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# THE STRENGTH AND WATER ABSORPTION OF HEATED EXPANDED POLYSTYRENE BEADS LIGHTWEIGHT-CONCRETE

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**ABSTRACT:** When an earthquake occurs, buildings experience a movement or mass transfer. Therefore, the use of lightweight building materials is expected to reduce the effects of the earthquake. Research on the use of expanded polystyrene (EPS) as a substitute for aggregate has been done, but the results obtained are far from the requirements of structural concrete. This research tried to improve the mechanical ability of EPS concrete with the innovation of giving heat treatment to the EPS (heated EPS) to make the bonding capacity between the concrete components better than EPS without heat treatment. This research was a low-risk laboratory-based experimental study, which involves the process of making lightweight concrete from EPS beads that replace part of the aggregate. The method examined the lightweight concrete with partial replacement of aggregate with EPS beads (with the ratio of EPS beads to fine aggregate=0%:100% ; 20%:80% ; 40%:60% ; 60%:40% ; 80%:20%). The results found that the heat treatment of EPS beads changes the internal structure of EPS which can make the pores smaller and the surface structure of EPS becomes rough so that it can provide better bonding and adhesion between concrete elements. The compressive strength of heated EPS concrete tends to be higher 2-10MPa compared to EPS concrete without prior heat treatment.

*Keywords: Expanded Polystyrene (EPS) Beads, Heat Treatment, Lightweight Concrete, Compressive Strength, Water Absorption*

## 1. INTRODUCTION

Concrete can be categorized into three types, Heavy Concrete (3200-4000 kg/m3), Normal Weight Concrete (2400-2600 kg/m3), and Lightweight Concrete (< 2000 kg/m3) [1]. Different aggregates will influence the weight of the concrete and have an impact to its mechanical properties [2, 3] The concept of lightweight concrete is a method of making concrete that is used to minimize the volume weight a below-average volume of conventional/normal concrete. The concrete then, simply known as lightweight aggregate concrete (LWAC). Lightweight aggregates (LWA) itself are classified into two types: natural LWA (volcanic ash, pumice, diatomite) and artificial LWA (fly ash, clay, perlite) [4]. If, by using structural lightweight concrete, a structure can be built so it weighs less, then during an earthquake any resultant lateral forces will be smaller [5]. Lightweight Aggregate Concrete (LWAC) presents better thermal properties compared to Normal Concrete (NC) in building applications [6].

The optimization of properties of lightweight concrete by using fly ash [7], coarse lightweight aggregates (LWA) [8], Lightweight Expanded Clay Aggregate (LECA) [9] have been observed in previous research. This included an experimental study on the effects of using recycled waste expanded polystyrene foam (EPS) as a potential aggregate in lightweight concrete [10]. Reuse, recycling, and reducing waste are considered the only methods to recover the wastes generated; however, the executions still have many opportunities for improvement [11]. EPS, with very low densities, are incredibly light (up to 95% air) which can cause segregation in mixtures. A hydrophobic characteristic lead to make results in poor bonding to cement paste [12]. Poor bonding will lead to low concrete strength, which means EPS concrete's compressive strength will decrease with an increase in EPS beads [5]. There was a previous research that has applied a heating treatment to waste polystyrene [11]. What distinguishes this research was that there is an addition to using EPS in granular form (aggregates tend to be more uniform in shape). Also, the use of finer particles than fine aggregate used in normal concrete was expected to provide a better density level.

This paper will study the mechanical properties of heating treatment of EPS beads on the density, compressive strength, tensile strength, and water absorption. This research will also provide some study results that will open up potentials for further research to enhance its aims.

## 2. MATERIALS AND METHODOLOGY

This research was a laboratory-based experimental study. The study was conducted at the Structure and Building Materials Laboratory and Transportation Laboratory of Civil Engineering Department, Faculty of Engineering, Atma Jaya University Yogyakarta, Indonesia. Besides, the literature study method is also used to be the basis of theories in conducting research and the research results obtained. This research will examine the mechanical properties of lightweight concrete with partial replacement of aggregate with EPS beads (with the volume ratio of EPS to fine aggregate = 0%:100%; 20%:80%; 40%:60%; 60%:40%; 80%:20%). This comparison ratio was based on previous research which used a comparison of modified polystyrene which replaced natural aggregate of 0, 60 and 100 [11]. The addition of the ratio of 20, 40 and 80 in this study was expected to be able to see the changes more gradually. In addition, round numbers (20, 40, 60, 80) will make the calculation and dosing of the mix design easier. The compressive strength, elastic modulus, splitting tensile strength, and water absorption was analyzed in this study.

### 2.1 Materials

This research was using Ordinary Portland Cement (OPC) according to ASTM type 1 cement manufactured by PT. Holcim Tbk (recently named as Dynamix). This cement's chemical compositions are listed as in Table 1. Sand as fine aggregate was taken from *Progo* river, which had a size limited to 0.85mm, bulk specific gravity SSD (Surface Saturated Dry) of 2.905 gr/cm3, and 0.81% water absorption. EPS beads (particle size +/-5mm) with a density of 5.6 kg/m3 used as the aggregate for this lightweight concrete. Sika® ViscoCrete®-1003 as a superplasticizer was also used to increase the workability.

### 2.2 Laboratory Tests and Procedures

Testing using Scanning Electron Microscopy (SEM) aims to determine the EPS surface's shape before and after it was heated. EPS beads in this study were heated at a temperature of 100°C for 15 minutes. The purpose of the treatment was to obtain hardened EPS grains but not until melted. This condition also based on the data on previous research [11], which mentioned that starting from 100°C EPS began to change shape and after 130°C for more than 15 minutes, the EPS tend to be melted. Cement and water are mixed to form a cement paste as the first step as a binder. The EPS that has been treated with heat then mixed into the cement paste. This method needs to be done to ensure bonding between the binder (cement paste) and the EPS beads. The volume of EPS beads according to the mix design for each variation. At the final step of mixing, fine aggregates were poured into the mixture and stirred evenly.

Table 1. Chemical compositions of ASTM type I cement [13]

| Compound | Weight (%) |
|---|---|
| CaO | 63.82 |
| SiO2 | 20.09 |
| Al2O3 | 3.87 |
| SO3 | 3.50 |
| Fe2O3 | 1.69 |
| MgO | 2.22 |
| Na2O | 0.30 |
| K2O | 0.39 |
| TiO2 | 0.16 |
| MnO | 0.05 |
| Bogue compositions | |
| C3S | 68.7 |
| C2S | 5.8 |
| C3A | 7.4 |
| C4AF | 5.1 |

The mixed material was poured into a cylindrical mold and pounded 25 times whenever it reached 1/3 of the mold height, then being leveled at the top surface. Lightweight concrete that has been put into the mold is left at a 24-hour room temperature. After that, the concrete released from the mold and then drowned out into a tub filled with water until the test time. The tests were carried out at 14 days, 28 days, and 56 days for compressive strength, but only 28 days specimens were observed for elastic modulus, splitting tensile strength, and water absorption test because the concrete has reached 100% strength in 28 days. The compressive strength at 56 days tends to be better, but the increase is not too significant. Non-heated EPS concrete was also produced but limited to compare the density and compressive strength. The test specimens to be made in this study are concrete cylindrical shapes with a diameter of 100 mm and a height of 200 mm for testing the compressive strength, splitting tensile strength, and water absorption. Simultaneously, the test specimens with a diameter of 150 mm and a height of 300 mm were being used for the testing of elastic modulus.

Table 2. Mix-Design EPS Concrete

| variation | PC (Kg) | Water (L) | Fine Aggregate (Kg) | Non-Heated EPS beads (Kg) | Heated EPS beads (Kg) | Super-plasticizer (L) |
|---|---|---|---|---|---|---|
| (control) -NC | 729 | 160 | 1,071.0 | - | - | 4.4 |
| H-EPS 20% | 729 | 160 | 856.8 | - | 1.0 | 4.4 |
| H-EPS 40% | 729 | 160 | 642.6 | - | 2.0 | 4.4 |
| H-EPS 60% | 729 | 160 | 428.4 | - | 3.1 | 4.4 |
| H-EPS 80% | 729 | 160 | 214.2 | - | 4.1 | 4.4 |
| NH-EPS 20% | 729 | 160 | 856.8 | 0.7 | - | 4.4 |
| NH-EPS 40% | 729 | 160 | 642.6 | 1.4 | - | 4.4 |
| NH-EPS 60% | 729 | 160 | 428.4 | 2.1 | - | 4.4 |
| NH-EPS 80% | 729 | 160 | 214.2 | 2.8 | - | 4.4 |

*Note: mix design is calculated to produce 1m3 concrete. NC: Normal Concrete; NH-EPS: Non Heated EPS Concrete; H-EPS: Heated EPS Concrete*

### 2.3 Compressive strength, Elastic Modulus

Compressive strength testing is carried out when the specimen is at the age of 14, 28, and 56 days. The initial preparation was measuring the dimensions (diameter and height) of the test specimen and weighing the concrete cylinder. This is to be used to determine the weight/density of concrete. Concrete compressive strength testing using Compression Testing Machine (CTM) by ELE. Calculation of concrete compressive strength values using the specified formula.

$$fc = \frac{P}{A} \tag{1}$$

Where fc is the compressive strength of the specimen (MPa), P is the maximum load applied to the specimen (N), and A is for the cross-sectional area of the specimen (mm2). For each variation, three specimens were tested, and the average of the measured values was recorded.

Elastic Modulus or Modulus of Elasticity (MoE) testing was carried out on cylindrical shaped specimens (150x300mm) aged 28 days. The testing step is carried out with the following stages: installing a compress-meter on a concrete cylinder. Note the shortening that occurs each additional load of 500kgf. To find out the value of elastic modulus, use the following formula.

$$E = \frac{\delta}{\varepsilon} \tag{2}$$

Where E is the modulus of elasticity (MPa), δ is stress (MPa), in this case, compressive strength, and ε is for strain (unitless). The strain is defined as the change of the length divided by the original (initial) length.

### 2.4 Splitting Tensile Strength

Concrete tensile strength testing is carried out on specimens aged 28 days. Concrete tensile strength aims to determine the tensile strength value of concrete. Concrete tensile strength testing is applied to a cylindrical test specimen, which is placed horizontally parallel to the concrete compressing machine's pressure surface. Before conducting the test, the concrete cylinder must first be identified its weight and dimensions. After that, the test specimen is given a load to the maximum or until the test object breaks/splitting. Then the maximum load value is recorded. The splitting tensile strength was calculated from the formula below.

$$T = \frac{2.P}{\pi.l.d} \tag{3}$$

Where T is the splitting tensile strength (MPa), P is the maximum load on the specimen (N), D is the diameter of the specimen (mm), and L is the length of the specimen (mm). For each variation, two specimens were tested, and the average of the measured values was recorded.

### 2.4 Water Absorption

Water absorption test of the concrete was applied to 28-days-old cylindrical specimens (100x200mm). The test specimen is dried in an oven for 24 hours to obtain absolute dry weight. After 24 hours, the specimens were weighed and then immersed in water for 24 hours for the next step. The specimens then dried to remove the excess water on the surface so that later the saturated weight was obtained. The calculation of concrete water absorption uses the formula as follows.

$$\mathbf{WA} = \frac{(\mathbf{Ws}-\mathbf{Wd})}{\mathbf{Wd}} . \mathbf{100\%} \qquad (4)$$

WA is (Water Absorption), Ws is saturated weight, and Wd is the specimens' dry weight. For each variation, two specimens were tested, and the average of the measured values was recorded.

## 3. RESULTS AND DISCUSSION

Data obtained from the test, the weight of EPS contents before heat treatment was 5.6 kg/m3, then after heat treatment was 8.08 kg/m3 due to the EPS beads' size getting smaller, thereby increasing the volume of EPS. The weight of heated-EPS beads can be used in calculating the amount of EPS beads for the composition of lightweight concrete. From the test results of Scanning Electron Microscopy (SEM), the surface of pre-heated EPS beads is rougher than the surface of non-heated-EPS (Fig. 1).

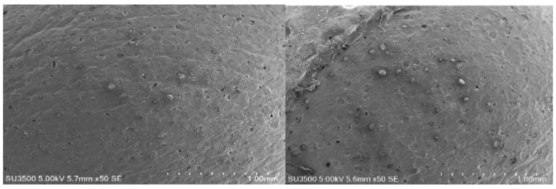

Fig.1 The surface of EPS bead before and after pre-heated treatment.

There was a space in the container that appeared after the heating process (Fig. 2). It showed that heat treatment reduced the dimensional and then influence the density of EPS beads. The EPS beads tend to be wrinkle and shrinking in shape.

Fig.2 The heat treatment process of EPS beads.

The density of lightweight EPS concrete varies between 1,421–2,252 kg/m3 for concrete with EPS that has heat treatment and between 1,358-2,048 kg/m3 for lightweight concrete using EPS without heating treatment (Table 3). These results showed that the use of heated EPS increases the density level between 4.64-9.96% (Fig. 3).

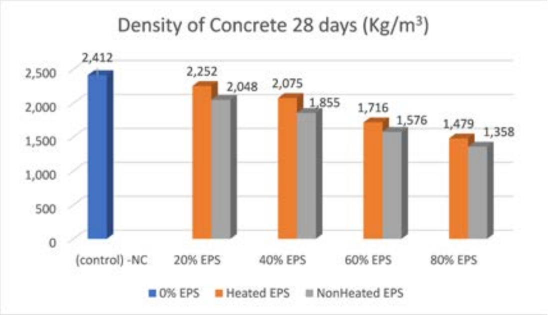

Fig.3 Density of EPS concrete

The increasing level of density also has an impact on the increase in the compressive strength of concrete. As can be seen in Fig. 4, the concrete using heated EPS aggregate has better compressive strength than the concrete using ordinary EPS beads. Comparison of the compressive strength between the concrete using heated EPS with normal (control) concrete and concrete using NonHeated EPS was only carried out at the age of 28 days with the consideration that the concrete standard have reached 100% strength at 28 days. The compressive strength value of concrete at 56 days tends to be better, but the increase was not significant. This can be seen in the results listed in table 3.

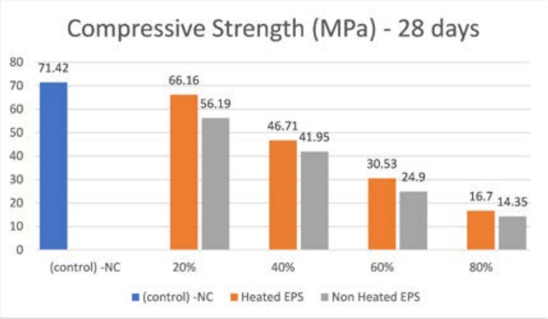

Fig.4 Compressive strength at 28 days

### 3.1 Compressive Strength, Elastic Modulus

As the concrete age increases, the concrete's strength also increases and reaches its peak at the concrete age reaching 56 days as shown in Table 3, the addition of EPS in a concrete composition results in a decrease in concrete's compressive strength. The decrease in compressive strength of the concrete was quite significant, ranging from 14.36-70.63% (14 days), 7.36-76.62% (28 days), and 5.98-75.28% (56 days) for the composition of

20% EPS to 80% EPS. As shown in Fig. 5, the increase in compressive strength of concrete occurs significantly at the age of concrete, 14 to 28 days. However, the increase of percentage in compressive strength decreases along with the increasing amount of EPS in concrete. This can be seen in the 80% H-EPS, where the increase is only around 6.85%. This could be due to the increasing amount of EPS filling the test specimen's volume, so that not enough reaction among cement, water, and fine aggregate. The hydrophobic property of EPS was also possible to give the effect of the ease with which water in the concrete is lost (evaporates). This condition leads to a negative impact due to the lack of the cement reaction process to form a paste. Therefore a less strong bond between the aggregate and the cement paste.

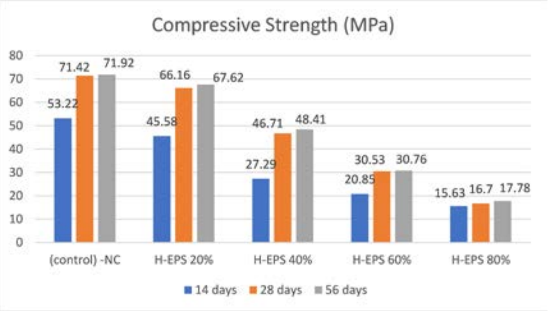

Fig.5 Compressive strength of Heated EPS concrete

The higher the elastic modulus value, the stiffer the material. Compared to normal concrete, EPS concrete's modulus elasticity decreases with increased EPS substitution in the concrete (Fig. 6). The more components/percentage of EPS beads in a concrete, the lower the MoE value. Although it looks unsatisfactory, there is a good thing from the data obtained, namely concrete with EPS can make concrete have ductile properties that can be used as a damper structure. By this trend, it can be shown that there are relationships among density, compressive strength, and modulus of elasticity.

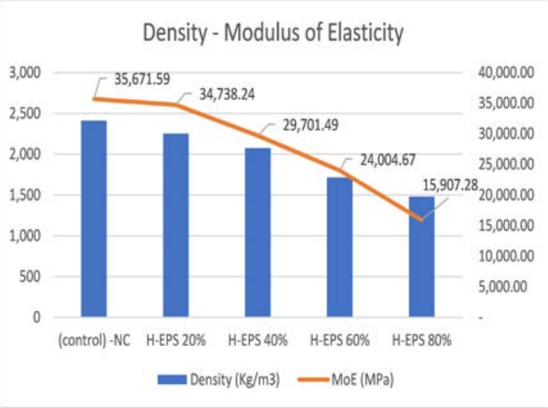

Fig.6 Density and MoE at 28 days

### 3.2 Splitting Tensile Strength

The results of tests on concrete cylinders show that the splitting tensile strength value of concrete containing EPS has a lower value than normal concrete, and it gets smaller as the amount of EPS in the concrete increases. Like compressive strength and modulus of elasticity, the splitting tensile strength is strongly influenced by the level of concrete density (Fig. 7). The lower the level of concrete density, the lower the splitting tensile value will also be weakened

There was no floating EPS on the concrete cylinder's surface and EPS beads' distribution were quite spread evenly (Fig. 8). The even distribution of the beads can prove that there was no segregation in the concrete. This result might be because using a superplasticizer that made a better concrete's workability [14].

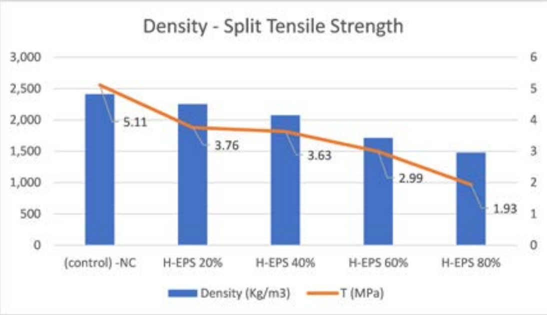

Fig.7 Density and splitting tensile strength

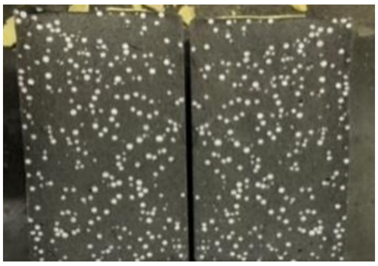

Fig.8 Cross section of the specimen after splitting tensile testing

### 3.3 Water Absorption

The water absorption test results showed that the greater the number of EPS in concrete, the greater the water's absorption capacity (Figure 8). Lack of bonding between the mortar and EPS could be why there are many cavities created in the concrete. However, the addition of cement content, the use of superplasticizer and preheating treatment on EPS can bring good enough impact to reduce water absorption. With the differences in the methods, this study produced concrete with better water absorption than previous studies [15], which had a water absorption capacity of 11.97% on average.

Table 3. Summary of the results for all variant

| variation | Density (Kg/m3) | | | fc (MPa) | | | E (MPa) | T (MPa) | WA (%) |
|---|---|---|---|---|---|---|---|---|---|
| | 14 days | 28 days | 56 days | 14 days | 28 days | 56 days | 28 days | 28 days | 28 days |
| (control) -NC | 2,346 | 2,412 | 2379 | 53.22 | 71.42 | 71.92 | 35,671.59 | 5.11 | 3.17 |
| H-EPS 20% | 2,213 | 2,252 | 2152 | 45.58 | 66.16 | 67.62 | 34,738.24 | 3.76 | 3.24 |
| H-EPS 40% | 2,078 | 2,075 | 1935 | 27.29 | 46.71 | 48.41 | 29,701.49 | 3.63 | 3.38 |
| H-EPS 60% | 1,786 | 1,716 | 1732 | 20.85 | 30.53 | 30.76 | 24,004.67 | 2.99 | 4.32 |
| H-EPS 80% | 1,563 | 1,479 | 1421 | 15.63 | 16.7 | 17.78 | 15,907.28 | 1.93 | 5.26 |
| NH-EPS 20% | - | 2,048 | - | - | 56.19 | - | - | - | - |
| NH-EPS 40% | - | 1,855 | - | - | 41.95 | - | - | - | - |
| NH-EPS 60% | - | 1,576 | - | - | 24.9 | - | - | - | - |
| NH-EPS 80% | - | 1,358 | - | - | 14.35 | - | - | - | - |

*Note: NC: Normal Concrete; NH-EPS: Non Heated EPS Concrete; H-EPS: Heated EPS Concrete*

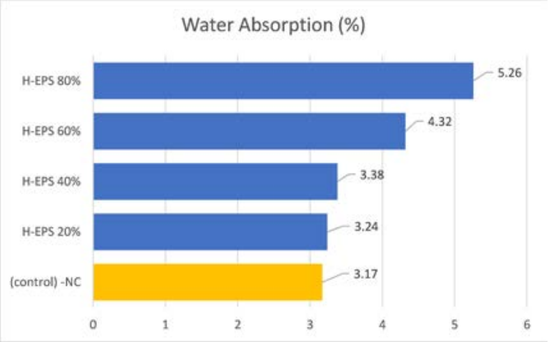

Fig.9 Water Absorption of EPS Concrete

## 4. CONCLUSION

From this study, several conclusions can be conveyed as follows. Heating treatment of EPS beads has an impact on a better level of concrete density. With a better concrete density, it affects the compressive strength and split strength as well as a better water absorption, compared with another previous research. However, the more of EPS composition in concrete also impacts the weakening of the concrete tensile strength. Likewise, the water absorption shows a higher value: more water is quickly absorbed while increasing EPS composition in concrete.

It is preheating treatment proven to create better compressive strength value than non-heated EPS beads. The resulting compressive strength and tensile strength have not been able to outperform normal concrete, even with the use of an admixture (superplasticizer) which help the EPS beads spread evenly (no segregation). However, the resulting density can be categorized as lightweight concrete (below 1800Kg/m3), with the percentage of EPS beads replacing the aggregate starting from 60%.

There are still many things that can be developed from this research. The use of fiber can contribute to increase the tensile strength. Fibers that have a base material that nearly the same as EPS, for example: polypropylene fibers, are highly recommended. The addition of this fiber can be used as a suggestion for further research. The lightweight polypropylene fibers are expected to be able to maintain the density of concrete so that it is categorized as lightweight concrete.

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