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Study on the Effect of Recycled Aggregate on the Performance of EPS Concrete

Luxin Fu, Zhirong Jia, Ruirui Jiang

Abstract— **The performance indexes of recycled aggregate and expanded polystyrene (EPS) particles were detected in order to study the effect of recycled aggregate on the failure mechanism and properties of EPS concrete. A series of parallel tests were designed that based on the strength forming mechanism and compressive failure theory of EPS concrete to study the effect of recycled aggregate on the performance of EPS concrete with EPS substitution rate of 50%. The results show that recycled aggregate instead of primary coarse aggregate used in EPS concrete can effectively inhibit the occurrence of segregation of EPS concrete and improve the compressive strength of EPS concrete. EPS concrete has the advantages of high safety performance, economic and environmental protection, and its application to engineering will achieve great economic and social benefits. The incorporation of recycled aggregate makes the thermal insulation coefficient of EPS concrete little change, so the effect of recycled aggregate on thermal insulation properties of EPS concrete is negligible.**

***Index Terms*— EPS concrete; recycled aggregate; compressive strength; thermal insulation**

I. INTRODUCTION

EPS concrete is a lightweight concrete that made of EPS particles instead of a part of aggregate of normal concrete. Zhu et al. indicates that the foamed concrete has good performance of high strength and light weight, heat insulation, sound insulation and environmental protection[1-3]. In recent years, EPS concrete has been widely used in the construction of nonstructural and structural members because of lightweight feature and good thermal properties, such as walls and slabs[4-5]. Especially, a new structure system named lightweight steel and lightweight concrete structure (LSLCS), which used EPS concrete as structural lightweight concrete, was proposed and applied to the building construction in China[6].

Cook used EPS particles instead of coarse aggregates and some fine aggregates to prepare EPS concrete with an intensity of 3.0-10.0MPa and an apparent density of below 1400kg/m^3, and studied the relationship between the strength and apparent density of EPS concrete[7]. Miled et al. also carried out research work, through the addition of polymers and micro-silica fume and other methods to prepare the strength of 20MPa and the apparent density of 1900kg/m^3 of EPS concrete[8-9]. Kan et al. obtained Modified EPS by heating the waste EPS foam in an hot air oven at 13℃ for 15 min and the density of EPS concrete was in the range of 900-1700kg/m^3 while the 28 day compressive strength was in the range of 12.58-23.34MPa[10]. Zheng et al. used the orthogonal design test method to study the influence of cementitious material content, admixture and other factors on the strength of EPS concrete[11]. Chen Bing modified EPS concrete with micro-silica fume, resin and steel fiber, and produced EPS concrete with compressive strength of 20MPa and apparent density of only 70% of ordinary concrete[12-13]. Cui et al. prepared EPS concrete with the dry density of 800-1200 kg/m^3 by replacing coarse aggregates with EPS beads, and obtained that the proposed stress-strain model agreed well with the test results[14]. Sayadi studied the effects of EPS particles on fire resistance, thermal conductivity and compressive strength of foamed concrete. EPS concrete is an environment friendly lightweight material, which is widely used for building construction in recent years[15]. Dissanayake point out that EPS concrete precast panel system has the potential to be promoted as a mainstream walling material with 100 mm or 150 mm thickness[16]. Fernando studied the structure feasibility of the EPS lightweight concrete sandwich wall panel[17]. However, EPS concrete is easily segregated during the stirring process and floated in the vibrating process, and the interfacial cohesive force between EPS and cement paste is relatively weak[18-19]. These shortcomings will lead to the failure of EPS concrete so that the strength of EPS concrete after curing does not satisfied with the design requirements. The surface cement slurry falls off, EPS exposing and spalling, which restricts the development of EPS concrete in the construction industry[20-23].

In this study, recycled aggregate instead of primary coarse aggregate used in EPS concrete can effectively inhibit the occurrence of segregation of EPS concrete and improve the compressive strength of EPS concrete. New EPS concrete has the advantages of high safety performance, economic and environmental protection, and its application to engineering will achieve great economic and social benefits. At the same time, EPS concrete with different recycled aggregate replacement rate was tested for its properties, such as compression resistance and thermal insulation. The results of the test were analyzed to reveal the influence of recycled aggregate on the failure mechanism and performance of EPS concrete.

Table 1. Performance index of recycled aggregate

project	Bulk density (kg/m^3)	Apparent density (kg/m^3)	10minWater absorption (%)	24h Water absorption (%)	Crush the value (%)
Recycled aggregate	1263.6	2645.2	3.2	5	22

Luxin Fu Graduated from Shandong University of Technology and got bachelor degree
ZhiRong Jia Graduated from Tongji University and got doctor degree.
Ruirui Jiang Graduated from Shandong University of Technology and got bachelor degree.

Table 2. Performance index of EPS particles

project	Particle size（mm）	Apparent density（kg/m³）	Bulk density（kg/m³）	porosity（%）
EPS particles	0~5	16	7.5	50

II. EXPERIMENT

A. Material

Cement: P • O 42.5 cement produced by Shanong Shanlv Cement Co.,Ltd.. Recycled aggregates: recycled aggregates produced by Zibo Rio Lituo Renewable Resources Co.,Ltd., with particle sizes of 5-10 mm and 10-30 mm, and Performance indicators in Table 1. Fine aggregate: natural yellow sand, with particle size of 0-2mm. The EPS particles produced by Zibo Ruixin Insulation Material Factory, that are shown in Table 2. Additives: Accelerator produced by Star Chemical. Polycarboxylate superplasticizer produced by Zibo Jianhua Co.,Ltd. HEA expansion agent produced by CCTD.

B. Recycled aggregate gradation

Aggregate is 5-10mm, 10-30mm two particle size range of recycled aggregate, which is recycled from Zibo lituo renewable resources Ltd. The recycled aggregate screening test is done, and the experimental results are shown in Table 3.

Table 3. Screening of recycled aggregate

Particle range	Pass rate of each sieve（%）				
	31.5mm	19mm	9.5mm	4.75mm	2.36mm
10~30mm	96.3	61.2	9.8	3.6	2.3
5~10mm	100	100	100	26.7	1.7

Using Trial algorithm, the proportion of recycled aggregates in two particle size ranges is 10-30mm: 5-10mm = 9:1, and the composite grading curves of recycled aggregate, as shown in Figure1.

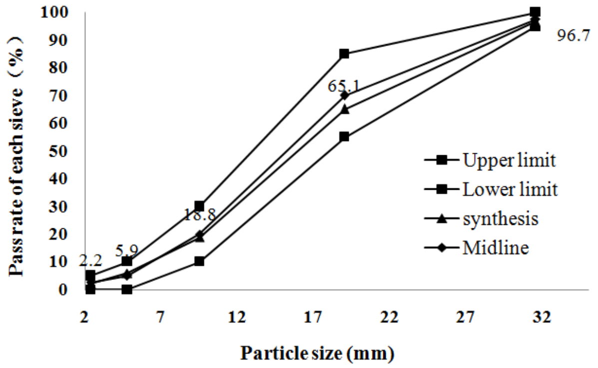

Fig.1. The composite grading curves of recycled aggregate

C. Mix proportion

The compressive strength, thermal insulation coefficient and durability of EPS concrete were measured by four groups of parallel experiments with water-cement ratios of 0.35, 0.4, 0.45 and 0.5. The final water-cement ratio was 0.4 and the sand rate was 0.39. Datum mix ratio is water: cement: sand: gravel =154:386:725:1124, and quick-setting additive and expansion agent were respectively added by the incorporation of 10% of cement material. The EPS particles replaced part of the gravel by the volume substitution method with a substitution rate of 50%, In the case of keeping the same rate of sand. In this experiment, primary coarse aggregate were respectively replaced by 0, 10%, 30%, 50%, 100% of the proportion of recycled coarse aggregate. Due to the higher water absorption of recycled coarse aggregate, water should be appropriately increased to compensate. The mix proportion of EPS concrete is shown in Table 4

Table 4. The proportions of recycled aggregate concrete

Sample	Mix proportion （kg/m³）								
	Water	Cement	Recycled aggregate	Primitive aggregate	Sand	EPS particles（m³）	Water-reducing agent	Expansion agent	Quick-setting agent
Y-1	154	308.8	0	215	119	0.5	2.316	38.6	38.6
Y-2	154	308.8	21.5	193.5	119	0.5	2.316	38.6	38.6
Y-3	154	308.8	64.5	150.5	119	0.5	2.316	38.6	38.6
Y-4	154	308.8	107.5	107.5	119	0.5	2.316	38.6	38.6
Y-5	154	308.8	215	0	119	0.5	2.316	38.6	38.6

D. Preparation of test pieces

Firstly, put water and EPS particles into the mixer for pre-stirring for 15s to attach water on the surface of the EPS particles. Then add the coarse and fine aggregate, cement and admixture to the mixer for 45s or so, and finally mix the mixture into the side Cube mold length of 150mm. Mold is removed after maintenance in the standard curing box 6 hours, and put back to the standard curing box within the conservation to 28d after the test block is numbered. Figure 2 and Figure 3 is the test block after demolition and the test block of maintenance of 28 days, respectively

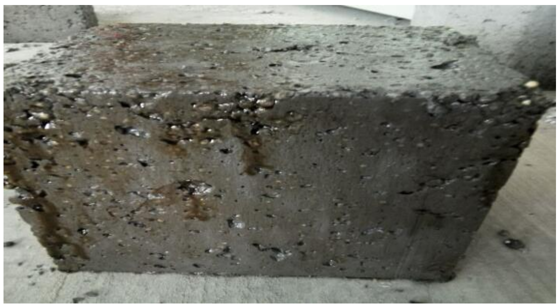

Fig.2. After demolition of the tested block

Fig.3. Maintenance 28d of the tested block

III. RESULTS AND ANALYSIS

A. Compressive strength

1. *Test process and damage morphology analysis*

The specimen size is a cube with a side length of 150mm. The specimen is cured for 28 days in an environment with a temperature of 20±2℃ and a humidity of 90%. The axial compression test of the specimen is carried out with the loading rate of the test is 0.5MPa/s. Through the analysis of the failure process of test piece failure, there are few visible cracks on the surface of the specimen before the peak of the load is reached. However, when stress is close to the peak stress, there is a crack along the edge of the compression edge. After the peak point, it can be seen that the cracks develop rapidly, and then the slanted cracks are formed, and the slanted cracks pass through the whole section to form the main slanting crack. The inclination angle of the main oblique fracture is between 63° and 72°, as shown in Figure 4. While the ordinary concrete is between 50° and 60°. Through the observation of the failure surface, the EPS particles at the failure surface of the EPS concrete did not destroy. The main failure mode was the

Fig.4.Cube compressive Failure

Fig.5.Failure interface of recycled aggregate concrete

destruction of the interface between the cement mortar and the EPS particles, and less the interface failure between the aggregate and the fresh cement mortar. The specimen is in a state of unconfined compression so that the edge of the test piece is pulled away to form a penetrating seam, and the interface destruction morphology is as shown in Figure 5.

2. *Analysis of test results*

In this experiment, the compressive strength of concrete at 0%, 10%, 30%, 50% and 100% of recycled aggregate was studied. The specific numerical analysis is shown in Table 5-9. The effect of recycled aggregates on the compressive strength of EPS concrete at different substitution rates , as shown in Figure 6.

Table 5. Unconfined compression strength value of EPS concrete with 0% replacement rate of recycled aggregate

Sample	Maximum test force（KN）	Unconfined compressive strength（Mpa）	average value（Mpa）	Standard deviation	Coefficient of variation	Representative value（Mpa）
1	151	6.73				
2	153	6.80				
3	148	6.59				
4	148	6.57				
5	151	6.70				
6	150	6.67				
7	151	6.73	6.69	0.0767	1.15%	6.56
8	147	6.55				
9	150	6.67				
10	151	6.70				
11	151	6.71				
12	153	6.80				
13	152	6.75				

Table 6. Unconfined compression strength value of EPS concrete with 10% replacement rate of recycled aggregate

Sample	Maximum test force（KN）	Unconfined compressive strength（Mpa）	average value（Mpa）	Standard deviation	Coefficient of variation	Representative value（Mpa）
1	153	6.80	6.71	0.1055	1.57%	6.54
2	146	6.49				
3	154	6.84				
4	149	6.63				
5	150	6.68				
6	152	6.74				
7	147	6.54				
8	152	6.77				
9	151	6.7				
10	113	5.03				
11	153	6.78				
12	151	6.71				
13	154	6.83				

Table 7. Unconfined compression strength value of EPS concrete with 30% replacement rate of recycled aggregate

Sample	Maximum test force（KN）	Unconfined compressive strength（Mpa）	average value（Mpa）	Standard deviation	Coefficient of variation	Representative value（Mpa）
1	162	7.2	6.96	0.1332	1.91%	6.74
2	158	7.00				
3	157	6.99				
4	158	7.01				
5	155	6.88				
6	155	6.87				
7	115	5.13				
8	157	6.99				
9	158	7.00				
10	160	7.13				
11	154	6.84				
12	150	6.66				
13	156	6.95				

Table 8. Unconfined compression strength value of EPS concrete with 50% replacement rate of recycled aggregate

Sample	Maximum test force（KN）	Unconfined compressive strength（Mpa）	average value（Mpa）	Standard deviation	Coefficient of variation	Representative value（Mpa）
1	155	6.89	7.00	0.1136	1.62%	6.81
2	153	6.79				
3	160	7.11				
4	—	—				
5	156	6.93				
6	157	6.98				
7	117	5.20				
8	162	7.20				
9	160	7.13				
10	157	6.96				
11	156	6.93				
12	159	7.07				
13	158	7.01				

Table 9. Unconfined compression strength value of EPS concrete with 100% replacement rate of recycled aggregate

Sample	Maximum test force（KN）	Unconfined compressive strength（Mpa）	average value（Mpa）	Standard deviation	Coefficient of variation	Representative value（Mpa）
1	—	—				
2	171	7.58				
3	173	7.67				
4	168	7.47				
5	171	7.59				
6	170	7.54				
7	172	7.63	7.53	0.1428	1.90%	7.30
8	162	7.20				
9	165	7.35				
10	172	7.66				
11	—	—				
12	171	7.61				
13	—	—				

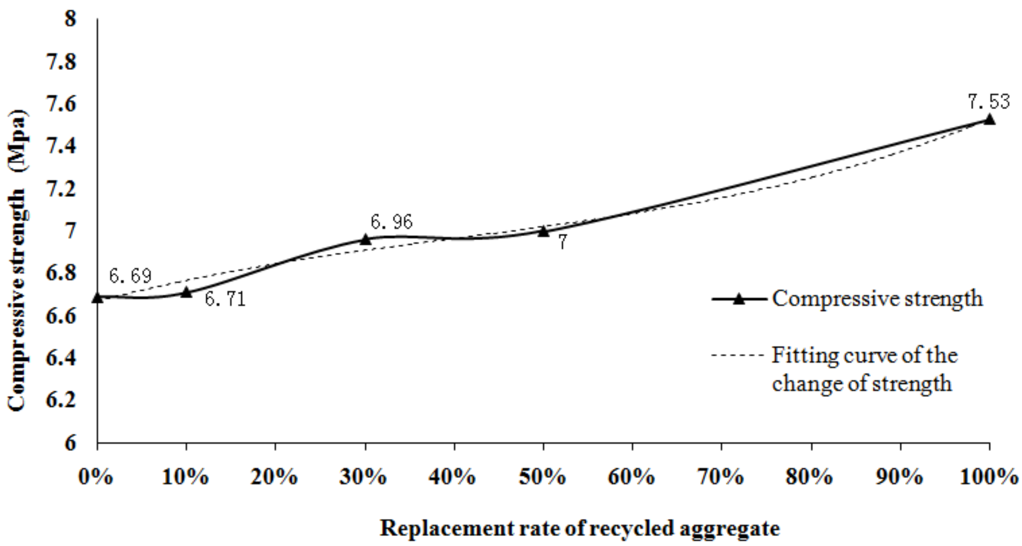

Fig.6. Relationship between Recycled Aggregate Replacement Rate and Compressive Strength

As can be seen from Figure 6, the compressive strength of EPS concrete increases with the replacement rate of recycled aggregates. When the replacement rate of recycled aggregate is more than 50%, the increase of compressive strength of EPS concrete becomes larger.

The relationship between the replacement rate of recycled aggregate and the compressive strength of EPS concrete is Eq.(1) through the Numerical simulation of spss statistics. The condition expressed in Eq.(1) is only verified ($0 \le x \le 1$) .

$$y = 0.4109x^2 + 0.3284x + 6.56 \quad R^2 = 0.9854 \quad (1)$$

Table 5 to Table 9 describe that the unconfined compression strength value of EPS concrete with 0%, 10%, 30%, 50% and 100% replacement rate of recycled aggregate, respectively From Table 5 to Table 9, it can be seen that the compressive strength of EPS concrete increases with the replacement of virgin coarse aggregate with recycled coarse aggregate while the other conditions remain unchanged. The increase of compressive strength of EPS concrete is related to the replacement rate of recycled aggregate. When the replacement rate of recycled aggregate is more than 50%, the increase rate of compressive strength of EPS concrete is larger than the increase rate of compressive strength of EPS concrete which under the condition of recycled aggregate replacement rate is less than 50%.

By analyzing the failure mechanism of EPS concrete, taking into account that the EPS particle strength is small and negligible in the EPS concrete, it can be concluded that the key to the formation strength of EPS concrete lies in the two factors such as the bonding strength and the matrix strength of the transition zone between the EPS particles and the cement slurry.

The transition zone between EPS and cement slurry is the enrichment area of calcium silicate hydrate, which is the weak area of the strength of EPS concrete. Cracks in concrete damage first appeared in this area, and finally penetrates the entire concrete and the components rapidly destroy. Poor cohesiveness between primary coarse aggregate and cement paste. Under the same pressure, the bonding force between raw coarse aggregate and cement paste reaches the limit, resulting in micro cracks. However, the cohesive force between recycled aggregate and cement paste does not reach the limit, and the compressive strength is relatively large. Therefore, the strengthening of the bonding properties at the interface can effectively improve the mechanical properties of EPS concrete.

B. THERMAL INSULATION

The mixture ratio of the test block used in the experiment is shown in Table 4. The thermal conductivity of EPS concrete is lower than the ordinary concrete, mainly because the incorporation of EPS particles makes the material contain a large amount of voids, and the porosity has an important influence on the thermal insulation properties. The greater of the porosity, the smaller of the thermal conductivity and the better of the insulation properties. Thermal conductivity that measured by the test is shown in Table.10.

Table 10. Thermal conductivity of EPS concrete

Sample	Thermal Conductivity (W/m·K）
Y-1	0.323
Y-2	0.320
Y-3	0.317
Y-4	0.315
Y-5	0.314

Figure 7 describes the relationship between the different replacement rates of recycled aggregate and thermal conductivity in EPS concrete. The thermal conductivity of EPS concrete is related to the replacement rate of recycled aggregate, but the replacement rate of recycled aggregate has little effect on the thermal conductivity. The regenerated aggregate cannot cause the change of the void fraction of the EPS concrete block by adding recycled aggregate into the EPS concrete. The thermal conductivity of EPS concrete is maintained between 0.31 and 0.32

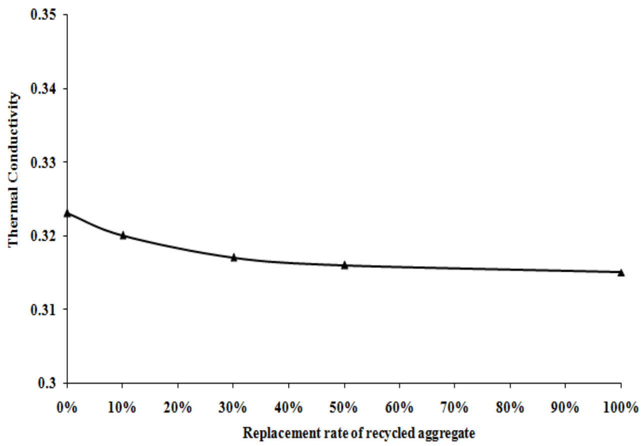

Fig.7. Relationship between replacement rate of recycled aggregate and thermal conductivity

IV. CONCLUSIONS

a. Recycled aggregate used in EPS concrete that make full use of the interface strengthening effect of recycled aggregate, and use of superplasticizer, expansive agent, accelerating agent and reasonable water cement ratio can make the aggregate bond more tightly, which can effectively avoid the segregation of EPS concrete and the floating of EPS particles.

The compressive strength of EPS concrete will be increased by replacing the raw aggregate with recycled aggregate in the condition that other conditions are kept constant. The increase of the compressive strength of EPS concrete is related to the replacement rate of recycled aggregate. When the replacement rate of recycled aggregate is more than 50%, the increase rate of compressive strength of EPS concrete is larger than the increase rate of compressive strength of EPS concrete under the condition of recycled aggregate replacement rate is less than 50%.

c. The thermal conductivity of EPS concrete is maintained between 0.31 and 0.32 by adding recycled aggregate into the EPS concrete, and the recycled aggregate has little effect on the thermal insulation performance of the EPS concrete.

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Luxin Fu Graduated from Shandong University of Technology and got bachelor degree. Major in concrete material. He is researching on EPS concrete.


ZhiRong Jia Graduated from Tongji University and got doctor degree. Major in new concrete materials.


Ruirui Jiang Graduated from Shandong University of Technology and got bachelor degree. Major in mechanics of materials. She is researching on mechanics of civil materials