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STUDY ON EXPERIMENTAL BEHAVIOUR OF CONCRETE WITH TOOTHBRUSH PLASTIC WASTE AS COARSE AGGREGATE

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ABSTRACT: Indonesia is one of the countries that cannot reduce the waste problem, especially plastic waste. The main cause is the lack of public understanding and awareness of the dangers in the future. Even though the government has implemented several regulations and methods to press the waste problem, it has not reduced the amount of value. Toothbrush Plastic waste (TPW) contributes the largest value to plastic waste apart from food packaging and household goods. The characteristics of TPW are that it is hard, heat resistant, can not rot, and has no economic value. Then, the TPW was chosen as the material for Toothbrush Plastic Waste of Concrete (TPWC), which would create a new type of lightweight concrete. This research used experimental methods to study the behavior of toothbrush waste plastic (TPW) as a substitute for concrete materials. The compositions of TPW in concrete were 2.5%, 5%, and 7.5% of the volume of coarse aggregate. The research on toothbrush plastic waste of concrete (TPWC) includes compressive strength tests, density tests, and modulus of elasticity tests. The results of compressive strength tests were TPWC 2.5 was 17.55 MPa, TPWC 5 was 16.52 MPa, and TPWC 7.5 was 14.91 MPa. The maximum stress on the three samples was 15.29 MPa, and the result of strain were TPWC 2.5 was 0.0029, TPWC 5 was 0.0039, and TPWC 7.5 was 0.0047. It is proven that if the volume of coarse aggregate is reduced, the strength value also decreases, but this does not affect the elastic modulus value.

Keywords: Toothbrush plastic waste concrete, lightweight concrete

1. INTRODUCTION

Concrete is a mixture of cement or other materials, among others cement, fine aggregate, coarse aggregate, and water, with or without additional mixed materials that form a solid mass. Concrete is a mixture of its constituent materials consisting of hydraulic cement materials, coarse aggregate, fine aggregate, and water with or without the use of additives. Lightweight concrete (LC), which aggregates from high-density-polyethylene (HDPE) in plastic bottles, waste as coarse aggregates. The lightweight concrete was 17Mpa. the compressive strength was increased [1]. The results showed the compressive strength was 13.16 MPa with a weight LC design of 1.373 kg/m^3. The research results prove that this type of concrete was used as a substitute material for lightweight concrete (LC) on light structural elements and non-structural elements [2]. Aggregate is the main material for concrete and has a very important role, especially in the strength of concrete. The type of aggregate determines the strength of concrete [3]. However, the development of concrete is not directly proportional to the limited natural resources that are provided and are utilized as coarse aggregate materials [4].

Aggregates are mineral grains that are the natural disintegration of the rocks. In Indonesia, aggregates are from broken rocks. The aggregate in concrete reaches approximately 70% - 75% of the volume. The mandatory specification of fine aggregates, coarse aggregates, and water in concrete, among others water, were clean water, odorless, water does not contain chemicals or organics, etc., which can cause damage to concrete or reinforcement.

Human activity produces organic waste 60-70%, and 30-40% inorganic waste. Plastic waste is 14% of inorganic waste. Plastic waste is a problem because it cannot decompose for 20-100 years. the waste plastic cannot decompose by microorganisms, reduces O2 levels, disturbs the ecosystem of soil, reduces rainwater infiltration, microorganisms can live, etc. The Indonesian government has established regulations to reduce waste production such as Degree of the Minister of Environment and Forestry of Indonesia No. 6 in 2022 concerning the management information system of waste [5].

Researched modulus elasticity of concrete by carpet fiber [6] proved the effect of concrete using Polyethylene Terephthalate (PET) plastic waste as coarse aggregate on lightweight concrete. PETs are beverage bottles that go through cutting, cleaning, cooling, and crushing. The results of the research were the maximum compressive strength in sample FM 7.08 was 15.14 MPa, the average values of tensile strength were FM 6.317 was 1.98 MPa, FM 6.738 was 4.297 MPa and FM 7.08 was 4.843 Mpa proved that if the composition of the plastic aggregate increases the compressive strength of concrete. The study of Lightweight Concrete (LC) by High-density polyethylene (HDPE) was as aggregate plastic from bag waste into concrete, and the results proved that plastic could decrease the compressive strength of concrete [7,8]. The lightweight concrete used concrete waste as coarse aggregate increasing the amount of round recycled coarse aggregate from concrete waste did not adversely affect the mechanical properties of the prepared concrete [9]. The plastic waste is used as a sand substitution for concrete. Compressive strength was able to increase up to 15.78%, with a waste substitution of 10%. The higher the amount of substitution, the stronger the ability to press reduced; the substitution of fine aggregate with plastic waste does not eliminate the ability of mortar [10].

Fig.1 Toothbrush plastic waste (TPW)

The plastic toothbrushes were waste with no value, which increases the amount of plastic waste. If each family has four adults and changes at least once every month, then each family produces 48 toothbrush waste/year. We can estimate toothbrush waste produced by Indonesians. The texture of the toothbrush handle, which is hard, does not rot easily, and is resistant to solar heat, is the basis for selecting which is used as a substitute for coarse aggregates for lightweight concrete. The SAN type of toothbrushes are safe to use as concrete material, so the weight of the concrete is light, and, at the same time, it can reduce plastic waste.

This research was preliminary research to know the behavior of concrete with Toothbrush Plastic Waste of Concrete (TPWC). The test object used a cylinder with D = 15 cm and height = 30 cm. Researches were density tests, modulus of elasticity tests, and compressive strength tests.

2. RESEARCH SIGNIFICANCE

The significance of the study was to test Toothbrushes Plastic Waste (TPW), which substitutes coarse aggregates. Based on this, a lightweight concrete composition was used. The toothbrush is cut into small pieces 1-2 cm long. The composition of TPW from the volume of coarse aggregate. The TPWC tested for compressive strength, modulus elasticity, and density, and the relationship was analyzed from the test result data.

3. MATERIALS AND METHOD

The research included cylindrical specimens measuring 150 mm × 300 mm. The variations of toothbrush plastic waste were 0%, 2.5%, 5%, and 7.5% of concrete volume. The aggregates are from Bili-Bili Village, South Sulawesi Province, Indonesia.

The research preparation, among others;

1. The design proportion of lightweight concrete [11,12,13], specification of concrete aggregate [14], and compressive strength test of Toothbrush Plastic Waste Concrete (TPWC) carried out after 28th days [15];
2. The characteristics test of aggregate, among others, specific gravity and absorption for fine and coarse [16,17], sieve analysis [18,19], bulk density [20], and degradation of coarse [21].
3. The cement tests, among others, cement specific gravity, cement fineness, normal consistency, binding time, and volume weight test [22,23].
4. The quality of water requirements [13].
5. The average compressive strength of concrete design as follows:

$$f'cr = f'c + 8.3 \tag{1}$$

6. The average of slump tests was 25–100 mm;
7. The water-cement ratio was 0.69 without air and 0.6 with air;
8. The sample was a cylinder, which is seen at Fig.2

Fig.2 The samples

9. The research used toothbrushes were SAN type of plastic waste (code plastic No.7 others) which processed by the cutting into small pieces measuring 1-2 cm and the TPW become coarse aggregates;
10. Proportion of TPW was 2,5 %, 5%, and 7,5 % of the volume of coarse aggregates;
11. The TPWC would be lighter because the percentage was from the volume reduction of coarse aggregate. If the proportions of TPW were based on weight, the volume of concrete would be larger;
12. The characteristic tests of TPW are the same as aggregate tests;

Fig.3 Toothbrush plastics waste (TPW) testing

13. The result of characteristics tests of Tooth Plastic Waste (TPW) is shown in Table 1.
14. The sieve test on TPW (Fig.3) was on sieve No.1/2 or 12.7 mm in diameter. The result of the sieve test showed that the TPW texture was between sand and coarse. The percentage of TPW is decided based on the volume of the coarse aggregate. if the percentage weight of TPWC increases, then the volume and dimensions of concretes are bigger, and the result in strength would be decreased.
15. The result TPW of the characteristic test can be seen at Table 1

Table 1. The characteristic test of TWP

Characteristic tests	Results
Sieve analysis	3.000
Water content	-
Mass of solid content	588 kg/m^3
Mass of loose content	634 kg/m^3
Specific Gravity	1.045

16. Based on the data of materials characteristic test and [12]. The concrete mix proportion in 1 m^3 as follows:

sand	=	726.193 kg
cement	=	277.484 kg
water	=	208.113 kg

Table 2. Proportion of TPW in 1 m^3

TPWC	Coarse Aggregate (kg/m^3)	TPW (kg/m^3)
0	1,067.649	0
2.5	1,052.674	14.975
5.0	1,037.699	29.950
7.5	1,022.724	44.925

Table 3 shows the proportion of TPW in 1 m^3 of concrete. The sand, cement, and water have the same weight the weight of aggregate decreases as the TPW increases.

Curing pool

The Density test

The Modulus elasticity test

The Compressive strength test

Fig.4 Testing activities

17. The research used experimental methods by concrete weight test, modulus of elasticity test [22,23], and compressive strength test [13]

4. RESULT AND DISCUSSION

From the results of the research, the following data were obtained:

Table 3. The weight of TPWC

TPWC	Weight (kg)	Compressive strength (MPa)
2.5	12.39	15.85
5.0	12.25	14,15
7.5	11.94	13,31

Table 3 shows the results of the weight test. If the percentage of concrete TPW increases, the total weight of the concrete will decrease. The TPWC 2.5 was 12.39 kg, TPWC5 was 12.25 kg, and TPWC 7.5 was 11.94 kg. The results show that weight can affect the compressive strength of TPWC.

4.1 Density Test

After 28 days, the TPWC was removed from the curing pool and then left for 3 days to dry at room temperature 26 C. The Density equation:

$$\mathbf{D} = \frac{\mathbf{P}}{\mathbf{V}} \tag{2}$$

Which were D = Density (kg/m^3), P = weight (kg) and V = Volume of sample (m^3)

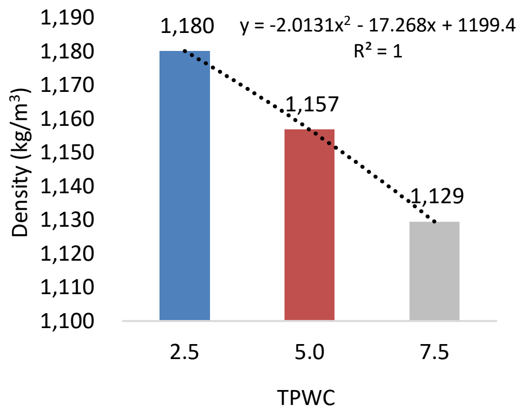

Fig 5. Density results

Fig.5 shows if the TPW value increases the weight of TPWC would be lighter. The reduction in coarse aggregate was replaced by TPW. Based on Eq. (2), the results of density (D) analysis were D2.5 was 1,180.09 kg/m3, D5 was 1,156.78 kg/m3, and D7.5 was 1,129.45 kg/m^3. The greater density was TPWC 2.5. Regression analysis results on density – the percentage of TPW returned polynomial function in which $R^2 = 1$ was

$$y_{density} = -2.0131x^2 - 17.268x + 1199.4 \tag{3}$$

Fig. 6 shows the relationship density-weight. It could be seen that TPWC 2.5 was greater in compressive strength and weight because it has the lowest percentage of TPW. The graph shows that the heavier TPWC was TPWC 7.5, which has lower density and is lighter. The TPWC has lower strength because the coarse aggregate can resist compressive strength on concrete.

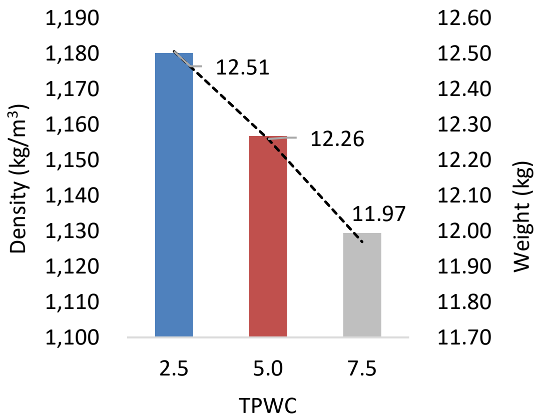

Fig.6 Density – weight

4.2. Compressive Strength Test

The equation used to determine the compressive strength is as follows:

$$f'c = \frac{P}{A} \tag{4}$$

which f'c = compressive strength (MPa), P = Load (N) and A = surface area of sample (mm^2)

Fig.7 Compressive strength – weight

Fig.7 shows the relationship between compressive strength increased from the 7th day until the 28th day. The compressive strength of TPWC 2.5 was 17.55 MPa, TPWC 5 was 16.52 MPa, and TPWC 7.5 was 14.91 MPa. Even though the compressive strength of TPWC decreased due to the large percentage of TPW, the compressive strength of TPW increased.

Fig. 8 shows that the greater the percentage of TPW, the smaller the compressive strength. This proves that coarse aggregate contributes to the compressive strength of concrete.

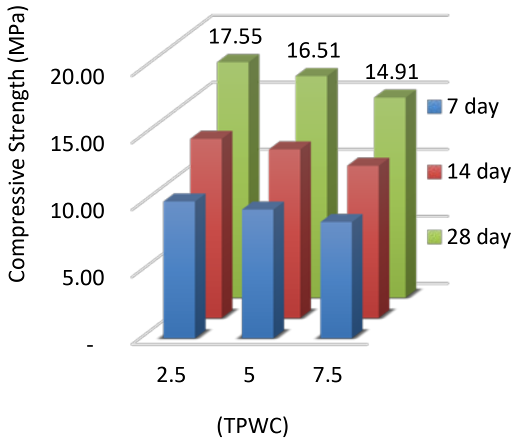

Fig.8 Compressive strength development of TPWC

This was due to the dense interface between the coarse aggregates being able to withstand the given compressive strength.

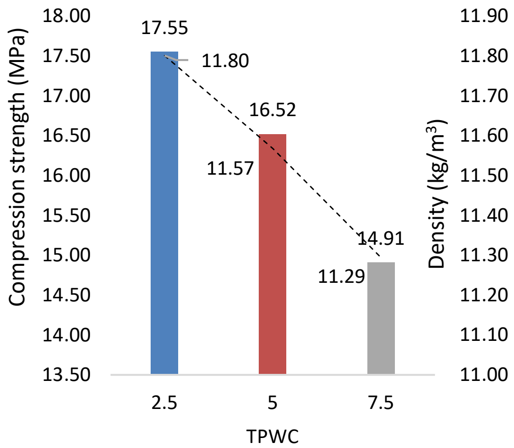

Fig. 9 Compressive strength - density

Fig. 9 shows the relationship between compressive strength and density. If the proportion of coarse aggregate becomes smaller, the density and compressive strength also decrease. This proves that coarse aggregate plays a role in maintaining strength because the hardness of the aggregate makes the concrete denser, thereby reducing rapid collapse.

4.3 Modulus Elasticity Test

The modulus elasticity test used a compressive strength machine and extensometer. Data recording took every 30 kN until it reached the maximum compressive strength at 300 kN. The modulus of elasticity (E) was based on [19] used Eq. (5)

$$\boldsymbol{EC} = \frac{\boldsymbol{S2 - S1}}{\boldsymbol{\varepsilon 2 - 0{,}00005}} \quad (5)$$

which were EC = Modulus of elasticity (E), $\boldsymbol{\sigma}_2$ = 40% of the collapse stress (MPa), $\boldsymbol{\sigma}_1$= the stress at strain ε_1 (MPa) and ε_2= Strain on S2.

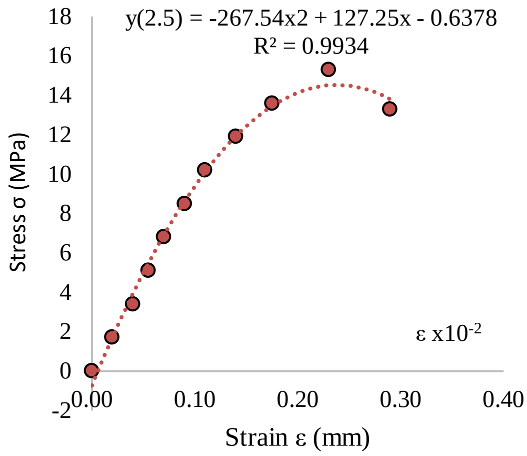

Fig.10 Modulus elasticity of TPWC 2.5

Fig.10 shows the modulus elasticity of TPWC 2.5. The elastic condition until the strength reached 8.48 MPa and the strain was 0.0009. The maximum strength was 15.29 MPa, and the strain was 0.0023. The graph decreases until the strength reaches 16.99 MPa, and the strain is 0.0029. Regression analysis on modulus elasticity of TPWC 2.5 result returned polynomial function which $R^2 = 0.9934$

$$y_{2.5} = -267.54x^2 + 127.25x - 0.6378 \quad (6)$$

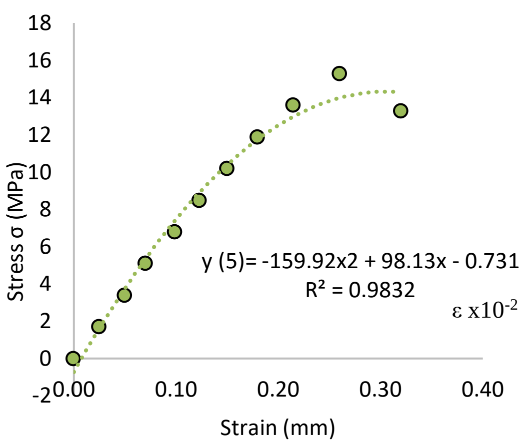

Fig.11 Modulus elasticity of TPWC 5

Fig.11 shows the modulus elasticity of TPWC 5. The elastic condition until the strength reached 8.48 N/mm^2 and the strain was 0.0012. The maximum strength of TPWC 5 was 15.29 MPa, and the strain was 0.0026. The graph decreases when the strength is 16.99 MPa, and the strain is 0.0032. Regression analysis on modulus elasticity of TPWC5 result returned a polynomial function in which R^2 = 0.9832

$$y_5 = -159.92x^2 + 98.13x - 0.731 \quad (7)$$

Fig. 12 shows the modulus elasticity of TPWC 7.5. The elastic condition until the strength reached 8.48 MPa and the strain was 0.0007. The maximum strength was 15.29 MPa, and the strain was 0.0039.

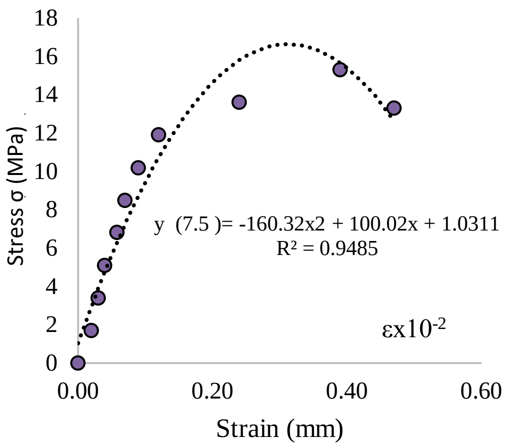

Fig 12 Modulus elasticity of TPWC 7.5

The graph decreases when the strength is 16.99 MPa and the strain is 0.0047. Regression analysis on modulus elasticity of TPWC 7.5 result returned polynomial function which R^2 = 0.9485

$$y_{7.5} = -160.32x^2 + 100.02x + 1.0311 \quad (8)$$

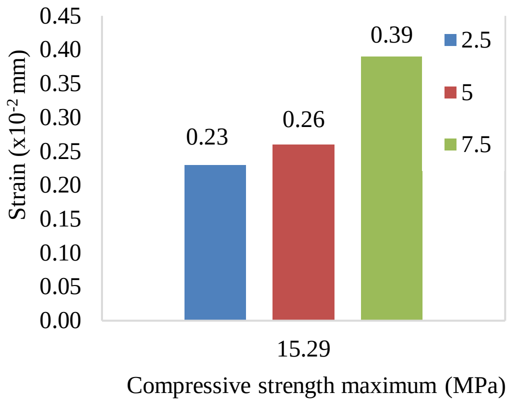

Fig.13 Compressive strength maximum - strain

Fig.13 shows the relationship between maximum strength between strains. The TPWC reached the same maximum compressive strength value of 15.29 MPa. The greater proportion was TPWC 7.5 because it has a higher compressive strength value and strain value. The conclusion is that coarse aggregate contributed to the compressive strength of concrete. The interface on coarse aggregates is able to withstand, which gives more strength to concrete.

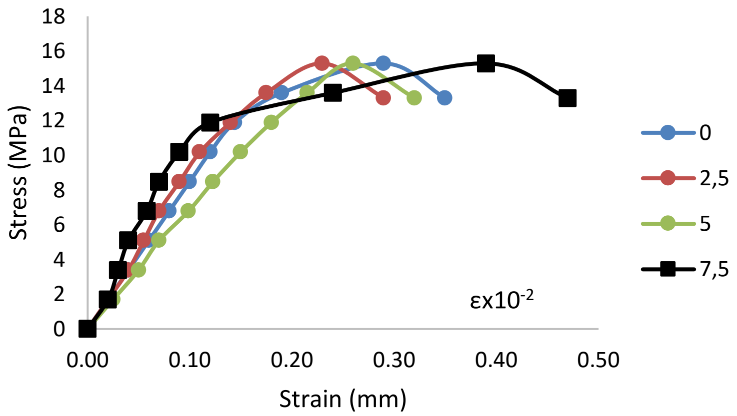

Fig.14 Stress-strain of TPWC

This modulus elasticity test used cylinders concrete [13]. The preliminary design was based on normal concrete because the object used TPW substitution, which reduced the weight of the concrete. Fig 14 shows the comparison of modulus elasticity TPWC, which shows the range of maximum compressive strength (f'c) was 13.31MPa – 15.85MPa. The decrease of the compressive strength TPWC was still within lightweight concrete requirements.

The modulus elasticity data takes until the maximum load and the object fail. The TPWC has the same maximum strength value of 15.29 MPa, and the maximum strain of TPWC 7.5 was 0,0039. It was lower than normal concrete. The maximum strain of normal concrete was 0.0035 according to present standards [14]. Fig.14 shows that the curve of normal concrete was linear until the strength was 11.89 MPa. On the other hand, all curves of TPWC were linear at 8.49 MPa. The TPWC conditions were more fragile due to TPW aggregate, whose surface was very sleek and did not have pores, causing the cement's adhesion to decrease.

There were two stages for the stress-strain curves of TPWC: The post-peak stage and the pre-peak stage. It can be seen in Fig. 11-12. The first condition was the pre-peak TPWC, where the strain was still in a linear condition until it reached a stress of 10.19 MPa, and then a plastic condition occurred until the maximum stress reached 15.29 MPa. The stress-strain relationship turns into a curve. The second condition was the post-peak stage; the condition of the concrete was damaged after the maximum stress, so the modulus of elasticity value is between 0.0023-0.0039, and the TPWC 7.5 has the best curve.

Fig.15 The sample after testing

When the load reaches the elastic condition, the first cracks begin to occur on the surface of the cylindrical specimens. The cracks started from the top and bottom. TPWC has crack patterns as cone cracks, and normal concrete has crack patterns as cone-shaped and split. The condition of TPW in concretes was united and very difficult to remove. The properties are almost the same as the natural aggregate. This proves that TPW can be substituted into the concrete mixture because it is able to interact.

5. CONCLUSION

The results of the compressive test showed that TPWC increased from the 7th day until the 28th day. The percentage of compressive strength increased as follows: TPWC 2.5 was 72.41%, TPWC 5 was 72.37%, and TPWC 7.5 was 72.36%. This shows that TPWC meets standards because there was an increase in compressive strength. However, the results also show that if the TPW increased, the compressive strength would decrease. The test objects were still in an elastic condition until the load reached 8.49 MPa. The test results obtained the maximum stress was $\boldsymbol{\sigma_{max}}$ =15.29 MPa, the maximum strain among others $\boldsymbol{\varepsilon_{2.5\ max}}$ = 0.0023, $\boldsymbol{\varepsilon_{5\ max}}$= 0.0026 and $\boldsymbol{\varepsilon_{7.5\ max}}$ = 0.0039.

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