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Effect of Steel Inorganic Fiber on Mechanical Properties of Lightweight Aggregate Concrete

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Abstract

In order to study the influence of steel-inorganic fiber on the mechanical properties of lightweight aggregate concrete, test parameters including single ceramic fiber and basalt fiber with different dosage and mixed steel-basalt fiber and steel-ceramic fiber reinforced lightweight aggregate concrete specimens with different doping methods were designed, and compared with the non-fiber reference group. The test results show that the compressive strength of cube is improved most obviously by steel-basalt fiber, with the maximum increase of 14.5%. Adding 1.35kg/m3 basalt fiber can increase the flexural strength of lightweight aggregate concrete by 62.2%. Adding ceramic fiber reduces the compressive strength of lightweight aggregate concrete, but improves the flexural strength.

Keywords

Lightweight Aggregate Concrete; Hybrid Fiber; Mechanical Properties.

1. Introduction

With the development of the times, concrete is widely used in various structures because of its excellent compressive performance. The disadvantages of ordinary concrete are low tensile strength, cracking strength and self-weight. In order to reduce self-weight, some scholars have replaced crushed stone aggregate in concrete with lightweight aggregate, which can effectively reduce the self-weight of concrete. However, compared with ordinary concrete, lightweight aggregate concrete has poor mechanical properties, easier cracking, lower strength and more obvious brittle behavior. Although adding steel bars can effectively improve these shortcomings, concrete generally works with cracks, which can easily lead to corrosion of steel bars, which reduces the mechanical properties of concrete structures and makes the structures unsafe. In order to improve the strength and toughness of lightweight aggregate concrete and reduce the micro-cracks of concrete in service stage, some scholars put forward that one or more fibers should be added to the concrete to improve the strength and toughness of the concrete. At present, more studies show that the mechanical properties of lightweight aggregate concrete can be effectively improved with appropriate amount of fibers. Because the performance of one fiber is limited, more scholars mix two or more different types of fibers into concrete members to make up for their respective shortcomings by giving full play to the advantages of different fibers.

In order to respond to the call of national energy conservation and emission reduction, and give full play to the resource utilization advantages of solid waste, this subject plans to replace the coarse aggregate of concrete with fly ash ceramsite. On the one hand, fly ash ceramsite is solid waste for reuse, reducing the damage to the natural environment; On the other hand, lightweight aggregate ceramsite, as the internal curing material of concrete, increases the internal hydration of concrete and reduces the cracks caused by concrete self-shrinkage.

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Different fibers are added to make up for the low strength of lightweight aggregate concrete, so as to meet the actual engineering needs. Xiao[1] has studied the influence of basalt fiber on lightweight aggregate concrete. The research shows that basalt fiber can effectively improve the mechanical properties of lightweight aggregate concrete, and its optimal dosage is about 0.3% of the mass of cementitious materials. Zheng[2] research shows that steel fiber can effectively reduce the tension and shrinkage of concrete and improve the internal pore composition of concrete. Li[3-5] It is found that the compressive strength and flexural toughness of ordinary lightweight aggregate concrete are the best when the content of corrugated steel fiber reaches 2.0% by volume. For self-compacting lightweight aggregate concrete, the content of steel fiber should be controlled below 1.0%, which will adversely affect the compressive strength of self-compacting lightweight aggregate concrete. Ye[6] found that steel fiber has great advantages in improving the mechanical properties of lightweight aggregate concrete. Considering the fluidity, mechanical properties and flexural toughness of concrete, the recommended dosage is 0.5%-1.0%. Li[7] Research shows that steel fiber is superior to high performance polypropylene fiber in improving the compressive strength of lightweight aggregate concrete. Xiao[8] found that basalt fiber has a positive impact on the compressive strength, flexural strength and flexural toughness of lightweight aggregate concrete, and has little impact on the quality loss after freeze-thaw cycle. The optimum content of basalt fiber is 0.1% of the amount of cementitious material. Li Rui [9] found that the compressive strength of lightweight aggregate concrete is lower than that of ordinary aggregate concrete with similar mix ratio, and found that the reinforcement effect of fly ash and silica fume on lightweight aggregate concrete is better than that of fly ash and silica fume alone. Shi Lei [10] found that for low-strength lightweight aggregate concrete, the amount of fly ash can improve the fluidity. The fibers used in this study are ceramic fiber, basalt fiber and copper-plated steel fiber. Among them, ceramic fiber is made of industrial waste fly ash, which is a kind of solid waste utilization. Moreover, after adopting new production technology, the cost is greatly reduced compared with before. Basalt fiber has the advantages of environmental protection, excellent performance, associated pollution and low cost. Moreover, ceramic fiber and basalt fiber are inorganic fibers, which are not easy to react with various additives in concrete. Copper plating on steel fiber also has its advantages. Copper plating on the surface of steel fiber can effectively prevent steel fiber from rusting and expanding in concrete, and prevent the internal damage of concrete caused by steel fiber rusting from affecting the mechanical properties of concrete.

2. Design of Mix Proportion

2.1. Raw Materials

Lightweight aggregate: round fly ash ceramsite. See Table 1 for physical properties. Fiber: copper-plated steel fiber, ceramic fiber and basalt fiber. See Table 2 for detailed fiber parameters. Cement: ordinary Portland cement (P.O 42.5). Fine aggregate: natural river sand with fineness modulus of 2.76. Other cementing materials: Class II fly ash and micro silica fume. Additive: polycarboxylate superplasticizer.

Table 1. Physical properties of fly ash ceramsite

Type	Apparent density /kg/m^3	Stacking density /kg/m^3	Bucket pressure strength /MPa	Sediment percentage /%	Poriness /%	Nominal particle size /mm
Parameter	1612	1013	11	0.55	38.0	5-16

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Table 2. Fiber parameters

Type	Length/mm	Diameter/mm	Draw ratio	Density/kg/m^3	Tensile strength/MPa
Copper fiber plating	6	0.22	27	7800	3000
Ceramic fiber	6	0.003	2000	2600	2400
Basalt fiber	6	0.022	261	2720	1385

2.2. Test Mix Ratio

In this study, LC40 is used as the strength grade of concrete matrix, and the concrete mix proportion is preliminarily designed with reference to Technical standard for application of lightweight aggregate concrete. After many trials, the benchmark mix proportion is obtained, and the water-binder ratio is determined to be 0.39, in which the dosage of water-reducing agent should be appropriately fine-tuned according to the workability of hybrid fiber concrete mixture. The final mixture ratio is shown in Table 3.

Table 3. Mix proportion design of lightweight aggregate concrete (kg·m-3)

Intensity	Ceramsite	Cement	Water	Ordinary sand	Fly ash	Silica fume	Polycarboxylate superplasticizer
LC40	572	357	200	739.2	102	51	3.06

3. Experiment Design

According to the current test codes and standards, the cubic compressive strength, flexural strength, flexural toughness and durability of lightweight aggregate concrete were tested.

Table 4. Test grouping (kg·m-3)

Category	Number	Ceramic fiber	Basalt fiber	Steel fibre
Plain aggregate concrete	A	0	0	0
Single basalt fiber	B1	0	1.35	0
	B2	0	2.7	0
	B3	0	4	0
Single doped ceramic fiber	C1	1.3	0	0
	C2	2.6	0	0
	C3	3.9	0	0
Steel-basalt fiber hybrid	S2B1	0	1.35	40
	S2B2	0	2.7	40
	S2B3	0	4	40
Steel-ceramic fiber hybrid	S1C1	1.3	0	30
	S1C2	2.6	0	30
	S1C3	3.9	0	30
	S2C1	1.3	0	40
	S2C2	2.6	0	40
	S2C3	3.9	0	40
	S3C1	1.3	0	50
	S3C2	2.6	0	50
	S3C3	3.9	0	50

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The fiber types and mixing methods selected in the experiment are single basalt fiber, single ceramic fiber, steel-basalt hybrid fiber and steel-ceramic hybrid fiber. According to the research content, it is divided into 19 groups of specimens, 12 groups of mixed fiber specimens and 6 groups of single fiber specimens. At the same time, for comparative analysis, a group of ordinary lightweight aggregate concrete specimens without fiber were designed. The geometric dimension of mechanical performance test is a cube with a side length of 100mm, and the geometric dimension of flexural and bending performance test is 100mm×100mm×400mm prism. After referring to relevant literature, the content of each fiber is determined, and the final number of test pieces is shown in Table 4.

The cube compressive strength test adopts the loading system controlled by force, and the loading speed is 0.5-0.8 MPa/s; The flexural strength test and flexural toughness test adopt concentrated force loading at four points, the loading system adopts displacement control, the loading speed is 0.2mm/min, and the testing machine and displacement meter adopt the same acquisition frequency (10Hz). See Figure 1 for the loading schematic diagram.

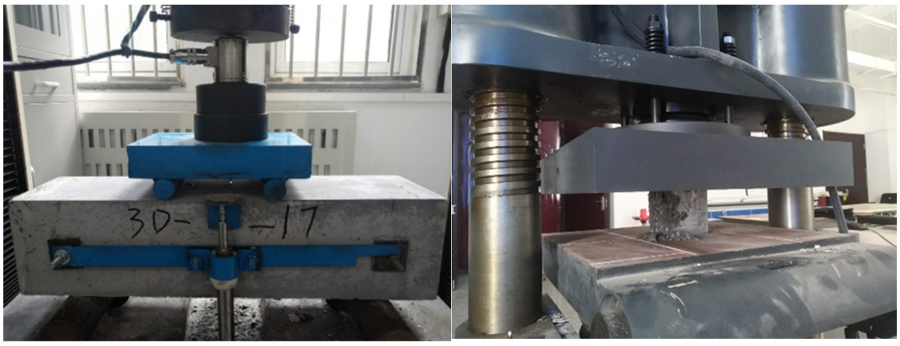

Fig 1. Test equipment

4. Test Results and Analysis

Table 5. Cube compressive strength and flexural strength (MPa)

Number	Cubic compressive strength	Rupture strength
A	40.9	2.59
B1	42.1	4.20
B2	42.5	4.13
B3	45.8	3.27
C1	37.2	2.62
C2	34.7	2.62
C3	36.4	3.54
S2B1	42.6	2.78
S2B2	43.6	3.44
S2B3	46.8	3.39
S1C1	39.0	2.35
S1C2	38.0	2.43
S1C3	37.7	2.38
S2C1	40.8	3.12
S2C2	39.0	2.45
S2C3	40.5	2.37
S3C1	42.5	2.60
S3C2	40.9	2.46
S3C3	40.8	2.22

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See table 5 for cube compressive strength and flexural strength of ordinary lightweight aggregate concrete and fiber lightweight aggregate concrete.

The results of cube compressive strength test are shown in Table 5. The compressive strength of lightweight aggregate concrete with basalt fiber is obviously improved, and the dosage is linearly related to cube compressive strength. The compressive strength of lightweight aggregate concrete with basalt fiber reaches the maximum value of 45.8Mpa, which is different from the optimal dosage obtained by Huang Daguan [11]. The reason is that the different fiber lengths lead to the different number of fibers with the same dosage. At the same time, long fibers are more likely to bridge the cracks, and longer fibers are more likely to agglomerate in the concrete, so it is necessary to However, the optimum volume content of basalt obtained in this paper is consistent with the optimum volume content range of compressive strength obtained by Lian Jie [12]. Ceramic fiber has a negative influence on the cubic compressive strength of lightweight aggregate concrete, and the dosage should not be too high. It is suggested that the optimal dosage is 1.3kg/m3. Basalt fiber and steel fiber show a good positive hybrid effect, and the content of steel fiber remains unchanged. With the increase of ceramic fiber content, the cube compressive strength increases, which also shows a good linear growth trend. Ceramic fiber and steel fiber don't show positive mixing effect, and cube compressive strength increases with the increase of steel fiber content, and decreases first and then slightly increases with the increase of ceramic fiber content, which indicates that the content of ceramic fiber needs to be controlled within a reasonable range. To sum up, the cubic compressive strength of lightweight aggregate concrete is increased by 11.9% by adding basalt fiber alone, and by 14.5% by steel-basalt fiber. Ceramic fiber has an adverse effect on the cubic compressive strength of lightweight aggregate concrete. Only the cubic compressive strength of S3C1 and S3C3 groups mixed with ceramic fiber and steel fiber is higher than that of ordinary lightweight aggregate concrete, which indicates that adding steel fiber to ceramic fiber concrete can't improve the defects caused by ceramic fiber.

For the flexural strength test, when basalt fiber reaches a certain amount, it will reduce the flexural strength, but it is higher than that of ordinary lightweight aggregate concrete. When the amount of basalt fiber is 1.35kg/m3, it reaches the peak value, increasing by 38.3% compared with the control group without fiber, which is lower than the optimal amount recommended by Huang Daguan [11]. It shows that the improvement of flexural strength is mainly due to the increase of basalt fiber quantity, so as to ensure the uniform distribution of fiber in concrete. It is basically consistent with the best dosage of basalt fiber reinforced concrete flexural strength found by Peng Miao, but the reason for not showing a completely similar trend lies in the difference of fiber length and concrete strength grade. Ceramic fiber also has a positive influence on the flexural strength of lightweight aggregate concrete. When the content of ceramic fiber is lower than 2.6kg/m3, the flexural strength is not obviously improved, but when the mass of ceramic fiber is 3.9kg/m3, the flexural strength is obviously increased, which is 26.8% higher than that of the control group without fiber. Basalt fiber and steel fiber did not show a good synergistic effect. Adding steel fiber to basalt fiber did not further improve the flexural strength of lightweight aggregate concrete. At a lower content, the flexural strength was lower than that of basalt fiber alone, but both were higher than that of ordinary lightweight aggregate concrete. Ceramic fiber and steel fiber did not show a good synergistic effect. Only the flexural strength of S2C1 and S3C2 specimens was higher than that of ordinary lightweight aggregate concrete, which indicated that adding steel fiber to ceramic fiber concrete could not effectively improve the flexural strength of lightweight aggregate concrete, and the flexural strength of S2C1 was even lower than that of C3. To sum up, the total fiber content should be controlled within a certain range. If it exceeds a certain range, the cementitious materials will fail to tightly wrap the aggregate and fiber, which will affect the proportion of aggregate and cementitious materials. At the same time, the added fibers will

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converge and aggregate into impurities in concrete, which will reduce the flexural strength of concrete.

5. Conclusion

(1) Ceramic fiber has an adverse effect on the cube compressive strength of lightweight aggregate concrete, but basalt fiber can improve the cube compressive strength. After adding steel fiber, the cube compressive strength is significantly improved, and the increase rate of steel-basalt fiber is higher than that of steel-ceramic fiber, and the maximum increase rates of steel-basalt fiber and steel-ceramic fiber are 14.5% and 3.91 respectively.

(2) The flexural strength of lightweight aggregate concrete should be controlled in the range of total fiber content. If it exceeds a certain range, the cementitious materials will fail to compact the aggregate and fiber, resulting in negative mixing effect. The optimum content of basalt fiber is 1.35kg, which can increase the flexural strength by 62.2% compared with the reference group.

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