Research article

Properties of Lightweight Concrete Using Expanded Polystyrene as Aggregate

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Abstract When large structures are built on the soft ground such as paddy field, the demand for lightweight concrete will be high. However, issues related to quality control of lightweight aggregates, decline in the tensile strength of lightweight concrete, the economic problems, and so on, have been inhibiting the promotion of its development. There are some conventional methods of construction to cast the large size of expanded polystyrene (EPS) blocks near the surface of soft ground. But there is concern that the EPS block will float up by liquefaction in case of earthquake. In this study, the strength properties of lightweight concrete which uses EPS waste as fine aggregate have been investigated. The above-mentioned concern could be wiped out by mixing EPS as aggregate in concrete aggregate. This EPS aggregate is manufactured product, but there is extremely little number of the factories. The volume of this aggregate was reduced by being irradiated the extreme infrared radiation to utilize the stockyards effectively. This aggregate is ecological because its origin is the industrial waste of EPS. That the absorption of water is zero is one of the merits as the aggregate for concrete. The author has obtained experimentally the mix proportions for the concrete that have the compressive strength enough to be used as structural material. As the results, the treatment of EPS using extreme infrared radiation was found to be effective in improving the strength of EPS concrete.

Keywords lightweight concrete, expanded polystyrene, strength, density

INTRODUCTION

In Japan, the annual discharge of industrial waste is over 400 million tons which is about 8 times that of general wastes (Japan Environmental Sanitation Center, 2000). About 80 million tons of them are discharged from the construction industry. After the recycling law was enforced, development of technologies for effective use of the waste has been much desired.

The main objective of this study is the successful utilization of expanded polystyrene waste (EPS for short) as fine aggregate to produce lightweight structural concrete. The quantity of EPS production in Japan is about 200,000 tons, which accounts for about 10% of the total global production. Only 64% of them have been recycled, the rest being incinerated or reclaimed. Various technologies have been developed for the reduction of EPS volume. Although structural lightweight concrete can be produced using artificial lightweight aggregates, the major drawback is the high cost of these aggregates. Using EPS as aggregate makes the production of lightweight concrete economical and environmentally friendly. In addition to the lightweight property, EPS has other beneficial properties such as high thermal insulation, high sound absorption, and super low water absorption.

There are extremely few studies on EPS concrete except the case study as non-structure material (Nagase et al., 2000). There are some studies on structural lightweight concrete which were confirming the basic properties and trying a multifunctionality, however the artificial aggregate is expensive (Kuku et al., 2000), (Onishi et al., 2000). Then the originality of this study is to use this EPS for structural concrete, and the objective of this paper is to quantify the basic properties of density and strength.

METHODOLOGY

a) Property of EPS Aggregate

Fig.1 shows the EPS used in this study and a section of an EPS concrete cylinder. Table 1 gives various physical properties of EPS aggregate. Methods of reducing the volume of EPS waste are extreme infrared ray irradiation processing, a new technology, has been performed on this EPS. In this method, firstly the EPS is roughly crushed, and inorganic powders are sprinkled on its surface using small amount of resin adhesive. Then, the volume is reduced to about 1/20 by irradiation of extreme infrared rays before being ground again into fine pieces. With this processing, the strength and the Young's modulus accompanying the increase of density is more than that of the conventional EPS. Because the processing is done in a low temperature of 120-130 degrees-C, generation of unpleasant odour is limited. Loss percentage of mass was 0.55% as shown by the stability examination (Test method for soundness of aggregates using sodium sulphate, JIS A 1122). The resistivity against aging deterioration was confirmed to be as high as that of aggregates for normal concrete.

In the case of conventional lightweight concretes, the limit of weight reduction has been about 1.5t/m^3. ALC (Autoclaved Lightweight Concrete) has been put into practical use to advance further weight reduction. In this case, if water from rain etc. is absorbed into air spaces, the density will increase greatly. There is little study on using EPS as aggregate for concrete (Matsuo et al., 1994, 1995, 1996, 1997).

b) Experimental Details

The key points in using a lightweight material like EPS are suppression of segregation, evaluation of fresh condition, and to control the decrease of strength. In the experiments, the relation between the density and the strength of specimens accompanying the change in the quantity of EPS and water cement ratio (W/C) was investigated first. The mix proportions were selected based on the result anticipating a compressive strength of 30N/mm^2 in the super lightweight domain. Segregation must be prevented in order to stabilize the strength. For this, adequate mix proportions of EPS concrete that could control the segregation and have good workability were established by obtaining the relationship between the segregation and viscosity of the cement paste prior to the strength tests.

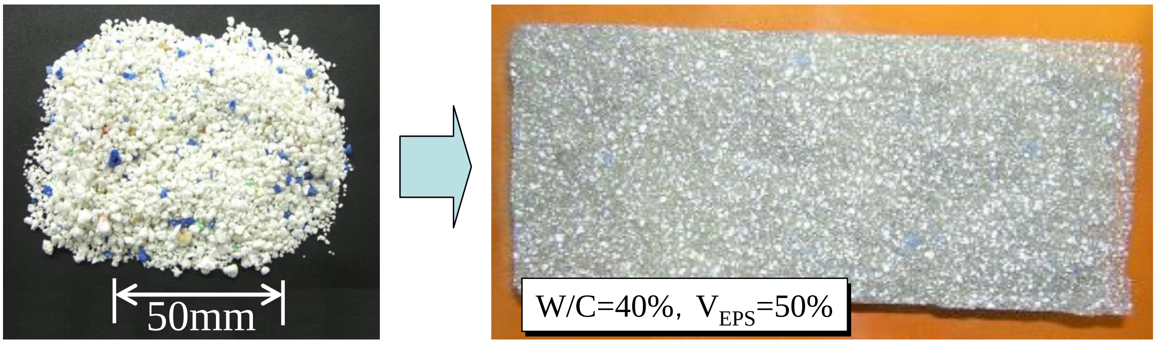

Fig.1 EPS and the section of an EPS concrete cylinder

Table 1 Properties of EPS

Density (g/cm^3)	0.53
Maximum size of sieve (mm)	4.0
Percentage of solid volume (%)	64.8
Fineness modulus	3.02
Water absorptivity (%)	0
Quantity loss of aggregate (%)	0.55

Strength properties and the density of EPS concrete were investigated and compared with past studies (Matsuo et al., 1994, 1995, 1996, 1997). Mix proportions that can control segregation were selected based on the results mentioned previously. The variation in the strength of EPS concrete was also examined. Admixtures were not used so that the most fundamental properties could be investigated. Additionally, the effect of a super plasticizer was also confirmed. It was also confirmed from preliminary experiments that segregation could be controlled even without the thickening agent (thickner, or viscosity increasing agent).

c) Mix Proportion and Casting Method

The material used here is the same as the one mentioned previously. The representative mix proportions are shown in Table 2 which can control segregation and have a small density difference. V_{EPS} means the volume ratio of EPS in concrete. Mixing was done using a mortar mixer/force mixer. Experiments were carried out using EPS concrete prisms (4×4×16cm) and cylinders (φ10×20cm). The prisms were compacted 40 times in two layers, and the cylinders were compacted 25 times in 3 layers. A table vibrator was used as required. Specimens were removed from the molds one day after casting and they were cured in water until the strength test.

Table 2 Representative Mix Proportions

Name	W/C	V_{EPS}	Unite Weight (kg/m^3)			Theoretical
	(%)	(%)	C	W	EPS	Density (g/cm^3)
A	30	40	972	292	212	1.48
B	40	50	697	279	265	1.24

RESULTS AND DISCUSSION

a) Relation between V_{EPS} and Strength

An instance of density change of EPS concrete with the increase of V_{EPS} is shown in Fig. 2. The density decreases linearly as V_{EPS} increases. Since the difference of theoretical density and actual density is very small in all mix proportions, it can be inferred that EPS waste had not been compressed with cement paste during the mixing and hardening.

Fig. 3 shows the relationship between V_{EPS} and the compressive strength. The compressive strength decreased with the increase of V_{EPS}. Even if V_{EPS} is about 50%, a compressive strength of 15-30N/mm^2 can be obtained with small water cement ratio. The fact that a compressive strength of 19-45N/mm^2 can be obtained for V_{EPS} as small as 20-30% suggests that EPS concrete can be broadly used as structural materials as well as non-structure materials.

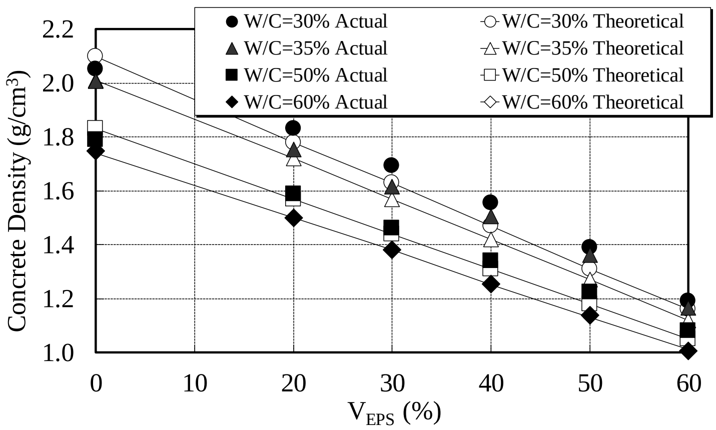

Fig. 2 Relationship between V_{EPS} and concrete density

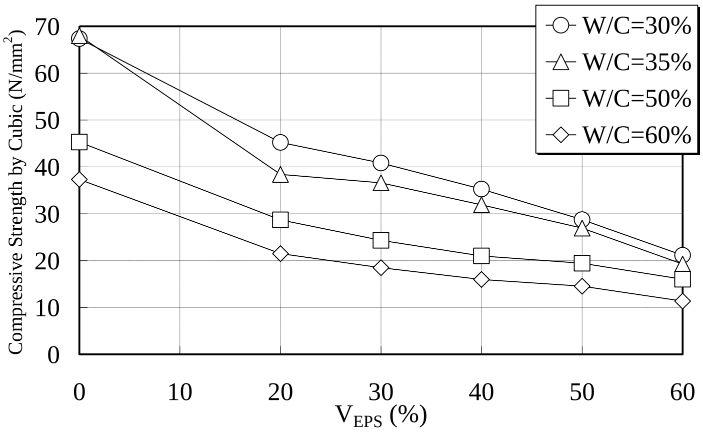

Fig. 3 Relationship between V_{EPS} and compressive strength

b) Density and Strength

Fig. 4 shows the relationship between concrete density and compressive strength for cubic EPS concrete specimens. The results for every V_{EPS} and compared with a previous study (Matsuo et al., 1994). For given concrete density, the strength of EPS concrete is larger than that of the previous beads-type EPS for all V_{EPS}. This reflects the effectiveness of the volume reduction method using extreme infrared ray to EPS is relatively more effective regarding the strength. Furthermore, it is also estimated that the increase in the strength can be attributed to the increase of adhesion strength between the paste and EPS due to the complexity of the surface shape of EPS.

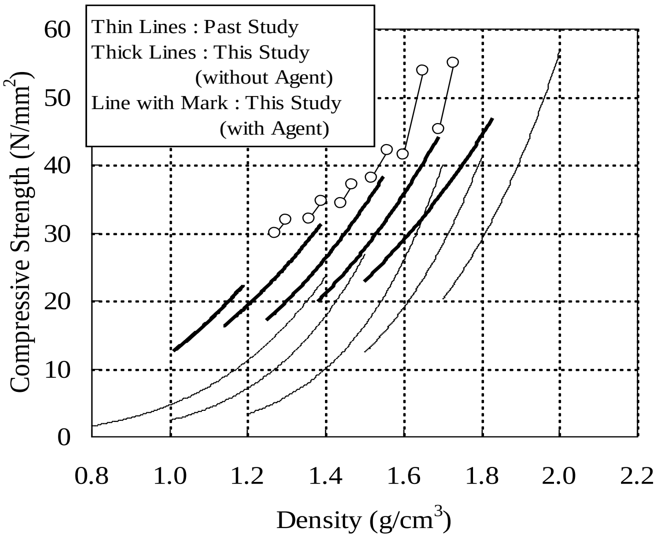

Fig. 4 Relationship between concrete density and compressive strength

Bache's equation was used in order to determine the mix proportion which can utilize the strength of EPS more effectively (Bache, 1967). Bache expressed the strength of concrete as Eq. (1) in case that the strength of aggregates is weaker than the matrix. This is empirical and has the general tendency to underestimate the strength of the aggregate to be calculated. The effective mixing ratio of the aggregate is said to be in the range of 0-0.5. There are various views regarding the effective range concerning the strength ratio of the aggregate and the matrix (Murata et al., 1968).

$$\sigma_c = {\sigma_{EPS}}^{V_{EPS}} \cdot {\sigma_p}^{1-V_{EPS}} \quad (1)$$

Here, σ is the compressive strength (N/mm^2), *c* means concrete and *p* means paste. Eq. (1) can be expressed as

$$\sigma_{EPS} = exp\left\{\frac{\log\sigma_c - (1 - V_{EPS})\log\sigma_p}{V_{EPS}}\right\} \qquad (2)$$

Substituting the result of Fig. 3 in Eq. (2) the compressive strength of EPS for all mix proportions can be found. In practice, since the strength of EPS is constant, the authors think that this calculation value is the resistance which EPS shares with the cement paste matrix to the acting compressive stress. Here, it is called "estimated strength". Change of estimated strength of EPS with V_{EPS} is shown in Fig. 5 for different water cement ratio of paste. The estimated strength of EPS changes not only with the paste matrix strength but also with V_{EPS}. Mix proportions with V_{EPS} about 40-50% and high paste strength can use the EPS strength advantageously. These mix proportions are closely in agreement to the ones which control segregation discussed previously.

Stress-strain curves for various V_{EPS} are shown in Fig. 6 with 35% of water cement ratio. The elastic modulus obtained from this figure is shown in Fig. 7. It is observed that the elastic modulus decreases linearly with V_{EPS}, a trend similar to that shown by the compressive strength.

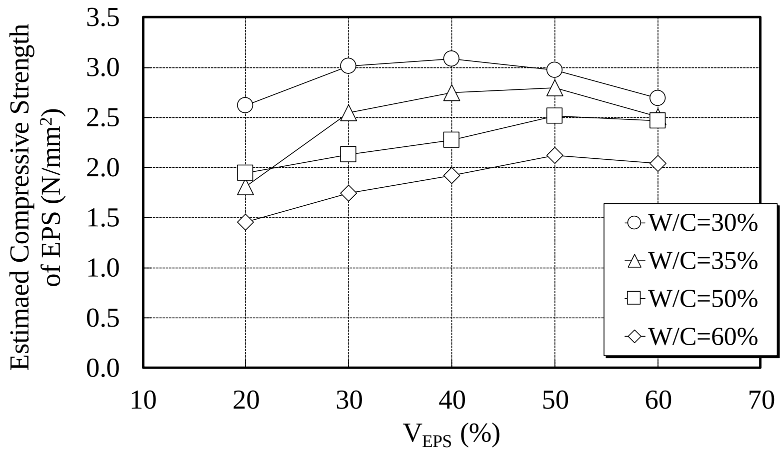

Fig. 5 Estimated compressive strength of EPS

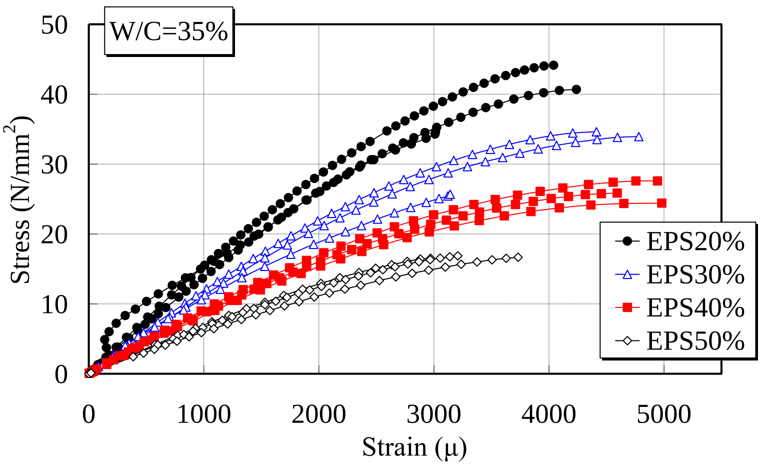

Fig. 6 Stress-strain curves

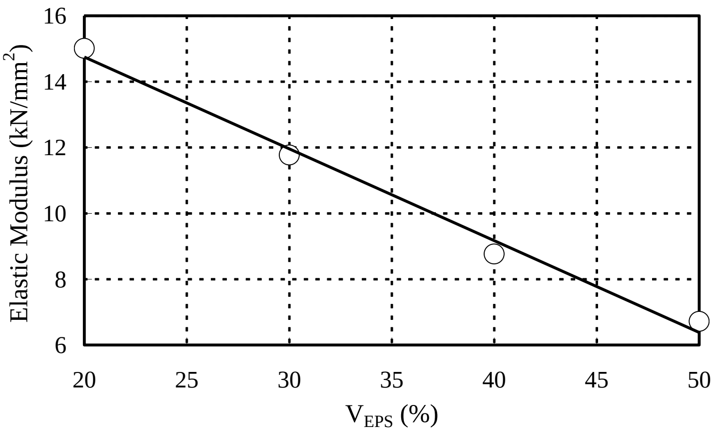

Fig. 7 Relationship between V_{EPS} and elastic modulus

CONCLUSION

In this study, fundamental strength properties of lightweight concrete using EPS as fine aggregate were investigated. The main conclusions are as follows.
(1) Irradiation of EPS by extreme infrared rays is effective in improving the strength of EPS concrete.
(2) The mix proportions which authors propose are "W/C=40% and V_{EPS}=50%" for weight reduction, and "W/C=30% and V_{EPS}=40%" for high strength.

Drying shrinkage is the subject for a further study in case of the applicability of this concrete in a large scale. It is necessary to quantify the adequate amount of shrinkage reducing agent.

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