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Research Article

Durability of Modified Expanded Polystyrene Concrete after Dynamic Cyclic Loading

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EPS concrete was produced by mixing the expanded polystyrene spheres (EPS) and polymer emulsion and thickener to the matrix concrete, and this concrete had good vibration energy absorption characteristics. Based on the experimental data obtained on EPS volume ratio of 0%, 20%, 30%, and 40% by replacing matrix or coarse aggregate, the two design styles had nearly the same compressive strength. By applying frequency of 5 Hz, 50000 or 100000 times, 40 KN, 50 KN, and 60 KN cyclic loading, it is shown that the higher the inclusion size was, the lower the compressive strength of the EPS concrete would be; the larger the applying dynamic cyclic load was, the more obvious the compressive strength changing would be. Meanwhile, the strength of EPS concrete had no evident change after durability test. The results of this research had practical significance on using EPS concrete in some long-term cyclic dynamic load engineering.

1. Introduction

Because the expanded polystyrene (EPS) light weight concrete has the characteristics of lightweight, energy absorption, and heat preservation, it is used in many specific construction industries like high rise buildings, floating marine platforms, and large-sized and long-span concrete [1, 2]. The lightweight concrete (LWC) has no pollution to the environment because manufacture EPS particle consumes little energy, and the particle has no poison and harm. The EPS concrete has the characteristics of economy, environmental protection, and energy saving, meeting the design concept of modern construction material.

In 1970s, Cook [3] put EPS particle into concrete and made research on it. The systematic research began in 1990s; French scholar obtained the relationship between strength of light weight concrete and porosity by putting different proportions of EPS particle into concrete [4]. The EPS concrete was produced by replacing the partially normal aggregates in concrete; the specific mix stage was depending upon the requirements of density and strength levels. The relationship between the strength and a wide range of density of the EPS concrete could be obtained by changing the mix scale of the EPS particle [1, 4–8]. Also there have been some researches focused on the influence of expanded polystyrene particles size to the concrete compressive strength [9, 10]. Styrene-butadiene rubber (SBR) latex was applied in EPS concrete as a polymeric admixture by Chen and Liu [11] to improve the homogeneity of the EPS particle in LWC and make sure the particle will not float during the concrete vibration. Babu et al. [12] increased the strength by mixing the fly ash into the EPS concrete and improved the early strength by mixing the silica fume into the EPS concrete [13]. With an introduction of a premix method utilized to make the EPS concrete by Chen and Liu [14], it avoided segregation of the EPS particles in the aggregate during casting. Laalai and Sab [15] verified the transformation formula among different specimen sizes.

EPS concrete has been considered as an energy-absorbing material for the protection of buried military structure and some specific constructions which suffer long-term cyclic loading. Meanwhile, it has requirements for strength and durability of EPS concrete. The main purpose of this paper is to quantify the influence of the EPS concrete inclusion size on compressive strength, improving the strength and the workability of the EPS concrete by mixing three admixtures.

Figure 1: Expanded polystyrene spheres.

The durability of the EPS concrete was obtained by making comparison between specimen before and after applying cyclic load of 40 KN, 50 KN, and 60 KN for 50000 or 10000 times.

2. Materials and Mix Design Principles

The test specimens were made with the same type as that used for very high strength concrete, and the EPS particle took the place of part of the concrete or coarse aggregate.

(1) Cement. It was made with CEM I 52.5 cement.

(2) Fine Aggregate. It is made with rounded river sand with a fineness modulus of 2.85.

(3) Coarse Aggregate. It is gravel with a diameter range of 4–20 mm.

(4) EPS Particles. EPS particles are expanded polystyrene spheres particle with a diameter range of 1–3 mm and density of 20 kg/m^3 which is shown in Figure 1.

(5) Silica Fume. Because the fineness of silica fume is very low, it is about 80–100 compared to normal cement and it is used in the concrete to fill up the pore among the cement granules and the hydrate products are similar to cement in water; the other mixture would been bonded by the gel. The mixing ratio of the silica fume is discussed by K. G. Babu and D. S. Babu [13].

(6) Admixture. A polycarboxylate-based superplasticizer was used to improve the workability and the compressive strength of the EPS concrete and the mixing ratio refers to the result of Miled et al. [4]. Expanded polystyrene spheres particles are hydrophobic material, extremely light with the density of only 12–20 kg/m^3 which can cause segregation in mixing and make the inhomogeneity of the EPS concrete, leading to the decrease of the compressive strength.

There are two ways to approach this issue: one is to increase the bond action between the EPS particles and aggregates by transforming the EPS particles from hydrophobic material to hydrophilic material and the other is to improve the viscosity of the EPS concrete. In order to improve the compressive strength of the EPS concrete as much as possible, the specimen was made by adopting both methods. Polymer emulsion was mixed in the mixture to increase the viscidity; the relationship between compressive strength and mixing ratio is shown in Figure 2. The hydroxypropyl cellulose ether was used as to control the consistence and water retention capacity of the concrete slurry; the relationship between compressive strength and mixing ratio is shown in Figure 3. The two admixtures could make sure that the EPS particles would not segregate during the concrete vibration.

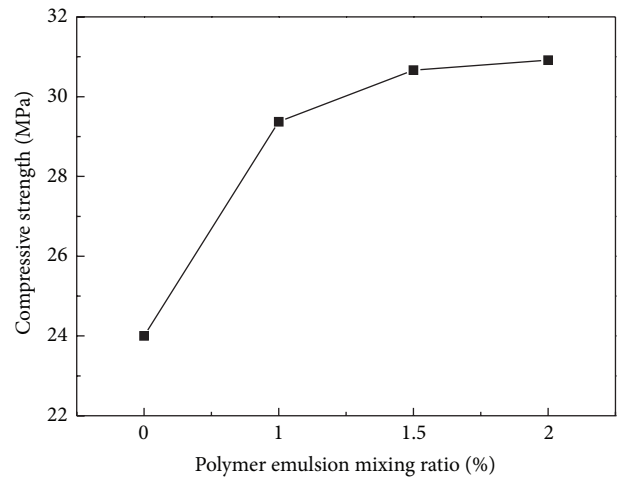

Figure 2: The relationship between compressive strength and polymer emulsion mixing ratio.

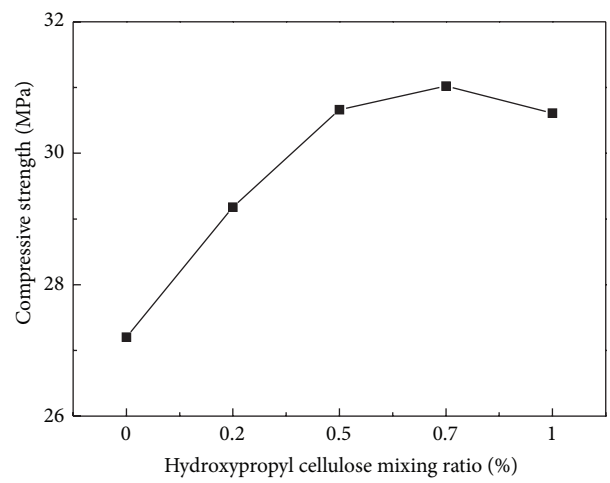

Figure 3: The relationship between compressive strength and hydroxypropyl cellulose mixing ratio.

(7) Mixing Method. Because of the hydrophobic material of the EPS particles, the workability and durability of EPS concrete were poor during the mixing process [16]. Indeed, after numerous mixing, a mixing method similar to the "sand-wrapping" technique was utilized to make EPS concrete. Firstly, it pulled the EPS particles and 1/3 water and 1/2 polymer emulsion into the mixed hopper. After mixing of one minute, it introduced the gravel into the mixed hopper and then mixed it for one minute and finally it pulled all the other aggregates into the mixed hopper and mixed them for two minutes. The mixing method would ensure the workability and homogeneousness of the EPS concrete.

Table 1: Proportion of EPS concrete mixes.

EPS volume ratio%	Design type	Water/ cement ratio%	Cement kg/m^3	River sand kg/m^3	Gravel kg/m^3	Water kg/m^3	Silica fume kg/m^3	Superplasticizer kg/m^3	Polymer emulsion kg/m^3	hydroxypropyl cellulose kg/m^3
0	No replacing	32	538	542	1152	172	26.9	8.07	8.07	2.69
0.2	Replace the concrete	32	430	434	922	138	21.52	6.456	6.456	2.152
0.2	Replace the gravel only	32	538	542	662	172	26.9	8.07	8.07	2.69
0.3	Replace the concrete	32	375	380	808	120	18.75	5.625	5.625	1.875
0.3	Replace the gravel only	32	538	542	662	172	26.9	8.07	8.07	2.69
0.4	Replace the concrete	32	323	325	691	103	16.14	4.842	4.842	1.614
0.4	Replace the gravel only	32	538	542	172	172	26.9	8.07	8.07	2.69

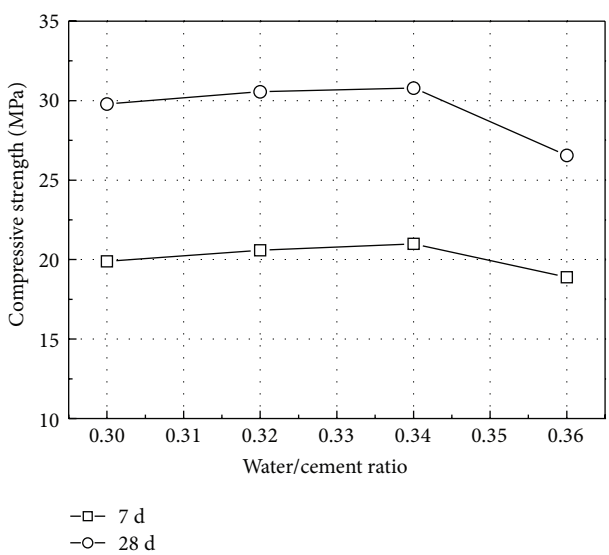

Figure 4: The influence of the water-cement ratio.

3. Compressive Strength Test

Cubes of 100 mm size of EPS concrete were used for studying the compressive strength after being stored in laboratory conditions for 28 days. Water-cement ratio is an important index to influence the compressive strength. The relationship between water-cement ratio and compressive strength is shown in Figure 4. The compressive strength significantly reduces as the water-cement ratio is set to 0.36, because the EPS particles are of hydrophobic material and the workability falls when the water-cement ratio increases. The compressive strength changes slightly when the water-cement ratio increases from 0.32 to 0.34, considering the economics as it applied to practical engineering the water-cement ratio is set to 0.32 in this paper.

In order to observe the influence of the EPS particle volume ratio on the compressive strength, various densities of the EPS concrete specimens were made according to Table 1.

The EPS volume ratio p considered here as the concrete porosity was determined by the following formula [4]:

$$p = \frac{\rho_{\text{matrix}} - \rho_{\text{concrete}}}{\rho_{\text{matrix}} - \rho_{\text{EPS}}}, \quad (1)$$

where ρ_{matrix} is the densities of the matrix and ρ_{concrete} and ρ_{EPS} are the densities of EPS concrete and EPS particles, respectively.

Three specimens were made according to each design style and each value was reported because porosity and compressive strength of the specimen vary slightly. The effect of porosity on compressive strength of EPS lightweight concrete is shown in Figures 5 and 6

The minimum and maximum compressive strength of EPS concrete with the design style of EPS particles replacing concrete at the age of 28 days were 18.05 and 40.31 MPa; meanwhile, the minimum and maximum compressive strength were 16.23 and 40.07 MPa following the design style of EPS particles replacing coarse aggregate from Figures 5 and 6. It could be found that volume ratio of EPS had the most significant effect on the compressive strength of EPS replacing concrete or coarse aggregate and increase of EPS volume and decrease of the compressive strength.

According to the test value, the compressive strength of the two design styles was basically coinciding, but the porosity of the EPS concrete was different from Figures 5 and 6. In consideration of the economy in practical engineering, the cost of EPS particles replacing concrete was less and the compressive strength of this design style was the same as the EPS particles replacing coarse aggregate. Therefore, the research emphasis of this paper is to study the mechanical properties of EPS concrete with the EPS particles replacing the concrete.

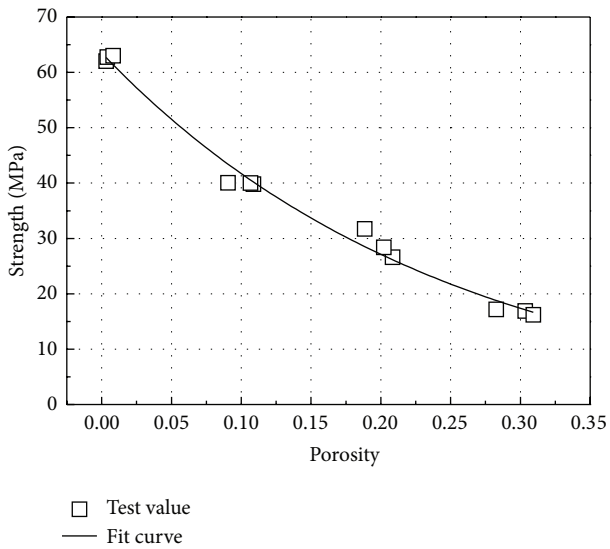

Figure 5: The variation of compressive strength of EPS particles replacing concrete with porosity.

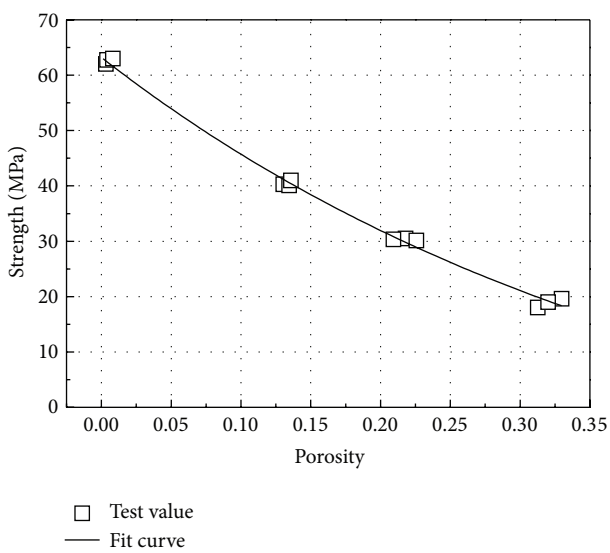

Figure 6: The variation of compressive strength of EPS particles replacing coarse aggregate with porosity.

Through exponential fit analysis, the empirical relations obtained can be written as

$$f = 82.27e^{-2.38p} - 19.05, \quad (2)$$

where f represent compressive strength (Mpa) at 28 days. Correlation coefficient (R) of the proposed relation is 0.989, indicating significant correlations.

Failure Mode. Different ratio of the EPS particles volume had different failure mode which is shown in Figure 7. The matrix was fracture after the compressive strength test, and the scale of crack was smaller along with the increase of the EPS particles volume ratio. This phenomenon was caused by the characteristics of energy absorption of EPS particles, and the appearance was still intact even if the EPS concrete was under destruction.

4. The Durability of EPS Concrete

EPS concrete has the characteristics of vibration resistance and energy absorption, which can be used in civil construction based on cycle loading to reduce vibration of system. However, it has great significance to test the durability of EPS concrete with vibration property since vibration load infliction often goes with the characteristic of low durability. This paper qualitatively analyzes the influence of EPS volume ratio, vibration cyclic times, and vibration load on EPS concrete durability by cycle loading test.

Cyclic dynamic vibration test used a 370.50 MTS electro-hydraulic servo fatigue test system shown in Figure 8 which had 500 KN load capacity and 150 mm dynamic travel and test data could be real-time shown and stored in the computer. EPS volume ratio was 0%, 20%, 30%, and 40%, times of vibration cycle were 50000 and 100000, vibration load was 60 KN, 50 KN, and 40 KN, and vibration frequency was 5 Hz; the sine wave was adopted to simulate the vibration process.

4.1. 50000-Time Durability Test. After 50 thousand cyclic loading tests, the concrete would be in strength test; the value of the compressive strength before and after cyclic loading is shown in Figures 9–11.

The compressive strength of concrete without EPS particles decreased to different degree after durability test and the greater the cyclic loading applied, the more obvious the reduction of concrete strength. The compressive strength of 20% EPS particles volume ratio concrete (20% EPS concrete) was less than before, while the compressive strength of 30% and 40% EPS concrete are varying degrees of increase when applying 40 KN cyclic load, mainly because cyclic loading led to EPS particles compression and the compaction of EPS concrete when applying load was small; therefore, the compressive strength of 30% and 40% EPS concrete was greater than before durability test. With applying load from 40 KN to 50 KN and finally to 60 KN, the influence of cyclic loading on durability of EPS concrete was becoming more and more obvious; meanwhile, the bigger the EPS particles volume ratio was, the smaller the compressive strength change after 50000 cyclic loading would be.

4.2. 100000-Time Durability Test. Because 100000-time cyclic dynamic test costs long time, the research took EPS concrete of particles volume ratio of 0% and 30% as an example by applying 50 KN sinusoidal cyclic loading 100000 times on EPS concrete; the compressive strength before and after durability test is as shown in Figure 12.

The change of compressive strength of the matrix was obvious after 100000 times of dynamic vibration loading as is shown in Figure 12, while the compressive strength of 30% EPS concrete decreased in comparison with the strength after 50000-time cyclic dynamic vibration loading, but the reduction was not large; thus it could be concluded that EPS concrete is a kind of material which has good durability.

Figure 7: Failure mode of the EPS concrete with different EPS particles volume ratio.

Figure 8: MTS 370.50 dynamic test system.

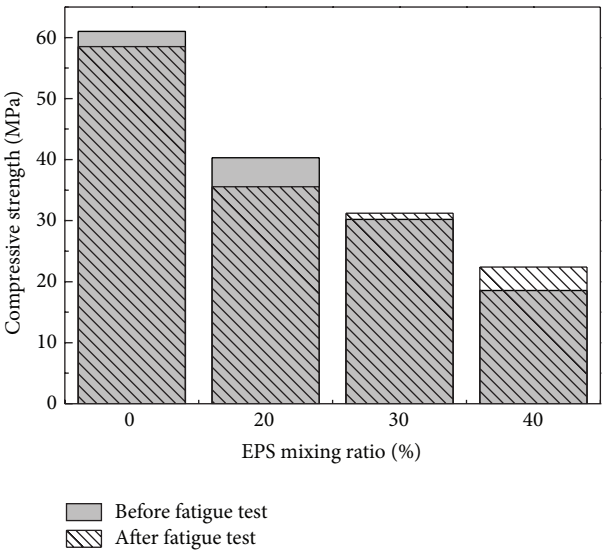

Figure 9: Later strength of 40 KN 50000-time cyclic loading.

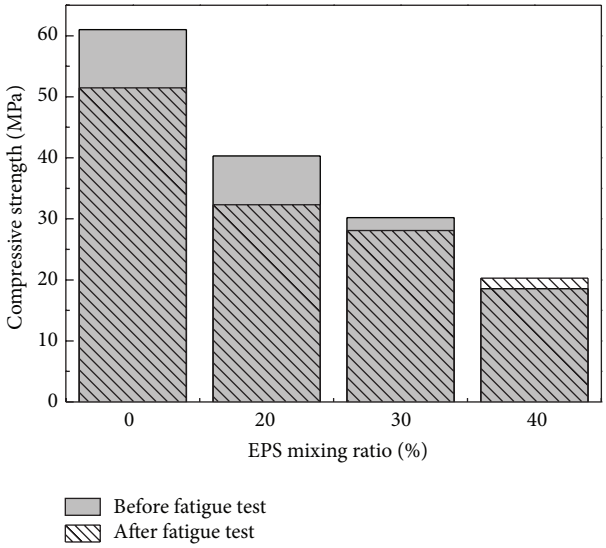

Figure 10: Later strength of 50 KN 50000-time cyclic loading.

5. Conclusions

EPS concrete has the advantages of small density, thermal insulation, and good seismic performance. So it is of great significance on the study of modern structural materials and practical engineering to research new concrete materials. The experimental investigations were conducted on three types of EPS concrete having EPS concrete of particles volume ratio ranging from 0% to 40%, with a view to confirming the presence of an intrinsic particle content effect on the EPS concrete compressive strength and durability. The conclusions are drawn as follows.

(1) In order to increase the compressive strength the polymer emulsion is mixing in the concrete grout which would bound other mixtures together, and the relationship between its mixing ratio and compressive strength is discussed. The hydroxypropyl cellulose is mixed in the EPS concrete for improving the workability of the grout and the influence of its mixing ratio on the concrete compressive strength is studied.

(2) The compressive strength of two types of EPS concrete in which concrete is replaced or only gravel replaced by EPS particles was basically identical; the result showed that the compressive strength of the two design styles was basically coinciding. The compressive strength of EPS concrete decreased obviously with the increase of EPS particles volume ratio; the reduction curve was similar to exponential type curve.

(3) The value of applying dynamic cyclic load had great effect on the compressive strength after durability

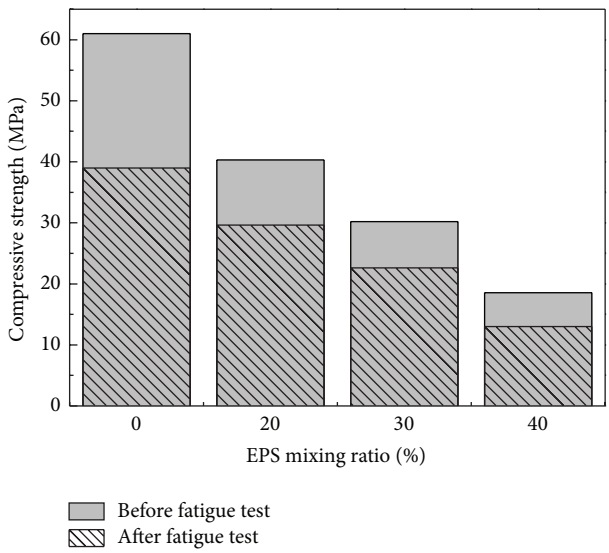

Figure 11: Later strength of 60 KN 50000-time cyclic loading.

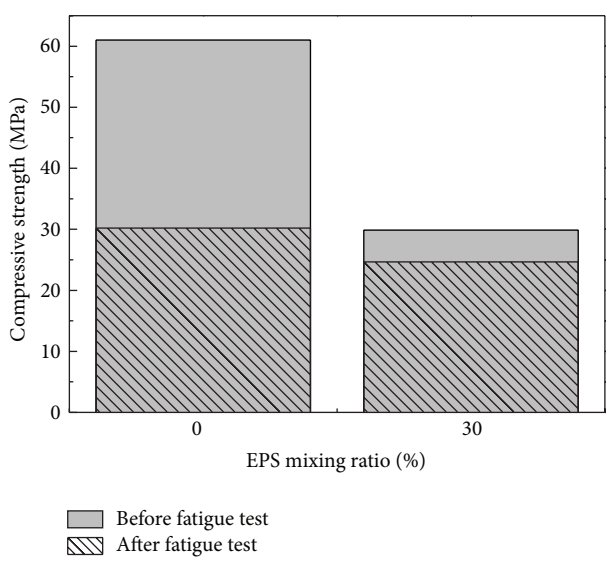

Figure 12: Later strength of 50 KN 100000-time cyclic loading.

test. The compressive strength of EPS concrete of particles volume ratio of 40% was increased after applying 40 KN and 50 KN cyclic dynamic load, and the other ratio of EPS particles volume concrete was reduced after durability test; meanwhile, the degree of compressive strength reduction was inversely proportional to EPS particles volume ratio. Also, the bigger the applying dynamic cyclic load was, the bigger the gap of compressive strength between before and after durability test would be. The compressive strength of EPS concrete of particles volume ratio of 0% and 30% would fall when dynamic cyclic load is applied 100000 times, and the reduction of matrix compressive strength was much more bigger than EPS concrete particles volume ratio of 30% compared with applying dynamic vibration load 50000 times.

(4) Through the results from the designed durability test, it proved that the EPS lightweight concrete has good durability and it has a very good use in practical engineering which has certain seismic requirements and applied cyclic load.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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