LAPORAN PENELITIAN

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INSTITUT TEKNOLOGI NASIONAL
BANDUNG - 2019

MATEC Web of Conferences **276**, 01028 (2019) https://doi.org/10.1051/matecconf/201927601028
ICAnCEE 2018

Mechanical properties of concrete with substitution of coated styrofoam balls on coarse aggregate

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Abstract. Substitution of Styrofoam balls on coarse aggregates reduced concrete self-weight. Coating on Styrofoam ball surface makes ball has shell on its surface and could increase the adhesive strength between ball surfaces and cement paste. The coating materials made by mixing of Portland cement and RCC-15 (Residual Catalytic Cracker-15) as pozzolanic material. 20 mm diameter Styrofoam balls are used. Coarse aggregates substituted by 5%, 15%, and 20% Styrofoam balls. The test specimens used three 10x20cm cylinders for each variant. Beam specimens of 15x15x60cm used for bending strength test by third point loading method. The testing of mechanical properties were 7, 14, and 28 days compressive strengths, 28 days split-tensile strengths and 28 days flexural strengths. The experimental results of concrete with various Styrofoam ball substitutions of 5%, 15%, and 20% at 28 days show the average compressive strengths are 27.6 MPa, 24.3 MPa, and 20.3 MPa, the split-tensile strengths are 2.5 MPa, 2.2 MPa, and 1.7 MPa, and the flexural strengths are 5 MPa, 4.5 MPa, and 3.8 MPa, respectively. The compression strength could be predicted by density ratio method and air content method. The experimental results show that all of the variants of Styrofoam ball coarse aggregates concrete are adequate to achieve structural strength, and have nearly compressive strengths compared with the prediction by density ratio method and air content method. Styrofoam balls substitution content could be increased to make the concrete density below 1,900 kg/m^3 and compressive strength above 17.5 MPa to reach structural lightweight concrete performance.

1 Introduction

The density of normal concrete of 2,200-2,500 kg/m^3 make the self-weight of the concrete-based structural element is rather high. Recent concrete technology develop concrete with has less density to generate semi-lightweight (less than 2,200 kg/m^3) and lightweight (less than 1,900 kg/m^3) concretes. Self-weight reduction on structural material could reduce overall building mass, reduce seismic force, and also reduce the dimension of structural elements such as column and foundation. Semi-lightweight and lightweight concretes are designed to achieve the compressive strength as strong as the normal concrete. On the mix

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design, material with very-low unit weight as styrofoam ball could be used as an alternative substitution for coarse aggregate.

Lightweight concrete is concrete with lower density compared with the normal concrete. Lightweight concrete could be generated by using lightweight aggregates such as fly-ash based aggregate, styrofoam, and plastic. The lightweight aggregate has unit weight ranged 400-1,900 kg/m^3 based on its strength level [1]. The weight of lightweight concrete could be set as designer need. Generally, the lightweight concrete density ranged 600-1,600 kg/m^3, and lower than 1,900 kg/m^3.

Low-density non-structural concrete which has density ranged 300-800 kg/m^3 and compressive strength ranged 0.35-7 MPa [2] generally used in a partition or isolated wall. Moderate strength lightweight concrete which has density ranged 800-1,350 kg/m^3 and compressive strength ranged 7-17 MPa [3] could be used in the loaded wall. Structural lightweight concrete which has density ranged 1,350-1,900 kg/m^3 and compressive strength ranged more than 17 MPa [4] could be used as normal concrete.

Adding 30% styrofoam as a concrete filler could reduce concrete unit weight to 1,881.25 kg/m^3, but concrete compression strength, split-tensile strength, flexural strength, and modulus of elasticity are also incrementally reduced as the increment of Styrofoam volume [5]. Enda et al. [6] studied density of concrete with styrofoam artificial lightweight aggregate ranged 1,633-1,713 kg/m^3 and the compressive strength could increase as a reduction of water-cement ratio. The compression strength, split-tensile strength, flexural strength, modulus of elasticity, and porosity of this concrete with the water-cement ratio of 0.5 at 28 days were 14.26 MPa, 1.47 MPa, 4.40 MPa, 12,143.67 MPa, and 18.92%, respectively.

In this research, the Styrofoam ball will be coated by cement-pozzolan mixture layer as ball shell to increase ball strength and aggregate-matrix bond. The pozzolanic material used in this research is Residual Catalytic Cracker-15 (RCC-15) as petroleum production waste from Balongan which has 64% silica content. The appearance of Styrofoam ball with very low density ranged 15-22 kg/m^3 in concrete could reduce density and increase air content. Concrete strength will predict base on density ratio method and air content method. The purposes of this research are generating structural semi-lightweight concrete with a coated Styrofoam ball and comparing the experimental strength with predicted strength with density ratio method and air content method.

2 Methodology

Specimens used in this experimental study are 100 mm diameter, 200 mm height concrete cylinder and 150 mm width, 150 mm height, 650 mm length concrete beams. Coarse aggregates in normal concrete are being substituted by 20 mm diameter styrofoam balls which have three substitution variations of 5%, 15%, and 20%, with three specimens for each substitution variation. Experimental tests in this research are 7, 14, and 28 days compressive strengths, 28 days split-tensile strength, and 28 days flexural-tensile strength in the universal testing machine (UTM) at Laboratory of Structure and Material, Department of Civil Engineering, Institut Teknologi Nasional, Bandung, Indonesia.

Coated material for Styrofoam ball surface made from Portland cement and pozzolan RCC-15 mixture with a weight composition of 1:1, and water with a water-cement ratio of 0.5. After styrofoam balls are coated, the diameter of coarse aggregates increases from 20 mm diameter to 25 mm diameter. The purpose of the coating is to improve the surface properties of coated objects, such as appearance, water resistance, roughness, and toughness. The process of coating on styrofoam ball surface is shown on Fig. 1.

Fig. 1. Process of coating on styrofoam ball surface.

Concrete mix design for normal concrete based on Indonesian Standard (SNI) for compressive strength of 30 MPa, before strength reduction due to styrofoam ball appearance. Coarse aggregates composition were substituted by 5%, 15%, and 20% styrofoam ball by the same volume, and mix design composition could be seen at Table 1.

Table 1. Concrete mix design with styrofoam ball substitution per m^3.

Percent of styrofoam ball substitution (%)	Styrofoam ball (kg)	Portland Composite Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)
0	0	420	809	989	185
5	0.5	420	809	940	185
15	1.6	420	809	840	185
20	2.1	420	809	791	185

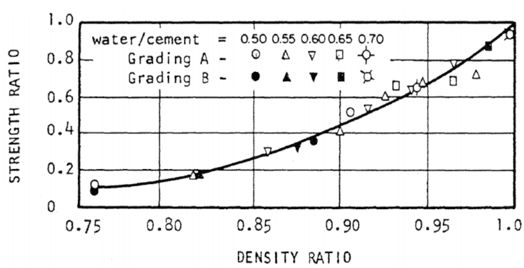

Fig. 2. Strength ratio influenced by density ratio [7].

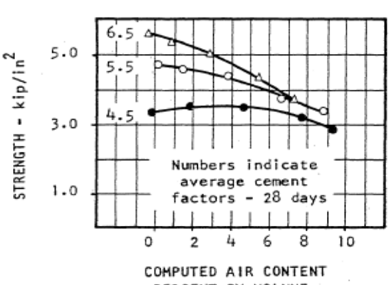

Fig. 3. Concrete strength influenced by air content [8].

The concrete compressive strength ratio could be predicted by the density ratio for any water-cement ratio and any material grading as shown in Fig. 2 [7]. The concrete compressive strength decrease as the increment of air content as shown on Fig. 3. The appearance of Styrofoam ball conservatively could be assumed as air content in concrete which reduces compressive strength. The reduction of strength could be predicted by Fig. 3 [8].

3 Results and discussion

Concrete with 5% substitution styrofoam ball has the highest average compressive strength at 7 days, 14 days, and 28 days than 15% and 20% substitution. Meanwhile, the increase of substitution percentage styrofoam ball shows the degradation of compressive strength concrete. The compressive strength are presented in Table 2 and Fig. 4.

Table 2. Test results of compressive strength of coated styrofoam balls concrete.

Age (days)	Average compressive strength (MPa)			
	0%	5%	15%	20%
7	22.5	16.0	14.0	11.1
14	30.3	23.2	20.0	17.0
28	33.1	27.6	24.3	20.3

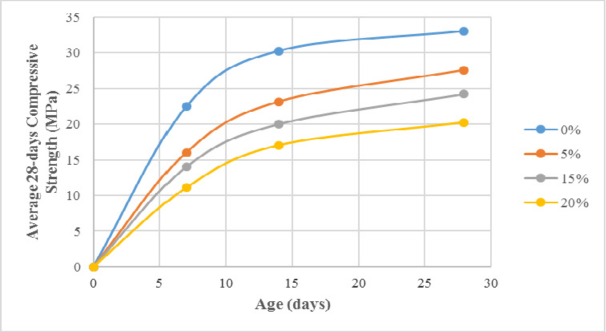

Fig. 4. Compressive strength influenced by styrofoam ball substitution.

Table 3. The results of calculation predicted compressive strength of coated styrofoam balls concrete.

Composition	Predicted compressive strength (MPa)		
	Density ratio	Void ratio	Experimental
0%	33.1	33.1	33.1
5%	37.7	31.3	27.6
15%	24.5	30.1	24.3
20%	18.2	28.1	20.3

Strength development of compressive strength in coated styrofoam balls concrete shows a similar trend as compressive strength of normal concrete so the predicted compressive strength of coated styrofoam balls concrete could refer to strength development of compressive strength in normal concrete. In this experimental study, the compressive strength of coated styrofoam balls concrete could be predicted from calculation of density ratio and void ratio as shown in Table 3 and Fig. 5.

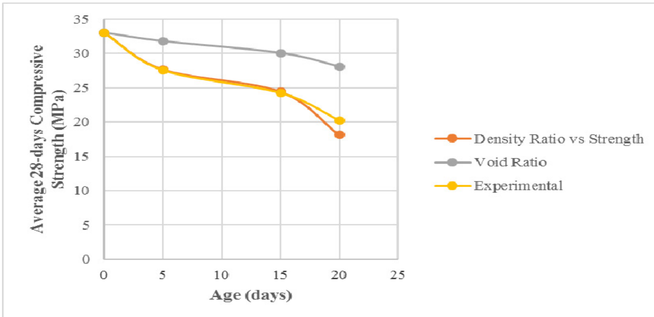

Fig. 5. Predicted versus actual compressive strength of coated Styrofoam balls concrete.

Fig. 6. Compressive strength test of coated styrofoam balls concrete.

The predicted compressive strength with density ratio approaches the result of experimental compressive strength, so the density ratio method is worth recommended to predict the compressive strength of coated Styrofoam balls concrete. From the test results of compressive strength of coated Styrofoam balls concrete (Fig. 6.) show the failure occurs in aggregate.

Table 4. Test results of split-tensile strength of coated styrofoam balls concrete.

Age (days)	**Average Split-tensile Strength (MPa)**			
	0%	5%	15%	20%
28	3.4	2.5	2.2	1.7

Concrete with 5% substitution styrofoam ball has the highest average split-tensile strength at 28 days than 15% and 20% substitution. Meanwhile, the increase of substitution percentage Styrofoam ball shows the degradation of split-tensile strength concrete. The results of the average split-tensile strength are presented in Table 4 and Fig. 7.

Concrete with 5% substitution styrofoam ball has the highest average flexural strength at 28days than 15% and 20% substitution. Meanwhile, the increase of substitution percentage Styrofoam ball shows the degradation of flexural strength concrete. The results of the average split-tensile strength are presented in Table 5 and Fig. 8.

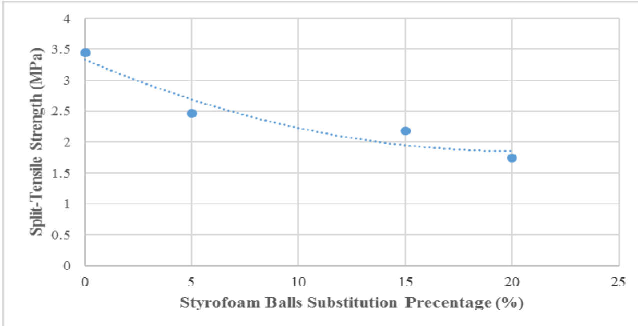

Fig. 7. Average split-tensile strength of coated styrofoam balls concrete.

Table 5. Test results of flexural strength of coated styrofoam balls concrete.

Age (days)	**Average Flexural Strength (MPa)**			
	0%	5%	15%	20%
28	5.2	4.9	4.5	3.7

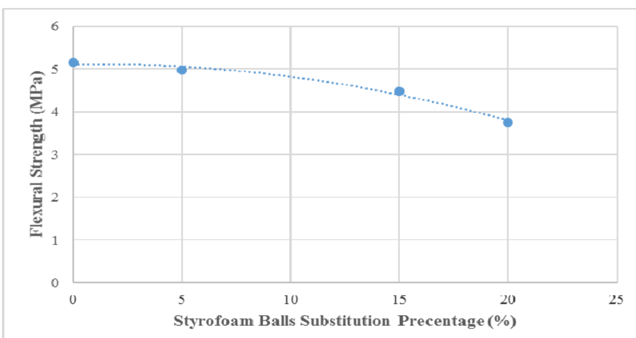

Fig. 8. Average flexural strength of coated styrofoam balls concrete.

From the test results of split-tensile strength and flexural strength of coated styrofoam balls concrete (Fig. 9. and Fig. 10.) show the failure that occurs is flexural crack and no shear crack so styrofoam balls release and it could reduce the concrete strength.

Fig. 9. Split-tensile strength test of coated styrofoam balls concrete.

Fig. 10. Flexural strength test of coated styrofoam balls concrete.

4 Conclusions

The degradation of compressive strength shows the increase of substitution of styrofoam balls content. The highest average compressive strength of coated Styrofoam balls concrete is 37.6 MPa with 5% substitution-content and the lowest average compressive strength is 20.3 MPa with 20% substitution-content.

In coated styrofoam balls, the strength development of compressive strength shows a similar trend as normal concrete so the strength development of compressive strength in normal concrete could be a reference. Density ratio method is eligible to predict the compressive strength of coated styrofoam balls concrete because its calculations approach the experimental results.

The increase of styrofoam balls content also shows the degradation of split-tensile strength and flexural strength. The highest average split-tensile strength of coated styrofoam balls concrete is 3.5 MPa with 5% substitution-content and the lowest average compressive strength is 2.7 MPa with 20% substitution-content. The highest average split-tensile strength of coated styrofoam balls concrete is 5.5 MPa with 5% substitution-content and the lowest average compressive strength is 3.8 MPa with 20% substitution-content.

Coated styrofoam balls concrete with all variants of substitution content achieved the required structural element application because the minimum compressive strength in C-331 is 17 MPa. The suggestion for next study is with the prediction of the strength reduction due to void appearance. It could be possible to design composition of the concrete mixture that has a density lower than 1,900 kg/m^3 and structured so that it could be categorized as lightweight structural concrete.

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