Effect of Carbon Nanotube on properties of lightweight concrete using recycled Expanded Polystyrene (EPS)

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Abstract. Expanded Polystyrene based Lightweight concrete (EPS-C) is a lightweight material with low compressive strength and high energy absorption capacity. This type of concrete is mainly applied for heat and sound insulation, towards energy saving and sustainable development. In terms of composition, EPS-C is made from a mixture of cement, mineral additives, water, chemical additives, and Expanded Polystyrene Beads (EPS) which are small hollow spherical, impermeable, and non-toxic balls. In this paper, the EPS particles were replaced with recycled polystyrene particles as aggregates for lightweight concrete. Besides, carbon nanotube (nCNT) was added to improve the properties of the concrete. The experimental results show that (i) it is possible to use recycled EPS aggregate in making lightweight concrete with a density of less than 1200 kg/m³; (ii) the combination of nCNT improved significantly the properties of lightweight concrete, i.e. reducing the water absorption, increasing compressive strength; (iii) lightweight concrete with a very low thermal conductivity, corresponding to 0.152 W/m°C for a sample with a density of 600 kg/m³.

1. Introduction

Expanded Polystyrene based Lightweight concrete (EPS-C) is a lightweight concrete manufactured by French technology, which is made from a mixture of different materials such as cement, fly ash, sand, Lightweight Expanded Polystyrene Beads (EPS), water and chemical admixture. EPS is a lightweight cellular plastic material consisting of small hollow spherical, impermeable, and non-toxic balls with a very low density of only about 10 to 20 kg/m³, easily produced with different size ranges. Therefore, EPS is allowed to add, even with a large amount, in a sticky concrete mixture with low mixing water. In particular, various a closed cellular structure or honeycomb-type structure can be easily created by the combination of multiple particle sizes of EPS.

EPS concrete includes macro-pore structure system created from porosity of EPS particles, and micro-pore structure made up of gel pores, and capillary system in the voids of inter-particles. The use of EPS beads will have great advantages in reducing the weight of lightweight concrete [1,2,3]. However, EPS is a lightweight aggregate with a very low density, the concrete mixture is easily caused by the segregation phenomenon. Many researchers have studied to overcome this such as Roy et al. [4] who used superplasticisers in combination with dispersed fibers to reduce the segregation of EPS particles, resulting in an increase of 5-10% compressive strength and an improvement of the waterproofing capacity of concrete. With the advantages of EPS-C that has been paid much attention...
and research, Sabaa's studies [5] on the influence of workability on some properties of EPS-C such as density, compressive strength. The results show that when the workability of the concrete mixture increases, the concrete strength is improved compared to concrete mixture with a low workability. In addition, Collins's studies [6] on the effect of density on the properties of EPS-C show that the density of EPS-C significantly affects the compressive strength of concrete, and this influence is greater than that of flexural strength and elastic modulus. EPS-C has been being researched and applied in the world in many fields. In Russia and China, many types of EPS-C are applied for producing bricks. Due to their low density, the bricks made from EPS-C have very good thermal insulation, especially in countries with the temperature is as cold as in Russia [7].

However, EPS-C uses a large amount of EPS and this material accounts for a large proportion of the price in concrete. Nowadays, the amount of EPS waste has been being increased, e.g. foam containers, slot inserts for fragile tools, etc., this type of foam is very harmful if it is not treated properly. According to the study, the majority of EPS waste belongs to solid waste and persistent, and this can cause environmental pollution, affecting human health [8]. Too much EPS waste when released into water or soil environment can change the properties of the soil, clogging the drainage system, which over time is the reason why many bacteria are constantly growing, causing many dangerous diseases for humans.

Derived from such practice, this study will focus on the treatment and use of this EPS waste in concrete manufacturing, which both reduces the cost of EPS-C by reducing the use of primary EPS particles, and also contributes to reducing the amount of EPS waste discharged into the environment. Besides, when used in combination with carbon nano tube (nCNT) will improve significantly the properties of the EPS-C.

2. Materials and methods

2.1. Materials

Materials used in the research including Portland cement PCB40 with some mechanical properties presented in Table 1; The recycled EPS has a density of 10 kg/m3. The particle size of recycled EPS in the range of (2.5-10) mm, in which (2.5-5) mm and (5-10) mm account for 52% and 48% by volume, of the mixtures, respectively (The image of EPS crusher and granules after recycling are shown in figure 1.

| Properties                  | Unit | Value | Specification | Test methods |
|-----------------------------|------|-------|---------------|--------------|
| Retained on 0.09mm sieve    | %    | 3.3   | ≤ 10          |              |
| Fineness Blain              | cm²/g | 3120   | ≥ 2800        | TCVN 4030-2003 |
| Standard consistency        | %    | 29.0  | -             | TCVN 6017-2015 |
| Compressive strength        |      |       |               | TCVN 6016-2012 |
| - 3 days                    | MPa  | 23.4  | ≥ 21.0        |              |
| - 28 days                   |      | 45.6  | ≥ 40.0        |              |
Figure 1. Recycled foam machine and EPS particle mixtures after grinding

Superplasticizer (SP) used in the research based on polycarboxylate. nCNT with composition is Hydroxylated multiwalled carbon nanotubes, inner diameter from 5-10nm and outer diameter from 10-30nm, density 0.14 g/cm³, some mechanical properties of nano CNT are shown in Table 2, CNT nanoparticles after being distributed are shown in Figure 2.

Table 2. Physical properties of nano CNT

| No | Properties                  | Unit | Value     |
|----|------------------------------|------|-----------|
| 1  | Color                        |      | Black     |
| 2  | Average Inside Diameter      | Nm   | 5-10      |
| 3  | Average Outside Diameter     | Nm   | 10-30     |
| 4  | Length                       | µm   | 10-30     |
| 5  | Specific Surface Area        | m²/g | > 140     |
| 6  | Density                      | g/cm³| 0.14      |

Figure 2. nano carbontube after dispersing

2.2. Experimental methods

The process of fabrication and curing of concrete samples is carried out in accordance with TCVN 3105-1993. The mold is clamped on a vibrating table with the frequency of 2800-3000 rpm, the amplitude ranges from 0.3-0.5mm, Concrete after casting is cured at standard temperature conditions of 27±2°C, Humidity above 95% during 24 hours. The samples continues to be cured under standard conditions until the age of testing
The density of concrete were determined according to TCVN 3108-1993 (Vietnamese standard). The compressive strength of concrete were determined at the age of 28 days with a sample size of 150×150×150 mm according to TCVN 3118 [9].

Thermal conductivity of concrete were tested according to ASTM C518 [10] on a sample of size 200×200×40 mm. The samples were exposed to hot and cold sources with a diameter of 10 cm at constant temperatures of 60°C and 10°C, respectively. Results of thermal conductivity were tested with 6 gradients using recycled EPS granules with different content and combined with nano CNT with 0%, 0.05% and 0.1% by weight of cement.

Determination of water absorption of concrete were carried out according to BS 1881-122 [11], in which the test samples were cube with dimensions of 100×100×100 mm.

### 2.3. Concrete mix design

This study will focus on assessing the effect of amount of recycled EPS particles on the possibility to make lightweight concrete and their effects on the properties of lightweight concrete. The workability of concrete mixtures is controlled from 4 to 8 cm. The designed densities of EPS-C are 600 kg/m³, 900 kg/m³, and 1200 kg/m³ using recycled EPS particles with EPS content of 41%, 56% and 71% by volume of concrete in combination with 0%, 0.05% and 0.1% nCNT by weight of cement, respectively. The mixture composition is calculated by absolute volume in which the ratio of water and binder (w/b) is fixed to 0.32 and superplasticizer (SP) is fixed at 0.6% by weight of cement. This SP content was chosen to ensure the workability of concrete as required, and does not cause the segregation of EPS particles in the mixture. The mixture proportion is shown in **Table 3**.

### Table 3. Mixture proportions of EPS-C

| Notation | EPS, %V_BT | W/B, % by mass | SP, % by weight of binder | CNT, % by weight of cement | Cement, kg | EPS, liter | Water, liter | SP, liter |
|----------|-----------|----------------|---------------------------|---------------------------|------------|------------|-------------|----------|
| Mix60    | 71.0      | 32             | 0.6                       | 0-0.05-0.1                | 450        | 710        | 144         | 2.7      |
| Mix90    | 56.0      | 32             | 0.6                       | 0-0.05-0.1                | 683        | 560        | 218         | 4.1      |
| Mix120   | 41.0      | 32             | 0.6                       | 0-0.05-0.1                | 916        | 410        | 293         | 5.5      |

### 3. Experimental results and discussion

#### 3.1. Density

The effect of recycled EPS-C particles and the content of nCNT on the density of concrete is shown in **Figure 3**. The results show that when the volume of EPS particle increases, the density of concrete decreases. This result is entirely appropriate because when the volume of recycled EPS particles increases, the volume of the binder will decrease, instead of the large amount of macro-pores and this has reduced the density of concrete. With concrete using nCNT, the workability and homogeneity of concrete mixture are improved. With the Mix60 mixture, when increasing the amount of nCNT, the density of concrete decreases compared to the sample without using nCNT. Whereas with mixtures having density of 900 kg/m³ and 1200 kg/m³, the density of concrete does not change with different nCNT contents. This can be explained with Mix60 that the recycled EPS content is very high (accounting for 71% of the volume of concrete). This is easy to cause segregation for lightweight EPS particles, however when using nCNT with a very small particle size of about 10 nm, it has a good
dispersion effect and adsorbs excess water while increasing the viscosity of the binder thereby creating a mixture with better workability and homogeneity, resulting in preventing the segregation in concrete.

The experimental results are different from the theoretical calculations, with the Mix60 sample, the actual density is smaller than the theoretical calculations, while the density of the Mix90 and Mix120 samples are higher than theoretical calculations.

![Graph showing density of EPS-C with nCNT content](image)

**Figure 3.** Effect of recycled EPS and nCNT content on density of EPS-C

### 3.2. Compressive strength

The relationship between compressive strength and density of concrete is shown in Figure 3. The results of the study show that the compressive strength of concrete depends significantly on the density of concrete, recycled EPS content and especially the nCNT content. When the recycled EPS content reaches 71%, the density of concrete is achieved about 600 kg/m³, and the compressive strength is less than 4 MPa. Besides, when the EPS content decreases to 41%, the density of the concrete increased greatly, reaching 1200 kg/m³ and compressive strength of concrete increased rapidly, reaching over 6MPa. With a mixture using 0.1% nCNT, the compressive strength of concrete can reach over 9MPa.

For concrete samples using nCNT, the density of concrete did not differ significantly. However, the compressive strength of concrete has improved greatly, with concrete density of 600 kg/m³ when increasing the nCNT content of 0.05% and 0.1%, the compressive strength of concrete increased by 6.1% and 14.3 respectively, in comparable with that of control sample (using 0% nCNT). For concrete with a density of 1200 kg/m³, when increasing the amount of nCNT from 0.05% to 0.1%, the compressive strength of concrete increases greatly, respectively increasing by 20% and 30% compared to the sample using 0% nCNT. Therefore, nCNT with superfine size, when used in concrete, has a filler effect with pores in hardened cement paste, creating a bridge between microcracks, thereby contributing to improving the compressive strength and durability.

It can be seen from the results that the volume of recycled EPS has a direct influence on the density and compressive strength of concrete. It means that increasing the volume of EPS will reduce the volume of hardened cement paste, increasing the macro-pores leads to a reduction in density and compressive strength. Besides, the use of angular recycled EPS particles not similar to the original EPS particle, so when the EPS content increases, the effect of this particle on the compressive strength of concrete is increasing.
3.3. Water absorption

Water absorption of EPS-C depends on not only cement content, density of concrete, but also on the characteristics of aggregates and other mineral admixtures. Experimental results on the relationship between water absorption and compressive strength of EPS-C are shown in Figure 4. It can be observed that when the volume of recycled EPS increased, the water absorption of the EPS increased. The water absorption of concrete is inversely proportional to the increase of compressive strength, this means that when the compressive strength increases, the water absorption decreases. With concrete samples using the same recycled EPS content, when the content of nCNT increases, the water absorption of the concrete tends to decrease, but the extent of the decrease depends on the EPS content used in concrete and correspondingly will depends on compressive strength of concrete.

For concrete with a density of 1200 kg/m$^3$, when increasing the amount of nCNT from 0.05% to 0.1%, the water absorption of concrete decreases by 5% and 9.4%, respectively, compared to the control sample using 0% nCNT. Meanwhile, concrete samples with the density of 600 kg/m$^3$, when the nCNT content increased from 0.05% to 0.1%, the reduction in water absorption was 2.3% and 6.1% respectively. The use of nCNT reducing the water absorption of concrete can be explained as nCNT is very small, about 10nm, when used in concrete has the effect of increasing the homogeniety of the concrete mixture, filling into the microstructure pores in hardened cement paste thereby contributing to improving the dense structure, increasing the durability and reducing water absorption for concrete.
3.4. Thermal conductivity
The thermal conductivity coefficient of concrete was determined with 03 samples without using nCNT with densities of 600 kg/m$^3$, 900 kg/m$^3$ and 1200 kg/m$^3$, respectively. The research results are compared with the experimental formula of ACI 213R14 [12] as follows:

$$\lambda = 0.086e^{0.00125Wc}, \text{W/m.}^\circ\text{C}.$$  

in which

$$e = 2.71828$$

$Wc$: dry density of concrete, kg/m$^3$

Experimental results on the effect of density, and the recycled EPS content on thermal conductivity coefficient are shown in Figure 5. Experimental results show that, when the EPS content decreases, the density of concrete increases, the thermal conductivity coefficient of concrete increases. When the concrete density increases from 600 kg/m$^3$ to 900 kg/m$^3$, the thermal conductivity coefficient increases slowly. This shows that the slope of the graph is small. However, when the density of concrete increased from 900 kg/m$^3$ to 1200 kg/m$^3$, the increase of the thermal conductivity coefficient was much larger, which showed that the slope of the chart greatly increased. This can show that EPS particles with a very high porosity, up to 90%, when used in concrete will create very large hollow structures thereby preventing thermal conductivity of EPS-C.

Experimental results when compared with the experimental formula of ACI 213R-14 have certain differences. For concrete samples with density less than 900 kg/m$^3$ the coefficient of thermal conductivity is smaller than that calculated from the experimental formula, while when density increased to 1200 kg/m$^3$, the thermal conductivity coefficient of the concrete is larger than that of the experimental formula. This is possible that the formula of ACI only mentioned when comparing the thermal conductivity coefficient with the density of concrete, while the experimental results are not only affecting the influence of density but also other factors, i.e. amount of EPS, shape and size of recycled EPS particles as well as the distribution of EPS particles in concrete.

![Thermal conductivity vs Density](image)

**Figure 6.** Experimental results on the thermal conductivity coefficient of concrete in comparable with the experimental formula of ACI 213R14

4. Conclusions
The paper presents the experimental results of the effect of recycled EPS and carbon nanotube content on the properties of EPS-C, some conclusions can be drawn as follows:

1. It is possible to use recycled EPS particles to make lightweight concrete. The recycled EPS content, cement content and carbon nanotube (nCNT) content have a direct effect on the physical and mechanical properties of the EPS-C;
(2) The EPS content has an influence on density of concrete, when the EPS content increases from 41-71% by volume of concrete, the density of concrete decreases from 1200 to 600 kg/m$^3$; The use of nCNT in concrete does not significantly affect the density of concrete.

(3) The compressive strength of concrete is directly affected by the EPS content, cement content and nCNT. When the amount of cement increases with the decrease of EPS, the compressive strength of concrete increases. The use of nCNT in concrete has increased the compressive strength of the concrete samples. This result is similar to results of the water absorption of concrete, when reducing the EPS content and increasing CNT content, the water absorption of the concrete decreases;

(4) The EPS content has an effect on the thermal conductivity coefficient of concrete, for the sample using the EPS content to make concrete with a small density, the degree of thermal conductivity reduction is significant.

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