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Silt Ceramsite Mechanical Properties for Reduction of Solid Waste Pollution

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Fiber reinforced silt ceramsite concrete (FSCC) is the concrete that natural aggregates are partially or completely replaced by silt ceramsite, while fibers are incorporated to enhance its mechanical properties. Orthogonal experiments on the strength of two kinds of FSCC were conducted in 2017. Effects of three factors on 28-day cube compressive & splitting tensile strength of polypropylene fiber silt ceramsite concrete (PFSCC) and steel fiber silt ceramsite concrete (SFSCC) were studied respectively. The experimental results revealed that the effects of aggregate replacement rate, water-cement ratio, and fiber content on the compressive strength of PFSCC decreased in turn. The effects of aggregate replacement rate and water-cement ratio on the splitting tensile strength of PFSCC were equivalent, while the effect of fiber content was the least. The influences of aggregate replacement rate, steel fiber content and water-cement ratio on the compressive strength of SFSCC decreased in turn, while the effects of water-cement ratio, aggregate replacement rate, and steel fiber content on the splitting tensile strength of SFSCC increased. The further variance analysis showed that water-cement ratio and aggregate replacement rate had evident effects on the splitting tensile strength of PFSCC. A few suggestions were made for configuring fiber silt ceramsite concrete.

1. Introduction

It is well known that there have been many studies on the mechanical properties of fiber reinforced concrete (FRC). The studies indicates that common fibers such as steel fiber and polypropylene fiber increased the strength, ductility and toughness of concrete by contrast with those of plain concrete (PC) (Feldman D., 1993). The biological fibers played the same part in those of kenaf FRC (A. Elsaid et al., 2010).
On the other hand, There have been many studies on lightweight aggregate concrete (LAC) to improve concrete's physical properties like density, heat preservation, thermal insulation and anti-permeability (Nie et al., 2011). The research on ceramsite concrete is one direction. The ceramsite concrete is widely used on roofs, water proof restoration (Zhao et al., 2014) and external walls thanks to ceramsite's features of heat insulation, good anti-permeability, low water absorption (Kong et al.,2009) and durability. However, the strength and ductility of ceramsite aggregates are lower those of natural aggregates, resulting in defects in ceramsite concrete. Thus, fiber or waste rubber was incorporated into the ceramsite concrete to improve its basic mechanical properties (Dong et al., 2013). Sand were partially replaced in shale ceramsite concrete by different amounts of waste rubber to prepare rubber lightweight concrete (RLC). An increase in the content of waste (Liu et al., 2018) rubber powders effectively improved the failure mode of ceramsite concretes. Xia et al. (2012) configured 54 model steel fiber-rubber powder ceramsite concrete specimens and tested their 7-day & 28-day compressive strength. He found that volume of the rubber powder had a special effect on reducing the early compressive strength of the specimens. Zhang et al. (2014) conducted a series of strength performance tests of the steel fiber fly ash recycled concrete by orthogonal test method. The results illustrated the validity and efficiency of orthogonal test method. Orthogonal test method can greatly reduce the test quantity thanks to selection from representative ones instead of comprehensive ones, so as to avoid the disadvantages of experience or the blindness due to the test results without typical. In addition, the orthogonal test results can be applied to complete range analysis and variance analysis. These analysis are fairly reasonable for indices

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of varying importance (Zhang et al., 2017). Therefore, the goal of obtaining the optimal test result with few tests can be achieved.

Although many experimental researches on LAC have been conducted, Most of the researches focused on properties of the ordinary ceramsite concrete (Abramova et al., 2018), in which ceramsite was made of shale and clay. Due to the lack of these ordinary resources for ceramsite, the solid waste like silt, urban sludge and fly ash become welcome as raw materials for ceramsite. These solid waste is feasible and safe to produce high performance green ceramsite (Liu et al., 2012). As such, there is an urgent need to study and reuse the silt and urban sludge deposited in lake, river and sewage treatment plants, etc. Making full use of these waste resources shows potential future for reduction of environmental pollution as well as promotion of resource recycling (Li et al., 2017).

Based on the investigations mentioned above, Huang et al. (2011) put forward ecological composite-wall which can be manufactured for precast concrete building. These walls were infilled with ecological materials like silt ceramsite concrete. In accordance with the policy of national ecological civilization construction, using of solid waste to manufacture ceramsite for ecological composite-wall is meaningful. In this study, Silt ceramsite was used as partial or total replacement for natural aggregate. Polypropylene fiber or steel fiber was selected as reinforcing materials. The effects of water-cement ratio, aggregate replacement rate, and fiber content on the 28-day cubic strength of two kinds of fiber reinforced silt ceramsite concrete (FSCC) were studied based on orthogonal experiments.

2. Experiment

2.1 Materials

The experiments adopted P.O grade-42.5 cement and fine aggregate with fineness of 2.8, and the silt ceramsite was selected as coarse aggregate with the related performance indexes as shown in Table 1. The fiber made of polypropylene and steel with the related performance indicators were shown in Table 2.

Table 1: Properties of the silt ceramsite

Item	Accumulated density (kg/m^3)	Tube strength (MPa)	Tensile strength (MPa)	Crush value (%)	1h water absorption (%)
Measured value	885	5.1	0.8	38.6	14

Table 2: Properties of the fibers

Fiber type	Tensile strength (MPa)	Elastic modulus (MPa)	Density (g/cm^3)	Length (mm)	Diameter (mm)
Polypropylene	400	3500	0.9	19	0.18
Steel	2300	21000	7.9	35	0.55

2.2 Experimental program

Take the factors as reference (Zhang et al., 2014), The water-cement ratio, aggregate replacement rate and the fiber content were determined as three factors of the orthogonal experiment and each factor had three levels, as shown in Table 3. The orthogonal table of $L9(3^4)$ was designed as shown in Table 4. It was assumed that any two factors did not interact with each other. A total of 108 fiber silt ceramsite concrete specimens were produced with the dimensions of 150 mm × 150 mm × 150 mm. These specimens were divided into 2 groups. Each group was divided into 9 squads, and 6 samples were involved in each squad.

2.3 Specimen preparation and experiment

The preparation of all mixtures and concrete curing were conducted in the Laboratory for Building Material Research in 2017 at Xi’an University of Architecture & Technology, Xi’an, China. All mixtures were prepared with a 60L mixing machine. The sand, cement, silt cramsite and the steel fibers (polypropylene fibers) were placed and mixed for about 2 min before water was added. Then 3 min of mixing was followed. The mixture in each group was cast in steel molds and then compacted on a vibration table. The molds were removed 24h after casting. All the concrete specimens were cured in a standard frog room (20□ and 95% relative humidity) for 28 days before test. Strength tests were performed according to the Standard for test of mechanical properties on ordinary concrete (GB/T 50081-2002) mentioned in the Standard test methods for the fiber reinforced concrete (CECS 13: 2009). The tests were taken into action by electro-hydraulic servo material testing machine at stress loading speed of 0.5MPa/s for compression test and 0.05MPa/s for splitting tensile test.

Table 3: The factors and levels of experiment

Level	Factor Water-cement ratio A	Aggregate replacement rate B	Fiber content C
1	0.45	30%	0.9%
2	0.50	65%	1.2%
3	0.55	100%	1.5%

Table 4: The mix proportion of concrete

No	Orthogonal design	Cement (kg/m^3)	Silt ceramic aggregate (kg/m^3)	Polypropylene fiber (steel fiber) (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Natural coarse aggregate (kg/m^3)
1	A1B1C3	400	155	13.65(117)	819	180	794
2	A2B1C1	360	155	8.19(70.2)	819	180	794
3	A3B1C2	330	155	10.92(93.6)	819	180	794
4	A1B2C2	400	335	10.92(93.6)	819	180	397
5	A2B2C3	360	335	13.65(117)	819	180	397
6	A3B2C1	330	335	8.19(70.2)	819	180	397
7	A1B3C1	400	516	8.19(70.2)	819	180	0
8	A2B3C2	360	516	10.92(93.6)	819	180	0
9	A3B3C3	330	516	13.65(117)	819	180	0

3. Results and analysis

3.1 Orthogonal test results

Table 5 summarized the test results of polypropylene fiber reinforced silt ceramsite concrete (PFSCC) and steel fiber reinforced silt ceramsite concrete (SFSCC) in terms of the 28-day cubic compressive strength & the splitting tensile strength. According to the orthogonal test analysis method (Wang R.X., 2002), calculations were made to obtain the ranges of the orthogonal experiment after treatment of each strength (Qin et al., 2017). These calculated results were listed in Table 6.

Table 5: Strength results of the orthogonal experiment

No	PFSCC		SFSCC	
	28-day compressive strength (MPa)	28-day splitting tensile strength (MPa)	28-day compressive strength (MPa)	28-day splitting tensile strength (MPa)
1	25.7	2.94	42.8	3.73
2	27.9	2.79	30.8	3.07
3	22.3	2.55	32.5	3.67
4	27.1	2.83	32.1	3.68
5	21.9	2.59	33.6	3.79
6	22.1	2.53	34.3	2.90
7	23.7	2.61	28.4	3.10
8	19.6	2.37	27.7	3.04
9	19.8	2.37	29.6	3.37

3.2 Analysis

3.2.1 Range and factor Index analysis

Considering the compressive strength and splitting tensile strength of the 28-day cubes of FSCC as an index, the average value of the strength at each level of each factor was calculated as shown in Figure1 and Figure 5 respectively. In addition. The average values of the same kind of strength at the same level (e.g.1, 2, 3) were shown in in Figure 1 and Figure 2 corresponding to Table 3.

For the cubic compressive strength of PFSCC, the range is 4.10, 4.27, 2.10 as shown in Table 6. It indicates that the effect of the three factors on the cube is B > A > C. The effect of aggregate replacement rate is the most significant, followed by the water-cement ratio. The fiber content has the least impact. To achieve the optimal compressive strength, the combination should be selected as A1B1C1 as shown in Figure1. The range for the cubic splitting tensile strength of PFSCC is 0.31, 0.31, 0.06 (Table 6), which shows that the effect of the three factors on the splitting tensile strength is A= B > C. The effect of the water-cement ratio and aggregate replacement rate is equivalent, while the effect of fiber content is the least. To obtain the optimal splitting and tensile strength, the combination should be selected as A1B1C1 inferred from Figure 1.

For the cubic compressive strength of SFSCC, the range is 3.73, 6.80, 4.57 as shown in Table 6, revealing the fact that the effect of the three factors on the cube is B > C > A. The effect of aggregate replacement rate is the most significant, followed by the fiber content. The water-cement ratio have the least impact. The range on the splitting tensile strength is 0.20, 0.32, 0.61 as shown in Table 6, which illustrates that the effect of three factors was C > B > A. Fiber content has the greatest impact, followed by the aggregate replacement rate. The water-cement ratio presents the smallest influence. To achieve the best compressive strength and splitting tensile strength in SFSCC, the combination A1B1C3 should be selected inferred from Figure 2.

Table 6: Ranges of the orthogonal experiment

Type	Strength	Water-cement ratio (A)	Aggregate replacement rate (B)	Fiber volume Fraction (C)
PFSCC	28-day compressive strength	4.10	4.27	2.10
	28-day splitting tensile strength	0.31	0.31	0.06
SFSCC	28-day compressive strength	3.73	6.80	4.57
	28-day splitting tensile strength	0.20	0.32	0.61

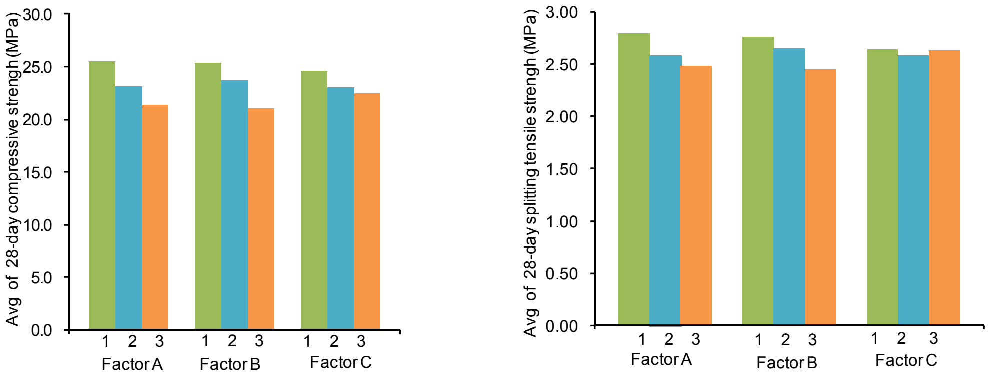

Figure 1: Effect of various factors on the Strength of PFSCC

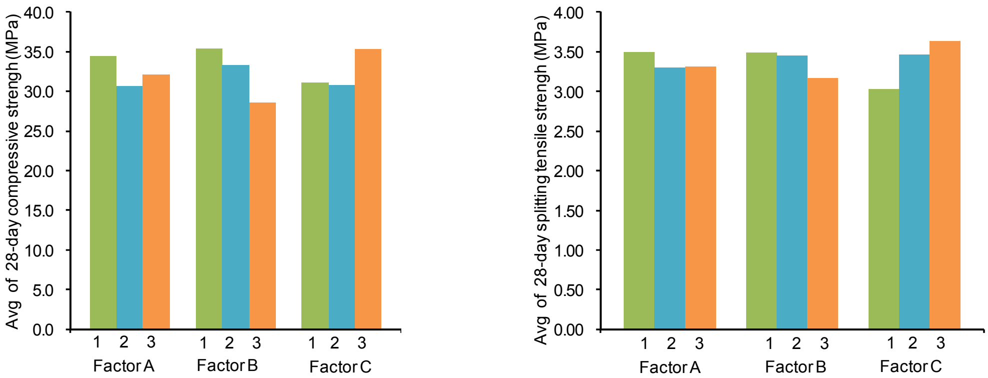

Figure 2: Effect of various factors on the Strength of SFSCC

3.2.2 Variance analysis

The variance analysis of the 28-day cube compressive strength and splitting tensile strength of two kinds of FSCC were summarized in Table 7 and Table 8. F values which obey F distribution were calculated according to statistical method, and significance was given by means of hypothesis testing. From the significance shown in Table 7, It seems that water-cement ratio and aggregate replacement rate are relatively greater as to the effect on the 28-day compressive strength of PFSCC, however, the effect of fiber content is negligible. The water-cement ratio and aggregate replacement rate have the most significant influence on the 28-day splitting tensile strength of PFSCC while the effect of fiber content is negligible. For the 28-day compressive strength of SFSCC as shown in Table 8, aggregate replacement rate have the largest effect, followed by the fiber content. The smallest effect is exhibited by the water-cement ratio. The influence of the fiber content is the most significant for the 28-day splitting tensile strength of SFSCC. The effect of the water-cement ratio is negligible. The analysis above are basically consistent with the results of range analysis.

Table 7: Variance analysis of the test results of PFSCC

Assessment indicators	Sources of variance	Degree of freedom	Sum of square of diviation	Mean Square	F (2,2)	Significance
28-day compressive strength (MPa)	A	2	25.42	12.71	2.23	*
	B	2	27.88	13.94	2.44	*
	C	2	7.15	3.57	0.63	~
28-day splitting tensile strength (MPa)	A	2	0.150	0.075	15.33	**
	B	2	0.148	0.074	15.12	**
	C	2	0.006	0.003	0.63	~

Table 8: Variance analysis of the test results of SFSCC

Assessment indicators	Sources of variance	Degree of freedom	Sum of square of diviation	Mean Square	F (2,2)	Significance
28-day compressive strength (MPa)	A	2	21.28	10.64	0.73	~
	B	2	73.10	36.55	2.52	*
	C	2	38.38	19.19	1.32	#
28-day splitting tensile strength (MPa)	A	2	0.078	0.039	0.59	~
	B	2	0.186	0.093	1.41	#
	C	2	0.589	0.295	4.46	*

Note: **represents the factors has a significant influence; If the factor has a greater impact, donated by *; if he factor has an impact, donated by #; ~ means that the factor is almost no influence.

The F values for Factors on the 28-day splitting tensile strength of PFSCC were calculated as follows:
Significant level: $\alpha = 0.01$, $F_{\alpha}(2,2) = F_{0.1}(2,2) = 9.00$, then assuming H_0: factor A, factor B have no influence

$$P\{F_A(2,2) \geq F_{\alpha}(2,2)\} = 0.01,\ P\{F_B(2,2) \geq F_{\alpha}(2,2)\} = 0.01 \quad (1)$$

Factor A：$F(2,2) = 15.33 > F_{0.1}(2,2)$, FactorB：$F(2,2) = 15.12 > F_{0.1}(2,2)$ (2)

The event of small probability happened according to formula (1) and formula (2), indicating that factor A and factor B have significant influence over the 28-day splitting tensile strength of specimens (The probability of influence is over 90%). Consequently, both the water-cement ratio and aggregate replacement rate has evident effects on the splitting tensile strength of PFSCC.

4. Conclusions

A total of 108 specimens have been studied in order to analyze factors on the mechanical behavior of fiber silt ceramsite concrete. The results obtained in this work and suggestions can be summarized as follows:
Aggregate replacement rate had the most significant effect on the 28-day compressive strength and splitting tensile strength of PFSCC. By increasing aggregate replacement rate, the compressive strength and splitting tensile strength certainly decreased. The water-cement ratio was another important factor. An increase in the water-cement ratio reduced the compressive strength and splitting tensile strength of PFSCC. Polypropylene fiber content had the least effect on compressive strength and splitting tensile strength.
Aggregate replacement rate presented the most significant effect on the compressive strength of SFSCC and had a great effect on the splitting tensile strength of SFSCC. The water-cement ratio had a negligible effect on the compressive strength and the splitting tensile strength. Steel fiber content presented little effect on compressive strength but had a great impact on the splitting tensile strength.
Through the tests and analysis, when configuring fiber silt ceramsite concrete, the water–cement ratio might be as low as possible. The replacement rate should be as high as possible to meet the strength requirement. The content should be combined with the actual situation in a reasonable range to take a high fiber volume fraction.

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