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Flexural Behavior Of Styrofoam-Filled Concrete

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ABSTRACT

Various kinds of innovations have been made to obtain lightweight concrete, for example using Styrofoam as partial replacement of aggregates. The objective of this study was to analyze the flexural behavior of Styrofoam-filled Concrete (SFC) by adding Styrofoam 30 % to replace the concrete volume. The testing was carried out on three variations specimens with a total of 6 specimens, which each variation consist of 2 specimens. The characteristic of Normal Concrete (NC) and SFC was first evaluated. Then, the behavior of SFC beam was compared with the behavior of NC beam and SFC with CFRP strengthening (SFC-CFRP). The specimens were statically loaded using two-point load system with constant speed ramp actuator at 0.1 mm/second until the beam failure. The results indicate that the strength of normal concrete (NC) and SFC has decreased with addition of 30% Styrofoam. However, when the SFC beam was combined with deformed bar, the ultimate bending strength of SFC specimens increase 12.6% compared to the NC specimens. Similarly, the ultimate strength of SFC-CFRP specimens improved by 39.74% compared to the SFC specimens.
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Keywords : SFC, Styrofoam, flexural behavior.

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1. INTRODUCTION

According to SNI 03-2847-2002, lightweight concrete is defined as the concrete that has a unit weight of not more than 1900 kg/m3. Concrete with high compressive strength can be determined as good concrete [1]. The lightweight concrete normally have compressive strength between 20-50 MPa, while for normal concrete it ranges from 20 to 70 MPa.

Styrofoam is a material with a very light density, ranging between 13-16 kg/m3 and commonly used as a protective packaging to prevent the influence of heat from the outside. Styrofoam will normally be discarded and become waste.

In this research, the use of Styrofoam as an alternative to produce lightweight concrete was studied. Expanded Polystyrene (Styrofoam) is a lightweight material granulated smooth balls comprising 98% air and 2% polystyrene, have a closed particle that does not absorb water. Polystyrene is made from styrene (C6H5CH9CH2) which has a phenyl group (six-carbon ring) arranged in an irregular manner along the lines of carbon molecules. Specification of Styrofoam is presented in Table 1.

Concrete made with the addition of Styrofoam hereinafter called as SFC (Styrofoam Fill Concrete). Besides SFC beam, SFC beam with CFRP reinforcement in the tension zone were also tested to analyze the strength. The use of CFRP-S is intended not only for preventing structural damage, but also to be used fore new structure as a protection from hazard environment conditions such as marine environments. In this study, the SFC was compared with Normal Concrete (NC) and SFC with CFRP reinforcement (SFC-CFRP) in terms of bending behavior.

Flexural strength of concrete beam occurs due to ongoing mechanism of stress-strain arising in the beam, which in certain circumstances is represented by internal forces [2]. Bending strength of beam is known as modulus of rupture. The collapse in the beam can occur according to one of three different type, i.e: flexural failure, diagonal tension failure and shear compression failure [3].

The previous research concluded that increased levels of polystyrene granules will reduce the compressive strength and tensile strength of concrete [4]. The addition of styrofoam granules in the concrete mix can improve workability; extra Styrofoam granules make concrete lighter than normal concrete, and the addition of 40% granules styrofoam will result in concrete that can be classified as light weight concrete. It is also noted that the compressive strength and modulus of elasticity of concrete decrease with increasing portion of grain Styrofoam [5]. Other research states that the addition of 30% styrofoam increase flexural strength by 1.21% against the addition of 20% Styrofoam [6].

Other researchers have found that the addition of 30% Styrofoam in tensile zone and vertical reinforcement, resulting in improved flexural strength of the beam by 0.98% or relatively the same as a normal beam [7]. Then, the compressive strength of concrete blocks rose by 40.6% with the addition of 33% Styrofoam, and increased by 2.5% with 50% addition of Styrofoam. The compressive strength of concrete blocks will decrease upon the addition of Styrofoam over 50% [8].

The permeability coefficient of concrete has increased due to the increased percentage of Styrofoam granules in the concrete mixture [9]. In addition, the addition of 1% Styrofoam will decrease the weight volume of concrete on average by 12%. Moreover, the addition Styrofoam on concrete will decrease the compressive strength of normal concrete [10].

Another research on Flexural Capacity of Concrete Beams Reinforced with Styrofoam as Coarse Aggregate Substitute concluded that the nominal moment capacity (Mn) of beam does not increase with the addition of tensile reinforcement because to the collapse of the beam is determined by the failure of bonding between shear reinforcement and surroundings concrete [11].

The herewith presented study was aimed at analyzing the flexural behavior of beam with the addition of 30% Styrofoam to the volume of normal concrete (SFC) compared to normal concrete (NC) and SFC with CFRP reinforcement (SFC-CFRP).

2. METHODOLOGY

A. Specimen

The specimens were divided into 2 groups. The first group is a cylinder of 10 cm in diameter and 20 cm high, and the beams with dimensions of 10 cm x 10 cm x 40 cm. The test specimen was used for testing the mechanical properties of normal concrete and SFC, namely compressive strength, indirect tensile strength and flexural strength. Testing was performed after the concrete reached the age of 28 days.

The second group of specimens was the reinforced concrete beam with the size of 15 cm x 20 cm x 310 cm. There were three types of beam, namely NC, SFC and SFC-CFRP with a total of six beams. The beams were reinforced using 2D8 at compression zone and 3D13 at tensile zone, and for stirrups D8-7.7 cm was used. The detail of specimen is shown in Figure 1. Compressive strength target of concrete was 25 MPa. Styrofoam used in this study is shown in Figure 2. Testing was conducted after the concrete reached the age of 28 days.

b. Set up Testing

Strain that occurs in the reinforcement was measured using 4 units of strain gauge type FLA-2-11 placed on longitudinal reinforcement (Figure 3b). To measure the strain of concrete, strain gauge type of PL-60-11 was attached to the upper surface of the beam, 1/3 high beam, as well as in areas of 1/6 high beams, each by one unit (Figure 3a). Meanwhile, to measure the strain of CFRP-S, strain gauge type FLA-2-11 placed on GFRP-S mid-span beam position and the beam belt 4 units (Figure 3c).

The test of beam was conducted with static load by two points loading until the beam collapsed, using ramp actuator on constant speed of 0.1 mm / second. Observation on the beam was continuously carried out to monitor the development of cracks caused by loading and failure behavior that occurs. Tests conducted until ultimate load is achieved, which is characterized by yielding of steel bars and no further increased on the load.

The deflection measurements was performed by installing LVDT (Linear Variable Displacement Tranducer) at bottom midspan beam for three points, as well as checking the pattern of cracks using phi crack gauge at two points.

3. RESULTS AND DISCUSSION

The mechanical properties of NC and SFC are presented in Table 2. As shown in Table 2 that the SFC compressive strength has been reduced by 52.5% compared to NC, with a reduction in density up to 17.7% on 30% addition of Styrofoam. Similarly, the indirect tensile strength decreased by 46% from normal concrete because Styrofoam is a water-resistant material with a smooth surface material, thus the adhesion between cement paste and Styrofoam is not good. Also flexural strength and modulus of elasticity decreased by 30% and 33.4% respectively. This indicates that the addition of 30% Styrofoam into concrete can reduce the mechanical behavior of concrete.

The SFC concrete was also applied to the reinforced concrete beams and bending test was conducted with two points loading. The results are presented in Figure 4 where the ultimate load increased 12.6% in SFC beam compared to NC beam. Similarly, SFC CFRP beam has increased in load by 39.74% to SFC beam. The increasing in flexural strength in SFC beam should be analyzed more, because the test results of mechanical properties (Table 2) showed decreasing in the concrete density on SFC which was followed by a decrease in strength compared to NC.

For NC beam, the load at the first crack, rebar yielding and ultimate load showed that design analysis data is relatively lower than the experimental results. Deflection and crack moments on the initial crack are relatively similar between theory and test results. However, on the rebar yielding and ultimate load, deflection test results 200% greater than the design deflection.

While the SFC beam showed that all the test results provide greater results than the design, except on the ultimate condition where data of the load and moment met between theory and test results. And for SFC-CFRP, all design load is exceeded by the load test results of the study. Similarly, the deflection and moments that occur.

The ductility of a reinforced concrete beam section is measured by the expression $\mu = \phi_u/\phi_y$. ϕ_u represents the curvature of the section when the concrete reaches its ultimate limit state and $/\phi_y$ is the curvature of the section when steels in tension reaches the elastic limit state as described in Table 3. It was shown that ductility of NC and SFC-CFRP higher than SFC due to reduction in the quantity ρ of tensile steels in NC.

The pattern of cracks that occur in all specimens beam is bending cracked pattern (Figure 5). Crack initiation occurs around the middle span, then propagate and expand into compression zone of concrete with vertical direction propagation to the longitudinal axis, until beam collapsed.

Table 1. Specification of expanded polystyrene (Styrofoam)

Specification	
Grain size styrofoam	3 mm – 5 mm
density	13 – 22 kg/m3
Modulus young's (E)	3000 – 3600 Mpa
Tensile strength styrofoam	40 – 60 Mpa
Specific heat styrofoam (c)	1,3 kJ / (kg.K)
Thermal conductivity styrofoam (k)	0,08 W / (m.K)

4. CONCLUSIONS

Based on the results of the characteristics of normal concrete (NC) and SFC it can be concluded that there is a decrease in strength with addition of 30% Styrofoam . However, when the SFC was applied in the reinforced concrete beam, an increase in bending strength of 12.6% toward the normal concrete beam (NC) can be noted. The SFC-CFRP beam flexural strength increased by 39.74% when compared to the SFC beam.

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