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Experimental Test on Polyended Polysterene Addition as a Partial Substitute of Fine Aggregate

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ABSTRACT

This research aimed to determine the values of specific gravity, compressive strength, and modulus of elasticity by replacing some fine aggregate with styrofoam (Polyended Polysterene). This research was done by using experimental methods in the Building Materials Laboratory, Department of Civil and Planning Engineering Education, Universitas Negeri Yogyakarta. The percentage of Polyended Polysterene addition as a partial substitute of fine aggregate was done at 0%, 15%, 30%, and 45%. Each percentage of Polyended Polysterene addition as a partial replacement of fine aggregate consisted of 3 cylindrical concrete specimens with a diameter of 150 mm and a height of 300 mm. Specific gravity testing of concrete was conducted 24 hours after concrete casting. The compressive strength and modulus of elasticity of the concrete were tested at 91 days. The results of the research showed that: (1) the specific gravity values of concrete decreased linearly with the value of 2345,83 kg/m^3, 2242,45 kg/m^3, 2154,88 kg/m^3, and 2040,79 kg/m^3, (2) the compressive strength values of concrete are 28,55 MPa, 18,52 MPa, 20,26 MPa, and 15,3 MPa, and (3) the modulus of elasticity values of concrete is 15969,61 MPa, 13395,58 MPa, 14994,2 MPa, dan 14479,03 MPa. From the test results, the optimal value at a percentage of 30% with a specific gravity value of concrete close to the lightweight concrete requirements and a compressive strength value meets the structural requirements.

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1. Introduction

The construction field has rapidly grown in this modern era. In this field, concrete as a building material has long been widely used by the community because it has advantages over other structural materials like good strength, fire resistance, and weather resistance. However, it is prone to specific high gravity that makes the dead load on a structure larger. The development of building construction today is influenced by high global warming. It urges construction experts and researchers to compete in carrying out the green building concept by applying the concept of green building to reuse used materials or waste as its materials. Concrete innovations are required to answer these challenges for being environmentally friendly and having a low specific gravity of less than 1900 kg/m^3. This innovation offers waste treatment, especially styrofoam waste as a substitute for fine aggregate in concrete. The used styrofoam has similarities with a fine aggregate such as grain size, suitable surface texture that is slippery and smooth, and it does not change in volume due to weather. Styrofoam waste which resembles fine aggregate and has a lighter weight, is expected to reduce its weight of concrete with the desired strength. The concrete in this study is applied to the building structure in a half slab. The half slab is a structure that functions as a diaphragm or horizontal stiffening element that supports beams and structures that receive loads vertically. The advantages of this concrete are strong and lightweight. The slab deflection is slight because of the deflection from prestressing forces, short installation time, and formwork elimination.

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In this study, it is necessary to examine the specific gravity, compressive strength, and modulus of concrete elasticity. Tests of particular gravity, compressive strength, and modulus of elasticity of concrete are necessary to determine the concrete load that can withstand a specific density of concrete and determines the material's stiffness in bearing the load. It also needs to know the deflection that occurs in the concrete. Lightweight concrete is one solution to reduce the weight of concrete as a commonly used construction material. The determination of dead loads on building structures can be minimized by using lightweight concrete [1]. The relatively large weight of concrete becomes a crucial part of reducing the weight of concrete in various ways.

Several studies have been done before replacing partial or entire aggregate with a lighter material whose shape resembles an aggregate, such as styrofoam. Widodo in his research, shows that the substitution of sand with polystyrene granules can reduce the specific gravity of concrete [2]. The type of lightweight concrete can be achieved using 25% of polystyrene in the total volume of fine aggregate with a specific gravity value of 2002.67 kg/m^3 and tends to decrease the strength of concrete. The lightweight structural concrete can only be achieved by using polystyrene of 25% of the total volume of fine aggregate for a water-cement factor of 0.50 with an average compressive strength of 17.35 MPa. Similarly, Giri et al. reveal that the addition of styrofoam granules in the concrete mixture makes the concrete lighter [3]. The unit weight of concrete is less than 1900 kg/m3 at the accumulation of 40% styrofoam granules, i.e., 1838,267 kg. /m^3. It can be classified into lightweight concrete.

Meanwhile, the compressive strength and modulus of elasticity of the resulting decreased concrete after the escalation of the Styrofoam granules percentage added to the concrete mixture. Yusuf indicates that the density of concrete decreases by 0.9% on average in each replacement of sand with EPS of 5% from the total sand volume [4]. The compressive strength of concrete decreases by 2.1% in average. Up to 40% volume replacement, the specific gravity of the concrete drops by 6.2% and the compressive strength by 14%. The replacement rate of sand with the optimum EPS is 16.6% with a specific gravity of 2155.87 kg/m3 and compressive strength of 20 MPa based on the provisions of SNI 03-2847-2002 stating that structural concrete that bears earthquake loads should be above 20 MPa.

2. Method

This study was done with the experiment method by comparing the concrete between a target compressive strength of 25 MPa as a control and the experimented concrete. The test object was concrete with the addition of styrofoam as a partial substitute for fine aggregate. The two concretes will be tested with the specific gravity, compressive strength, and modulus of elasticity. These processes were expected to reveal the effect of styrofoam addition as a partial replacement for fine aggregate on the specific gravity, compressive strength, and modulus of elasticity. This research was conducted at the Building Materials Laboratory, Department of Civil and Planning Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta for four months.

Styrofoam waste as a partial substitute for fine concrete aggregate was used in the form of half slabs in high-rise buildings. The value comparison of specific gravity, compressive strength, and modulus of elasticity in the concrete was compared between the concrete control results and the concrete produced from the partial replacement of fine aggregate with styrofoam. There were three variables in this study, including (1) the independent variable, namely the variation in the amount of styrofoam waste of 0%, 15%, 30%, 45%, respectively, and the comparison of the composition of the essential ingredients in forming concrete with styrofoam added material, (2) the dependent variable was specific gravity, compressive strength, and modulus of elasticity of concrete with the addition of styrofoam waste as a partial substitute for fine concrete aggregate, and (3) the control variables include water-cement factor, maximum aggregate size, temperature, stirring time. Those were tested at 91 days of concrete age. This had been through several stages: testing materials, concrete mix design, test objects, test objects maintenance, and data analysis.

The concrete test object was a cylinder with a diameter of 150 mm and a height of 300 mm for testing specific gravity, compressive strength, and modulus of elasticity of concrete. These tests were conducted to determine the category or class of hardened concrete. The weight and dimensions of the specimen must be measured 24 hours after placing the concrete To determine the specific gravity in the opened mold as stated in BS EN 8500:1 2006 [5]. The following formula can calculate the specific gravity of concrete:

Relative density = $\frac{m}{v}$..(1) with:

m = concrete weight (kg)
v = concrete volume

The compressive strength of concrete refers to the load magnitude per unit area. The press machine produced the causes of the concrete test object to crumble when it is loaded with a certain compressive force. The compressive strength of concrete against the test object could have a varying effect depending on the constituent materials of the test object. The specimens in this study were tested for compressive strength at 91 days. The value of the compressive strength of concrete was obtained through standard testing procedures using a test machine. It was to provide a multilevel compressive load with a certain speed of increasing the load on the concrete cylinder test object until it was crushed. According to SNI 1974:2011, the formula for compressive strength of concrete is as follows [6]:

compressive strength = $\frac{P}{A}$ ....(2) with:

P = maximum load imposed by the test object

(N) A = cross-sectional area of the test object (mm^2)

Modulus of Elasticity

According to SNI 2847:2013, the modulus of elasticity is the ratio of normal stress to related strain for tensile or compressive stresses below the proportional limit of the material [7]. The specimens in this study were tested for their modulus of elasticity at 91 days. The modulus of elasticity of concrete was calculated based on the provisions of ASTM C469, referred to as chord modulus or chord elasticity (Ec), with the following formula [8]:

Modulus Elasticity = $\frac{S_2 - S_1}{\varepsilon_2 - 0{,}00005}$ MPa ....(3) with:

S_2 = voltage of 0,4 f'_c(MPa)
S_1 = voltage corresponding to longitudinal strain of 0,00005 (MPa)
ε_2 = longitudinal stress due to S_2 stress

3. Results and Discussion

The results of the experimental research on the physical and mechanical properties contained concrete consist of slump test, specific gravity, compressive strength, and modulus of elasticity of concrete. Table 1 and Fig. 1. show that the concrete slump value at a percentage of 0% was 7.50 cm.

The slump value of the concrete was relevant to SNI 7656:2012 because it met the recommended slump value range for construction work of floor slabs of 2.50 cm to 7.50 cm, respectively.

Table 1. Concrete Slump Test

Styrofoam (%)	Slump (cm)	Specific gravity (kg/m^3)	Compressive Strength (MPa)	Elasticity Modulus (MPa)
0	7,5	2345,83	28,55	15969,61
15	20	2242,45	18,52	13395,58
30	19	2154,88	20,26	14994,20
45	18	2040,79	15,30	14479,03

The slump value significantly increased when there was an escalation in the percentage of fine aggregate replacement with styrofoam. Its nature cannot absorb water, so the fresh concrete mixture becomes a waterier. In addition, the slippery surface of the styrofoam can make it difficult for the cement paste to bind the Styrofoam grains together with the aggregate. The slump test results show that the percentage of replacement of fine aggregate with styrofoam greatly affected the workability of the concrete.

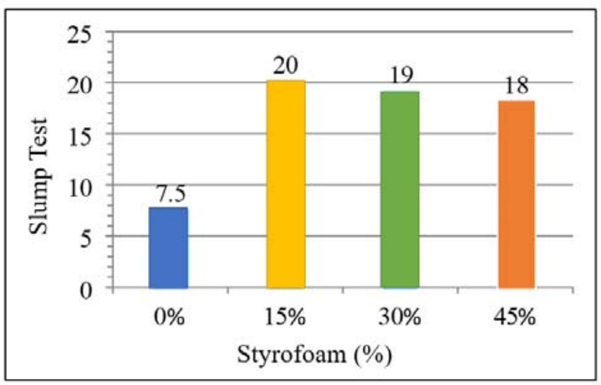

Fig. 1. Relationship between Styrofoam (%) versus Slump Test

Table 1 and Fig. 2 show that the density of concrete due to the percentage of styrofoam as a partial replacement for fine aggregate decreased linearly. The density of concrete at 0% percentage was 2345.83 kg/m^3. The lowest concrete density was 2040.79 kg/m^3 at a rate of 45%. In a 15% escalation of styrofoam as a partial replacement of fine aggregate, the density of concrete decreases by 101.68 kg/m^3. Styrofoam granules were very lightweight and can be considered air voids in concrete. In general, concrete with air voids has lower specific gravity than normal concrete. The more styrofoam grains in the concrete, the more air voids were produced so that the weight of the concrete was reduced. In addition, the lower specific gravity of styrofoam than the specific gravity of fine aggregate made concrete with styrofoam produced concrete with a specific gravity that was lower than normal concrete in general. The higher the percentage of styrofoam as a partial substitute for fine aggregate, the lower the value of the specific gravity of the concrete.

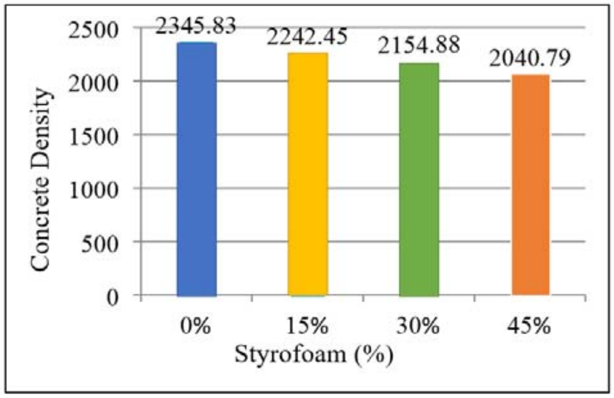

Fig. 2. Relationship between Styrofoam (%) versus Concrete Density

According to Tjokrodimuljo, the specific gravity value of concrete can be classified as light ranging from 300 to 2000 kg/m^3 [9]. It means that the specific gravity of the concrete with the specified percentage is not classified as lightweight concrete. Table 1 and Fig. 3 show that the compressive strength of concrete with a rate of 0% was 28.55 MPa. Every 15% increase in styrofoam as a partial substitute for fine aggregate, the compressive strength of concrete has decreased significantly because the surface of styrofoam tended to be more slippery. It resulted in a perfect bond between styrofoam and cement paste. The styrofoam gradation used was relatively uniform, which influenced the concrete voids not being filled. Compared to fine aggregate, styrofoam was weaker in weight-bearing and easy to shrink. In addition, styrofoam grains which were considered as air voids in the concrete, could reduce the compressive strength of the concrete. According to ASTM C330-82a, lightweight structural concrete is required to have a characteristic compressive strength of at least 17 MPa [8]. There is the most optimum concrete compressive strength value with the specific gravity value approaching the lightweight concrete requirements, i.e. the percentage of replacement of fine aggregate with 30% of styrofoam. In this section, the specific gravity of concrete was 2154.88 kg/m^3 with a compressive strength of 20.26 MPa.

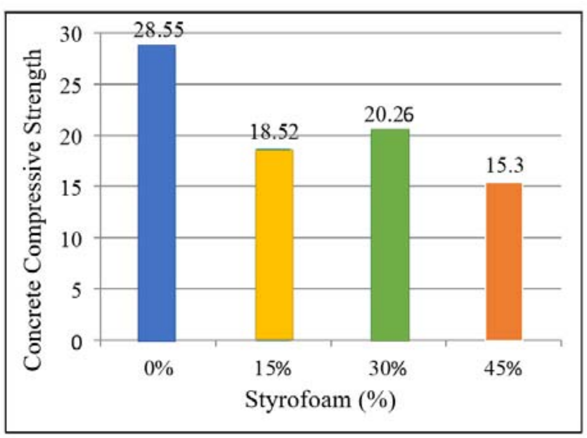

Fig. 3. Relationship between Styrofoam (%) versus Concrete Compressive Strength

Table 1 and Fig. 4 show that the modulus of elasticity of concrete tends to decrease with the percentage of styrofoam as a partial substitute for fine aggregate. The value of the modulus of elasticity of concrete with 0% styrofoam percentage was 15969.61 MPa. The modulus of elasticity has increased at 30% styrofoam percentage of 14994.20 MPa. The decrease in the value of the elasticity modulus is due to the imperfect bond between the styrofoam granules and the cement paste in the concrete. When the cement paste hardens, the concrete will shrink, and it can cause microcracks in the area around the styrofoam grains. The more styrofoam grains in the concrete, the tinier cracks (microcracks) form around the styrofoam grains.

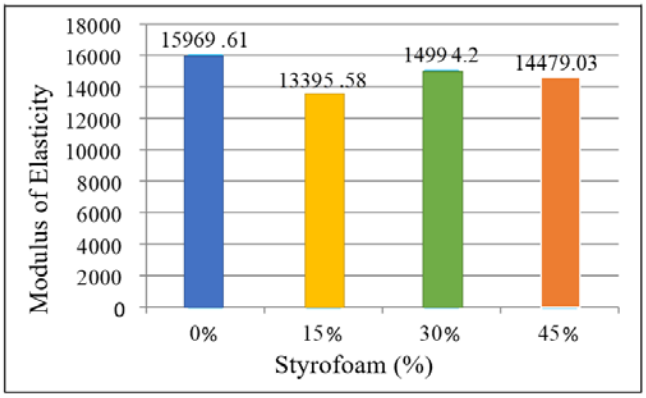

Fig. 4. Relationship between Styrofoam (%) versus Modulus of Elasticity

4. Conclusion

Based on the research and discussions, the following conclusions can be drawn: styrofoam as a partial substitute for fine aggregate in concrete can reduce the specific gravity of concrete. The lowest concrete density reached 2040.79 kg/m^3 at a percentage of 45% with fine aggregate with styrofoam replacement. The type of lightweight concrete has not been achieved at the percentage of styrofoam as a partial replacement for the fine aggregate. The compressive strength of concrete tends to decrease along with the addition of styrofoam as a partial substitute for fine aggregate. A compressive strength value of the most optimum concrete meets the structural requirements with a specific gravity value close to the lightweight concrete needs, namely replacing fine aggregate with styrofoam of 30%. The modulus of elasticity of concrete tends to decrease with adding the percentage of styrofoam as a partial substitute for fine aggregate—the most optimum value of the modulus of elasticity at the fine aggregate replacement with 30 % styrofoam.

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