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The effect of fly ash as coating powder on compressive strength of lightweight concrete

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ABSTRACT

Expanded polystyrene (EPS) has been used and studied for decades in lightweight concrete. Because EPS beads are incredibly light, using these beads in concrete will cause the particles to segregate. Furthermore, the hydrophobic nature of EPS materials weakens the bond between them and cement paste. This research will investigate the compressive strength of lightweight concrete using EPS beads as a coarse aggregate replacement, focusing on the effect of fly ash coating with a binder made from a mixture of Polyvinyl Acetate (PVA) and water. A comparison of density and compressive strength between normal concrete and concrete made from EPS beads was conducted in this study. EPS beads will replace 100% of coarse aggregate. Coated EPS beads that were being produced in this research have an average weight per volume of 246–251 kg/m3. The concrete that uses EPS beads coated with fly ash showed positive results for an increase in compressive strength of 8%, 20%, 38%, and 27% at the age of 7, 14, 28 and 56 days of concrete with EPS beads without modification.

1. Introduction

The occurrence of natural disasters such as earthquakes throughout the world has increased the demand for lightweight structural designs, as light structures decrease their own weight. Concrete is considered lightweight when it has a density of less than 2200 kg/m3 [1] (the weight of normal concrete is between 2300 kg/m3 and 2400 kg/m3). The same idea about the description of lightweight concrete, the BS EN 206–1[2] defines the lightweight concrete is the type of concrete that has an oven-dry density of at least 800 kg/m3 and not more than 2000 kg/m3, corresponding to the replacement of natural aggregates with lightweight aggregates. Although lightweight concrete in construction projects has the disadvantage of high cost per cubic meter, but it can reduce concrete volume, rebar branches, and beam size [3]. Moreover, the construction that used the LWC decks lowered the superstructure loads, allowing for cost savings, faster construction, and minimum traffic impacts [4]. Therefore, by reducing the load placed on the building structure, it may also help to reduce the costs associated with the construction process in a whole, related to cost efficiency and time management. Depend on the application, the form of lightweight concrete can either be lightweight aggregate concrete, foamed concrete or autoclaved aerated concrete (AAC). Instead of using for structural concrete, the use of lightweight concrete blocks is relatively common in the construction of houses [5].

Expanded Polystyrene has been used and studied for decades in lightweight concrete [6 7 8]. One of the reasons is that EPS is lighter and has better thermal and sound resistance [9]. A typical EPS aggregate is produced from polystyrene products (boxes, boards) that are shredded into fine and coarse aggregates [9]. However, because of EPS beads are extremely light, using these beads in concrete will cause the particles to segregate [6]. Furthermore, the hydrophobic nature of EPS materials weakens the bond between them and cement paste. In several studies, researchers have attempted to improve cement paste-EPS beads adhesion and concrete mixture segregation by using a two-stage casting process [10], creating novel LWA called Stabilised Polystyrene (SPS) [11], heat treatment [12 13] and also including a coating technique on EPS beads surface [14].

This research will investigate the compressive strength of lightweight concrete using EPS beads as a coarse aggregate replacement, with a focus on the effect of Fly Ash coating. In addition to

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the study outcomes, this research will present some study outcomes that will be of benefit for future research.

2. Methodology

This study involves a laboratory experiment. This study took place at the Concrete and Materials Laboratory, Faculty of Engineering, Environment and Computing at Coventry University, United Kingdom. Additionally, a literature review also supported the analysis and discussion and served as a basis for theories. The purpose of this experiment is to create an artificial aggregate and to report the result as part of an ongoing and enhancement process for future research.

2.1. Material

A cement manufactured by Hanson, 52.5 N High Strength Cement, was used in this research. Its weight was approximately 1370 Kg/m3. As fine aggregate, sand with a fineness modulus of 1.95 is used. Its dry weight in loose, compacted and wet conditions was 1350 kg/m3, 1650 kg/m3 and 1850 kg/m3, respectively. For coarse aggregate, 10 mm gravel with a modulus of 6.22 was utilized. The weights of gravel in dry, compacted, and wet conditions were respectively 1365 Kg/m3, 1425 Kg/m3, and 1525 Kg/m3.

The artificial aggregate that being used to replace the coarse aggregate was created from three types of materials. In this study, EPS beads are the primary component of the artificial aggregates. Next, the coating material/powder, and third, the adhesive/binding solution. A range of diameters from 3 to 6 mm of EPS beads were used in this study, and the weight of the beads per 1000 ml was 9–10 g. Pulverized Fuel Ash (PFA) or fly ash, a residual waste material from coal-fired electricity power stations, is used as the coating material. The density of PFA derived from Cornish Lime, U.K is approximately 1,070 kg per cubic meter and 83.96 percent of the chemical composition is SiO2 + Al2O3 + Fe2O3. While for the adhesive, PVA (Polyvinyl Acetate) was being used mixed with water with composition 4:3 by its weight. This adhesive material will later enable the EPS beads to be covered with powder [14]. Fig. 1 depicts the method of creating coated EPS, whereas Fig. 2 shows the EPS beads that have been wrapped with PFA powder. It generates coated EPS beads with an average weight per volume of 246–251 kg/m3 as a result.

2.2. Sample preparation

In this study, the production of lightweight concrete is divided into two steps. First, an aggregate formed of EPS beads covered with PFA powder is created. Fig. 1 depicts briefly the process steps for these modified EPS beads. Later, these EPS beads will replace 100% of coarse aggregate in normal concrete. The second step is to create concrete test objects to compare normal concrete (NC), concrete with unmodified EPS aggregate (EPSC), and concrete with modified EPS aggregate (MEPSC). Based on the mix design in the making of normal concrete (NC), the coarse aggregate composition was approximately 76% of the volume of concrete produced.

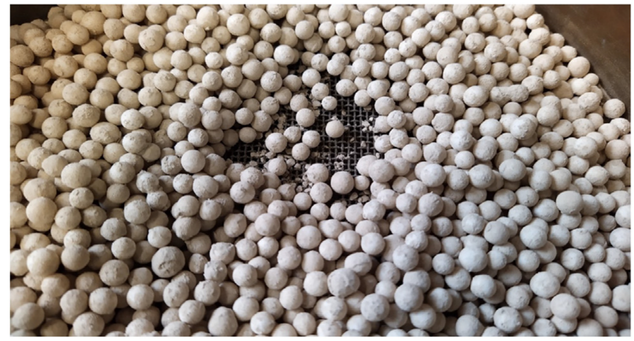

Fig. 2. Coated EPS beads.

Because EPS beads will replace the whole gravel as coarse aggregate in EPSC and MEPSC, the need for EPS beads in the sample concrete uses the same weight-per-volume ratio. Table 1 presents the material composition of each type of concrete sample. The fresh concrete is then poured into 100 mm3 cube moulds conforming to EN 12390 1 [15].

2.3. Test procedures

In line with BS EN 12390–3:2019 [16], the compressive strength of cubic specimens with edges of 100 mm was tested, while the volumetric density of hardened concrete specimens was assessed in compliance with BS EN 12390–7:2020 [17]. The number of specimens consisting of a total of 12 pieces per concrete type. The compressive strength test for the ages of 7, 14, 28, and 56 days was then performed on a total of 36 specimens.

3. Result and discussion

The compressive strength of concrete is largely influenced by its density. Concrete in this study has a weight of 2366 kg/m3, whereas concrete with beads made from EPS only weighs 1273 kg/m3. EPS coating with PFA powder turned out to have an impact on increasing the weight of the concrete significantly by 14% to 1431.1 kg/m3. Therefore, the use of EPS beads as coarse aggregate was able to reduce the density of concrete by approximately 40% of the normal weight of concrete in this study.

However, for the compressive strength of EPS concrete, there was a decrease of 70–80% from the compressive strength of normal concrete. The results of the density and compressive strength are presented in Fig. 3. and Fig. 4, respectively.

All types of concrete tested exhibit an increasing compressive strength trend alongside the concrete age. Even though, as shown in this study, there was a decrease in compressive strength, particularly at 28 days of concrete setting. This fact was due to the concrete specimens previously used for water absorption tests in which a dry furnace and a water immersion were applied successively to the test object before being tested for compressive strength. The samples may have been affected by this treatment.

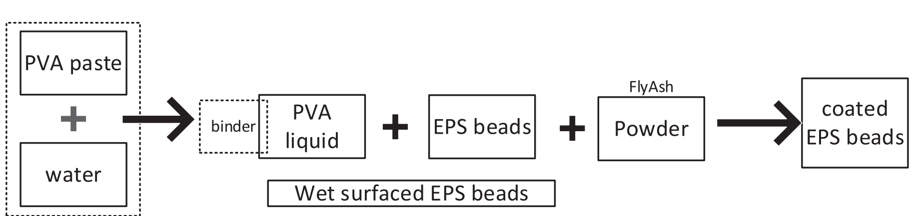

Fig. 1. The creating process of coated EPS.

Table 1
Composition for making 1 m3 concrete.

Specimen code	Cement (kg)	Water (kg)	Sand (kg)	Gravel (kg)	EPS Beads (kg)
NC	490	225	572	1063	–
EPSC	490	225	572	–	7.25[a]
MEPS-PFA	490	225	572	–	190[b]

[a] non-coated EPS beads;
[b] coated EPS beads;

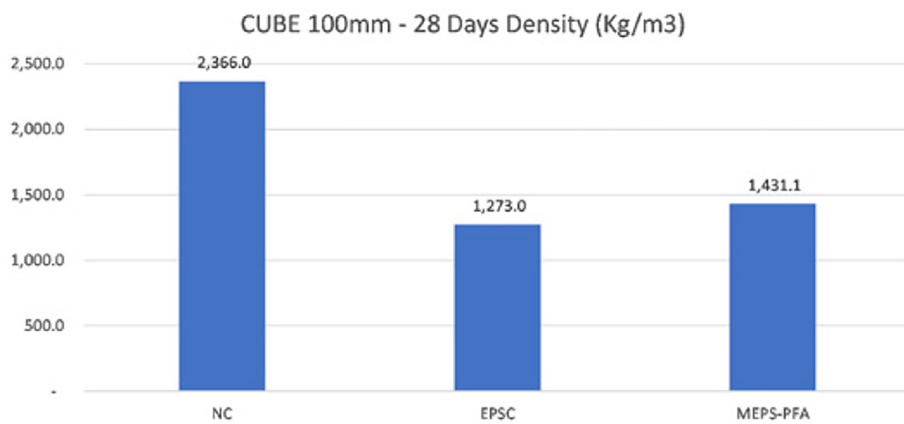

Fig. 3. The Density of Concrete.

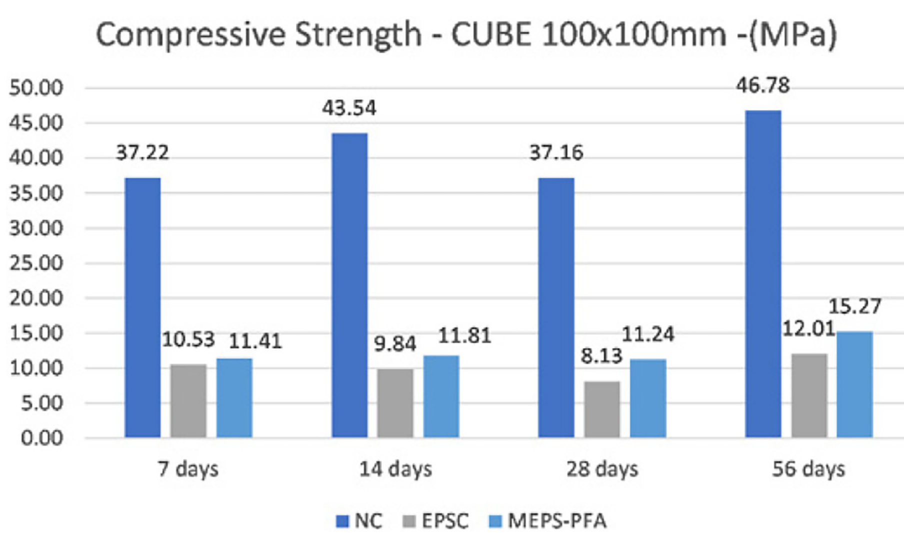

Fig. 4. The Compressive Strength of Concrete.

The thing that is quite promising in this study is an increase in compressive strength compared to using EPS beads without modification. The process of coating eps beads with Fly Ash showed positive results for an increase in compressive strength of 8%, 20%, 38%, and 27% at the age of 7, 14, 28 and 56 days of concrete with EPS beads without modification. This result is better than other studies conducted previously using a coating of cement slurry [18]. In the study conducted by Major and Halbiniak, the increase in compressive strength was only 18.1%, which only replaced the coarse aggregate with the EPS beads by 50–75%.

4. Conclusion

Using EPS beads as lightweight aggregate can significantly reduce the weight of the concrete. But this has the consequence of decreasing the compressive strength. However, there is a possibility that EPS beads coated with fly ash improved the adhesion with cement paste and mortar compared with concrete using EPS beads without coating. As a result, it brings an effect on enhancing compressive strength. Moreover, it is still necessary to conduct further research and other tests to find different characteristics of the type of concrete that uses coated EPS beads to get a bigger picture of the effects of this coating technique or process.

The use of additives to increase workability can also be a topic for further research. As many have done in previous studies, that the addition of admixture is able to have a significant impact on increasing the compressive strength of concrete. Including alternative coating materials other than fly ash.

Data availability

The authors are unable or have chosen not to specify which data has been used.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Andi Prasetiyo Wibowo reports financial support was provided by Directorate General of Higher Education, Ministry of Education and Culture, Republic of Indonesia. Andi Prasetiyo Wibowo reports a relationship with Directorate General of Higher Education, Ministry of Education and Culture, Republic of Indonesia that includes: funding grants].

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