirect tension strength). Concrete tensile strength test should not be used as a basis for acceptance of concrete in the field. The maximum concrete tensile strength, \( f_{cr} = T \) in MPa obtained from the compressive test can be calculated by Eq. 2 [19], where \( P \) is maximum load, (N), \( D \) is diameter of specimen, (mm), \( L \) length of specimen, (mm) and \( \pi = 3,14 \),

\[
T = f_{cr}(MPa) = \left( \frac{2P}{\pi DL} \right)
\]

(2)

The strength of concrete used for the pavement layer is expressed in the value of flexural strength \( (f_{cf}) \) at 28 days, which is obtained from the results of beam testing by three points loading. The relationship between the compressive strength with the concrete tensile strength can be approached by Eq. 3 in MPa and the tensile strength with Eq. 4 in kg/cm², where \( K = 0.70 \) for natural aggregate and \( K = 0.75 \) for crushed aggregate [20].

\[
f_{cf} = K(f'_c)^{0.50}
\]

(3)

\[
f_{cf} = 1.37f_{cr}(MPa)
\]

(4)

1.3. Strength of concrete for local road

Road as one of the transportation infrastructure is an important element in the development of national and state life, in fostering the unity and integrity of the nation, state territory, and community functions as well as in advancing public welfare as referred to in the preamble of the 1945 Constitution of the Republic of Indonesia. According to Law No.38 on roads. The local road (jalan lingkungan) is a public road that serves to serve local transportation with the characteristics of short-distance travel, and low average speed. Generally, compressive strength is low about \((10 \leq f'_c < 15)\) and typically of flexural strength about 3–5 MPa (30-50 kg/cm²) [20].

2. Methods

The method used is experimental research and several testing methods for concrete and concrete mix materials are in accordance with Indonesian National Standards (SNI). Sample data is the result of compressive strength and tensile strength test of concrete-weight mixtures in the laboratory. Substitution of plastic waste (PET) with the proportion of 0% as reference concrete and 2%, 4%, 6%, 8% and 10% where each proportion is made with 12 test specimens with 6 test samples taken randomly for compressive strength test and 3 for tensile strength test.
3. Results and discussion

3.1. Mix design
Mix design used weight-volume absolute according Indonesian Standard for concrete mixture of 1 m³ with $f'c = 19.3$ MPa (K 225), slump (12 ± 2) cm, w/c = 0.58 and superplastisizer 2% [21], shown in Table 1, where A is reference concrete mixture, B; C; D; E; and F with substitution plastic waste 2%; 4%; 6%; 8% and 10% by weight of coarse aggregate.

| Treatment (Plastic Waste) | Cement (kg) | Water (liter) | Fine Aggregate (sand), (kg) | Course Aggregate (crushed stone), (kg) | Chemical Admixture (Plastocrete 1003), (liter) | Plastic Waste, (kg) | Total (kg) |
|---------------------------|-------------|---------------|-----------------------------|----------------------------------------|-----------------------------------------------|--------------------|------------|
| A (0%)                    | 371         | 215           | 827                         | 1049                                   | 4.3                                           | 0.00               | 2466       |
| B (2%)                    | 371         | 215           | 827                         | 1028                                   | 4.3                                           | 20.98              | 2466       |
| C (4%)                    | 371         | 215           | 827                         | 1007                                   | 4.3                                           | 41.96              | 2466       |
| D (6%)                    | 371         | 215           | 827                         | 986                                    | 4.3                                           | 62.94              | 2466       |
| E (8%)                    | 371         | 215           | 827                         | 965                                    | 4.3                                           | 83.92              | 2466       |
| F (10%)                   | 371         | 215           | 827                         | 944                                    | 4.3                                           | 104.90             | 2466       |

3.2. Results of compressive strength and splitting tensile strength
The results of the compressive strength test at the age of 28 days concrete (Figure 1) and splitting tensile strength (Figure 2). From Table 2 the data is converted using Eq. 3 and 4, the results as a flexural strength shown in Table 3. The compressive strength of concrete tends to decrease by around 1.44 MPa and splitting tensile strength about 0.16 MPa for 1% increased proportion plastic waste in the aggregate mixture.

| Treatment (Plastic Waste) | Average compressive strength (MPa) | Average splitting tensile strength (MPa) |
|---------------------------|------------------------------------|----------------------------------------|
| A (0%)                    | 21.268                             | 2.853                                  |
| B (2%)                    | 13.298                             | 1.981                                  |
| C (4%)                    | 14.430                             | 2.216                                  |
| D (6%)                    | 11.506                             | 1.863                                  |
| E (8%)                    | 6.602                              | 1.155                                  |
| F (10%)                   | 5.753                              | 1.179                                  |

| Treatment (Plastic Waste) | Flexural strength calculated from the compressive strength | Flexural strength calculated from the splitting tensile strength | Average (MPa) |
|---------------------------|-------------------------------------------------------------|---------------------------------------------------------------|---------------|
| A (0%)                    | 3,909, 3,656, 3,432, 2,877, 3,216, 3,568                   | 3,876, 3,780, 4,070, 3,598                                     |
| B (2%)                    | 2,904, 2,985, 2,148, 2,877, 2,932, 2,459                   | 3,488, 2,519, 2,132, 2,716                                     |
| C (4%)                    | 2,523, 3,568, 2,821, 2,764, 2,706, 2,585                   | 3,198, 3,198, 2,714, 2,897                                     |
| D (6%)                    | 2,185, 2,706, 2,427, 2,616, 2,706, 2,585                   | 3,198, 2,132, 2,326, 2,542                                     |
| E (8%)                    | 1,261, 1,382, 1,596, 2,257, 2,394, 2,326                   | 1,939, 1,551, 1,260, 1,774                                     |
| F (10%)                   | 1,596, 2,292, 1,693, 1,645, 1,828, 1,645                   | 2,132, 1,163, 1,551, 1,727                                     |

\(^a\) Using Eq. 3: $f_{cf} = K(f_c)^{3.58}$
\(^b\) Using Eq. 4: $f_{cf} = 1.37 f_{cs}$
The test results show the flexural strength which is slightly above the minimum compared design and for all treatments by adding plastic waste 2% - 10% of the weight of coarse aggregate does not meet the criteria for local roads, because all of them are less than 3 MPa. Previous study state, the flexural strength with 10% plastic waste M20 concrete (20 MPa) increased 12.5% compared to conventional [5], 1% PET increases flexural strength 23.11% [12], compared the results of research conducted show the difference. The use of plastic waste (PET) up to 10% substitution in coarse aggregate shows the lowest decrease with 4% PET resulting in 19.5% decrease in flexural strength compared to reference concrete. For every 2% increase in PET as coarse aggregate, the flexural strength is 10-20% decreases.

![Figure 1. Compressive strength average.](image1)

![Figure 2. Splitting tensile strength average.](image2)

4. Conclusion
The compressive strength of concrete with 6 test samples without plastic waste as reference concrete is 21,268 MPa on average larger than designed. Respectively of 2%, 4%, 6%, 8% and 10% of plastic waste from the weight aggregate of all the compressive strength under the reference concrete and the higher the proportion of waste plastic made a lower compressive strength.

The test results show the flexural strength for reference concrete which is slightly above the minimum criteria. All treatments by substitution plastic waste about 2% - 10% of the weight of coarse aggregate does not meet the criteria for local roads, because all of them are less than 3 MPa. For every 2% increase in PET as coarse aggregate, the flexural strength is 10-20% decreases. This is presumably because the adhesion between plastic and cement or aggregate cannot be adhered perfectly.

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