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EXPERIMENTAL STUDY ON EPOXY POLYSTYRENE AS A PARTIAL SUBSTITUTION OF FINE AGGREGATE OF CONCRETE MIXTURE

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ABSTRACT

This study has an objective to assess the utilization of grains epoxy polystyrene, or better known as Styrofoam that have light density, to serve as a partial substitution of sand in concrete materials . On the use of 5% EPS concrete compressive strength characteristics obtained amounted to 18.69 MPa (down approximately 20.9% of the normal mixture). While the use of 10% EPS, decrease concrete compressive strength of 21.67% ie 18.51 MPa. Modulus of elasticity of concrete decrease with the addition of the percentage of EPS, the use of EPS up to 40% decrease modulus of elasticity to be 16.219 MPa (down around 21%). The relationship between the modulus of elasticity (E), Specific Gravity (w_c), compressive strength (f'_c) and the percentage of EPS (p) can be expressed in an empirical equation as follows : $E = (w_c)1,5\cdot 0,05\cdot \exp(-0,23\cdot p)\cdot\sqrt{f'_c}$.

Keywords: Epoxy polystyrene; concrete; compressive strength; modulus of elasticity; flexural strength; tensile splitting strength.

1. INTRODUCTION

Concrete is a construction material, the most widely used in the construction of infrastructure facilities and infrastructure. A mixture of normal concrete is generally composed of cement, fine aggregate, coarse aggregate and water as reagents cement. To get better properties of concrete, sometimes admixtures are added to the concrete mixture. This material can improve the performance of concrete, including increased compressive strength

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of concrete, workability level and others. As a construction material, concrete has a density ranged from 2200 to 2400 kg/m^3. The special characteristics of a normal concrete is a high level of porosity. The higher level of porosity, the density of the concrete will be smaller. With a high porosity level, concrete allowed water to infiltrate.

However, lately more and more use of lightweight concrete products with a specific gravity of about 1800 kg/m^3. Many of the benefits gained by using this lightweight concrete, among others, can reduce the weight of construction, to minimize construction costs and would provide ease of implementation in the field because of the relatively light weight. In addition to these lightweight concrete has better heat resistance than normal concrete. Lightweight concrete is generally made in three different ways, namely by using lightweight aggregate such as pumice stone, the second way is to add air into the use of Admixture mixed concrete, called the air entrained concrete, the third way is to use non- sand concrete.

Material innovation in producing the lightweight concrete is a necessary point. The material must have a low density and a high level of porosity. This material is functioning as a partial substitution of fine aggregate. It is expected that the using of this material can reduce the sand mining and the environmentally friendly lightweight concrete can be created.

This experimental study used Expanded Poly Styrene material (EPS) or better known in the trade name Styrofoam, as a partial substitution of fine aggregate (i.e. sand). EPS was chosen as a substitute material because it has low specific gravity compared to the density of concrete, which ranges between 16-27 kg/m^3.

Park and Chisholm [1] use polystyrene as fine aggregate and has a less specific gravity ranges from 520 to 1040 kg/m^3 has a very low compressive strength, which is in the range 0.7 MPa to 6.7 MPa. These results are far from the minimum requirement of concrete to be used as structural concrete. The need for water in the mixture is lower than design mix, the excess water will cause segregation of the cement paste. Concrete mold compaction process can not be performed conventionally for material that is light enough. Compaction process into the mold is done layer by layer by using the pressure of human hands. Compaction method using a vibrator is also not recommended in the manufacture of lightweight concrete mixtures with polystyrene aggregate. Park and Chisholm also showed that the mixture with a cement content of 1000 kg/m^3 are able to produce cement paste enough to wrap the aggregate and produce a good surface. Meanwhile, Kuhail [2] showed approximately the same results, that the more the content of polystyrene in the mixture it will reduce the compressive strength of concrete. By using the ratio of polystyrene: sand = 5: 1 and the cement content of 600 kg/m^3 can generate compressive strength of 15 MPa and density of 1200 kg/m^3, so it can be said that the concrete has been produced can be used as a concrete structural and non-structural concrete. Momtazi et.al [3], doing research on the durability of lightweight concrete epoxy polystyrene in an environment with high salinity. The results Momtazi mention that within 210 days, the presence of polystyrene epoxy material in the concrete mix at high salinity environments, can provide fairly good protection against the risk of corrosion of reinforcing steel, however, the nature - the mechanical properties of concrete decreased slightly due to the presence of epoxy polystyrene.

Another study conducted by Babu et.al [4] and Fonteboa and Abella [5], the two researchers are using pure EPS beads and recycled EPS beads are mixed with silica fume as the building blocks of concrete mixes. The results showed that the concrete mixture obtained has a specific gravity of between 1500 to 2000 kg/m^3 with compressive strength ranging from 10 to 21 MPa. Silica Fume able to increase the initial compressive strength of concrete mix at the age of 7 days.

Bhikshma et.al. [6] conduct an experimental study on RC Beams, which has been damaged and repaired with epoxy resin. From their study, it has been concluded that material comes from epoxy can be used to repair the damaged structures, cheaper than to reconstruct the structure. Another study conducted by Bakhtiyari et.al [7] investigate the influence of expanded polystyrene as a formwork on fire resistance of self compacting concrete.

2. RESEARCH SIGNIFICANCE

This research has an objective to investigate the effect of epoxy polystyrene grain used as a partial substitution of fine aggregate. To accommodate this objective, 9 different types of concrete mixture proportions were made. The first one is the normal concrete mixture without the addition of epoxy polystyrene. While the other 8 types of mixture were made with the additional 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% epoxy polystyrene. The concrete mixture then cast in a standard cylinder mould, and each of the specimens will undergo a compressive strength test and Modulus of Elasticity test at the age of 7, 14 and 28 days.

3. TEST PROGRAM AND MEASUREMENTS

This research use concrete cylinder specimens, with 150 mm diameters and 300 mm height. There are nine different types of concrete mixture proportions used in the experimental program. Each of the specimens from each compositions were tested either compressive strength test or Modulus of Elasticity Test after the specimens reach 7, 14, and 28 days of age. The normal concrete composition mixture were designed to achieve concrete compressive strength of f'_c = 25 MPa, without the addition of epoxy polystyrene grain as fine aggregate. The other 8 proportions use epoxy polystyrene to substitute a little portion of fine aggregate, i.e. 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% of fine aggregate volume.

Compressive Strength Test

Concrete compressive strength test were conducted under the provision of ASTM C39 / C39M - 09a "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens". The specimens with 7, 14 and 28 days of age will undergo compressive strength test using compression machine. Loading was increased with constant speed, until the peak load achieved, and then the peak load value was recorded. Concrete compressive strength of each specimens, were calculated using the following expression:

$$f_c^{/} = \frac{P}{A} \tag{1}$$

where $f^{/}_{c}$ is concrete compressive strength (MPa), P is the peak load (N), A is the cross section of the specimens (mm^2)

Modulus of Elasticity Test

The concrete's modulus of elasticity test is conducted to the concrete's sample in a cylinder with 150 mm diameter and 300 mm height. Dial gauge is installed at the concrete's samples to measure the samples' deflection. Dial gauge's reading is done every 2 tons interval load. The standard test for modulus of elasticity refers to ASTM C469 / C469M – 10 "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression". Modulus of Elasticity can be calculated using this expression:

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0{,}00005} \tag{2}$$

where E is the Modulus of Elasticity of concrete, S_2 is the stress at 40 % limit load (MPa), S_1 is the tension when the strain is 0,00005 (MPa), and ε_2 is the strain at 40% limit load.

4. TEST RESULTS

Concrete mixture proportion is designed under the provisions of SNI 03-2834-2002, "Tata Cara Pembuatan Rencana Campuran Beton Normal" (Provisions for Proportioning Normal Concrete Mixture). The material proportions required per m^3 for each EPS percentage are shown in the Table 1.

Table 1: Concrete mix design composition

Sample Code	% EPS	water (kg)	cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	EPS (kg)
EPS0	0				700.34	0
EPS5	5				665.323	0.319
EPS10	10				630.306	0.638
EPS15	15				595.289	0.957
EPS20	20	215.075	410	929.95	560.272	1.276
EPS25	25				525.255	1.595
EPS30	30				490.238	1.914
EPS35	35				455.221	2.233
EPS40	40				420.204	2.552

Analysis of the concrete compressive strength test results

In Table 2, we can see the result of Concrete compressive strength test at age of 7,14, until 28 days. Concrete compressive strength at age of 7 days should reach 65% strength of the total strength, which is gained at 28 days. While at age 14 days, the concrete compressive strength should reach 88% strength of the total strength, which is gained at 28 days. Fig. 1 shows the graphic of concrete compressive strength's growth at age of 7, 14, 28 days.

Table 2: Concrete compressive strength

% EPS	Avg. Compressive Strength (MPa)		
	7 days	14 days	28 days
0%	19.62	24.62	25.46
5%	18.11	20.56	21.50
10%	17.64	19.05	21.31
15%	16.79	18.49	19.81
20%	16.41	17.35	19.81
25%	16.03	16.79	19.43
30%	14.05	15.66	19.05
35%	12.83	15.37	18.67
40%	12.64	15.28	17.73

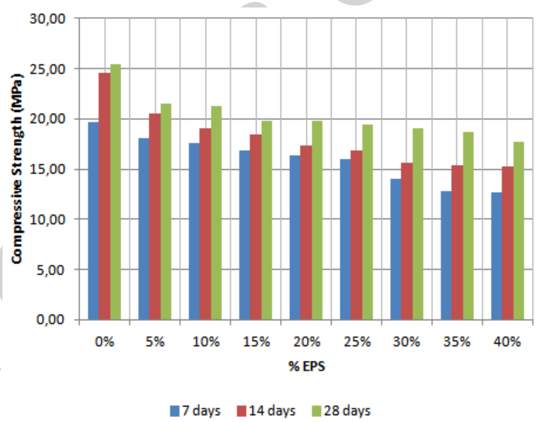

Fig. 1 Concrete compressive strength at 7,14 and 28 days of age

Fig. 3 shows the percentage of concrete compressive strength at age of 7, 14, 28 days. From that percentage, it's shown that the average of concrete compressive strengths at age 7 days, have already reached 65 % of the total strength (which is gained at 28 days). But for the concrete compressive strength at the age of 14 days, that should reach 88 % of the total strength, it only can be reached by concrete mix design with 0%, 5 %, 10% and 15% EPS. The characteristics of the concrete compressive strength of each mix designs will be analyze next.

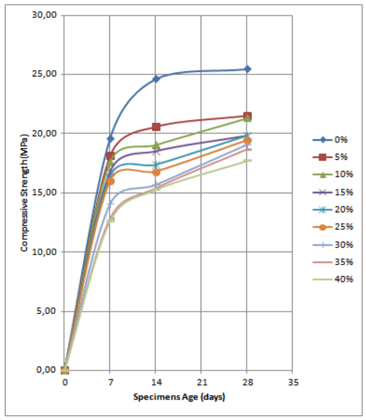

Fig. 2 Concrete compressive strength

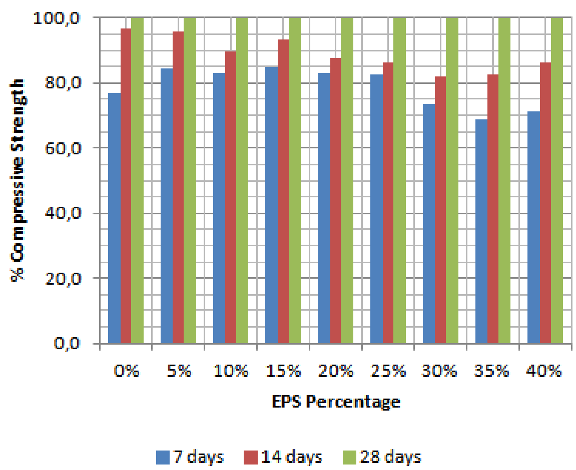

Fig. 3 Percentage of concrete compressive strength at 7, 14 and 28 days of age

The characteristics of the concrete compressive strength is the compressive strength in which almost of the results, there is a possibility that numbers of the specimens have the compression strength less than standard (it's required less than 5 %). The characteristic of the concrete compressive strength can be calculated using this expression:

$$f'_c = f'_{cr} - 1{,}64s \tag{3}$$

where f'_c is characteristics of the concrete compressive strength, f'_{cr} is average of the concrete compressive strength, and s is the deviation standard. Standard deviation can be calculated using this expression:

$$s^2 = \sum_1^n (f_c - f_{cr})^2 / (n-1) \tag{4}$$

Fig. 4 shows the characteristic of the concrete compressive strength for each EPS variation percentage. According to ACI-318-08 sections 1.1.1, it's required the characteristic of the concrete compressive strength that can be used as a structural element is 2500 psi (17.50 MPa). From this requirement, it's concluded that concrete mix design with 5% and 10 % EPS can be used as structural concrete.

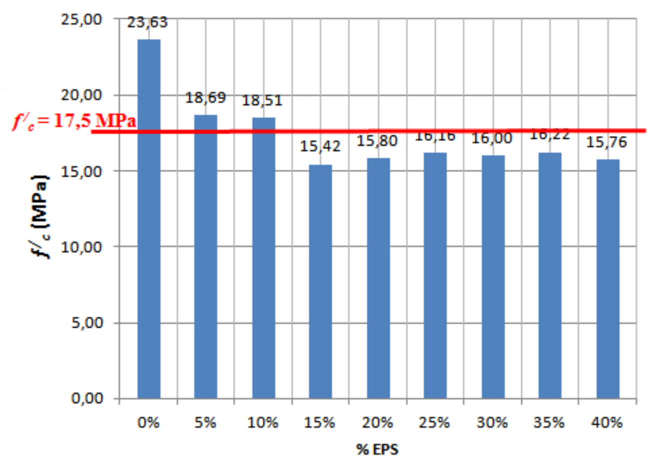

Fig. 4 Characteristic of concrete compressive strength based on EPS percentage

Analysis Result of Concrete Density Testing

Table 5 shows relations between average concrete density and percentage of EPS. From the result, we can see that the using of 40% EPS hasn't produced the light weight concrete yet. The maximum density for light weight concrete is 1800 kg/m^{3}. But the using of 40% EPS as a replacement of fine aggregate has already reduced 9.4% of the total concrete density. Generally, each 5 % EPS will reduce 20-25 kg/m^3 of the total concrete density.

Table 5: Average density of EPS concrete

% EPS	Average Density at Specific Age			Avg.Density (kg/m^3)
	7 days	14 days	28 days	
0%	2281.23	2287.21	2299.41	2289.28
5%	2205.49	2191.27	2218.26	2205.01
10%	2173.85	2193.98	2205.24	2191.02
15%	2151.45	2166.67	2173.53	2163.89
20%	2128.30	2123.65	2150.95	2134.30
25%	2114.21	2126.35	2132.58	2124.38
30%	2084.14	2094.46	2114.71	2097.77
35%	2105.02	2112.83	2098.92	2105.59
40%	2065.96	2072.00	2085.33	2074.43

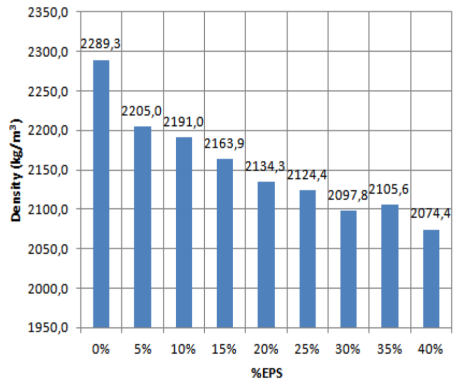

Fig. 5 Correlation between density and percentage of EPS

The correlation between Modulus of Elasticity concrete and EPS percentage is showed in Table 6. According to SNI 03-2847-2002 sections 10.5 about concrete Modulus of Elasticity, it's stated that concrete with the density between 1.500 -2.500 kg/m^3 , its modulus of elasticity E_c is $(w_c)^{1,5}\cdot 0,043\cdot\sqrt{f'_c}$. Based on the analysis of the test results, the empiric equation which correlate Modulus of Elasticity , density, concrete compressive strength and EPS percentage can be proposed :

$$E = (w_c)^{1,5}\cdot 0,05\cdot\exp(-0,23\cdot p)\cdot\sqrt{f'_c} \qquad (5)$$

where E is Modulus of Elasticity (MPa), w_c is density of concrete (kg/m^3), p *is* EPS percentage, and f'_c is concrete compressive strength

Table 6: Relation between E and % EPS

% EPS	E (MPa)
0	20533
5	20229
10	20064
15	19055
20	20615
25	19006
30	17448
35	16352
40	16219

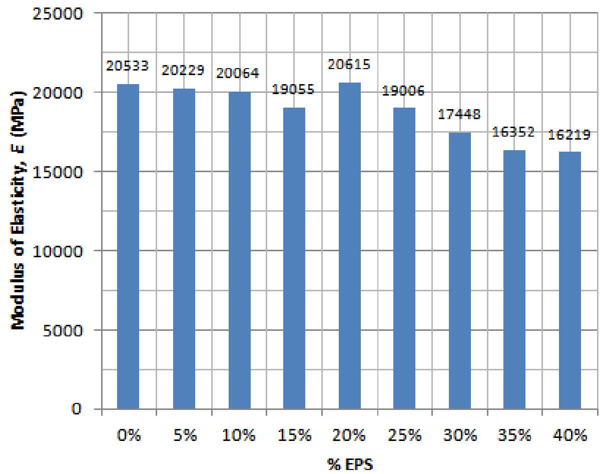

Fig. 6. Modulus of elasticity and EPS percentage

5. CONCLUSIONS

Based on the test results, the following conclusions are drawn:

1. The using of EPS materials as a partial substitution of sand, generally will decrease the concrete compressive strength. The concrete compressive strength characteristics will decrease to 18.69 MPa (decrease around 20.9 % from normal concrete) at the using of 5% EPS. While using 10 % EPS will cause the decreasing 21.67% of concrete compressive strength characteristics (decreasing to 18.51 Mpa). The using of EPS above 10% will produce the concrete compressive strength characteristics under 17.5 MPa. This result means the concrete can't be used for structural elements.

2. Concrete with 5 %, 10% and 15% EPS material from fine aggregate has the same growth like the normal concrete. At age of 7 days, the Concrete compressive strength reach 65% strength of the total strength, which is gained at 28 days. While at age 14 days, the concrete compressive strength reach 88% strength of the total strength, which is gained at 28 days. Generally in the using of over 15 % EPS will not make the percentage of compressive strength at age of 14 days reach 88% strength of the total strength, which is gained at 28 days.

3. The using of 40% EPS will decrease 9.4 % concrete's density to 2074,4 kg/m^3, compared to normal concrete. But it can't be called as light weight concrete because its density is over 1800 kg/m^3

4. Each increasing of 5% EPS will decrease 20-25 kg/m^3 concrete's density.

5. Concrete modulus of elasticity decreases along with the increasing of EPS percentage while the using of 40% EPS in concrete's composition decreases 21 % modulus of elasticity to 16.219 MPa.

6. Correlation between modulus of elasticity (E), density (w_c), characteristics compressive strength (f'_c) and EPS percentage (p) can be expressed in an empiric's equation:

$E = (w_c)^{1,5} \cdot 0,05 \cdot \exp(-0,23 \cdot p) \cdot \sqrt{f'_c}$

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