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Research on the properties and influencing factors of high-efficiency joining materials based on orthogonal tests

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Abstract
To address the cracking and damage problems at the node joints of assembled buildings, an efficient connecting material concrete (Precast Connect Efficient Concrete Material, PCECM) dedicated to the nodes of assembled structures was developed, and the effects of ultrafine composite powder, silica fume, and steel fiber aspect ratio parameters on its The effects of ultrafine composite powder, silica fume, and steel fiber aspect ratio parameters on the flowability and compressive strength at different maintenance ages were comprehensively investigated by orthogonal tests. The results show that: silica fume has the greatest influence on the mobility, the steel fiber aspect ratio has the greatest influence on the compressive strength at different ages, and when the dosage of ultrafine composite powder is 25%, silica fume dosage is 4%, and the steel fiber aspect ratio is 73, it can meet the economy at the same time and also can achieve high compressive strength.

Keywords: *Assembled buildings, Efficient joining materials, Orthogonal tests, Fluidity.*

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I. INTRODUCTION

In assembled building structures, the reliability of nodes largely determines the durability and safety of the structure [1]. In the current development of the connection stage of building nodes in China, dry connection and wet connection are commonly used, but the socket grouting technology in the wet connection requires high professional and technical ability of workers during construction [2], the workload of grouting connection of reinforcement bars one by one is large, and there is no easy and effective testing method to test the quality of its connection, which can not effectively supervise the safety risk of the structure hidden danger [3]. The dry connection method has a narrow scope of application and poor structural integrity.

In a large number of practical applications of the project found that: the market has a general-purpose connection materials, although high compressive strength, but too high compressive strength and the surrounding compressive strength of ordinary concrete is too large a difference, so that the damage form of the component changes. In addition, in the connection of these components often have the appearance of shrinkage joints, which has a great negative effect on the transfer of structural internal forces, largely affecting the safety of the structure.

Aiming at the deficiencies proposed above, this paper develops an efficient connecting material dedicated to nodes through orthogonal tests, and explores the effects of ultrafine composite powder, silica fume, and steel fiber aspect ratio parameters on its mobility as well as its compressive strength at different curing ages.

II. OVERVIEW OF THE TRIAL

2.1 Raw Materials

Cement: P·O52.5 ordinary Portland cement. Ultra-fine composite powder: ultra-fine composite powder made of fly ash, slag and other industrial solid wastes as raw materials. Silica fume: the moisture content is not more than 1%, and the ignition loss is not more than 3%. Steel fiber: tensile strength is not less than 2000MPa. Water reducer: water reduction rate is greater than 25%, moisture content is less than 1%, chloride ion content is less than 0.1%. Bulking agent: the initial setting is greater than 45 minutes, and the final setting is less than 600 minutes. Plastic swelling agent: moisture content is less than 3%, chloride ion content is less than 0.05%. Fine sand and coarse sand are ordinary river sand. Mineral powder: the grade is S95, and the fluidity ratio is greater than 95%. Water: Tap water.

2.2 Orthogonal Test Mix Ratio Design

The water-cement ratio of this test was 0.2, the volume dosing of steel fiber was 1.2%, the sand-cement ratio was 1.1, the water reducing agent dosing was 2%, and the expansion agent dosing was 3%. The variables of this test are A superfine composite powder dosage (15%, 20%, 25%), B silica fume dosage (4%, 5%, 6%), and C steel fiber L/D ratio (59, 65, 73). The steel fibers were flat steel fibers with specific specifications of 13×0.22mm, 13×0.20mm, 16×0.22mm. The test was conducted using three-factor, three-level orthogonal test with a total of 9 groups. The orthogonal test factor levels are tabulated in Table 1.

Table 1: Orthogonal test factor and level.

factor	level		
	1	2	3
A: Dosage of ultrafine composite powder %	15	20	25
B: Silica Fume Admixture %	4	5	6
C: Steel Fiber Length to Diameter Ratio	59	65	73

2.3 Specimen Preparation and Maintenance

PCECM mixing process and specimen preparation: weigh the material; moisten the mixer; pour the weighed powder into the mixer and mix it dry for 3min, then add the fine sand and coarse sand and mix it dry for 3min, after that add the water evenly and slowly while mixing and mix it for 7min; after that add the steel fibers evenly and slowly with a sieve and mix it for 3min.

Nine cubic specimens (100mm×100mm×100mm, every three specimens were used for 3, 7, 28d compressive strength test respectively) were prepared for each set of mixing ratio. After molding, the specimens were demolded and placed in a curing box at a temperature of 20˚C±2˚C and a relative humidity of more than 95%.

2.4 Performance Test Methods

The testing process of the mobility test refers to GB/T 50080-2016 "Standard Test Methods for Properties of Ordinary Concrete Mixes" [4]. The measurement is carried out twice and the measured diameters are perpendicular to each other, and the result is taken as the average value of the two measurements. As shown in Figure. 1.

Figure 1:PCECM Fluidity Test

The compressive strength test was conducted in accordance with GB/T 50081-2019 "Standard Test Methods for Physical and Mechanical Properties of Concrete" [5], using electro-hydraulic servo pressure tester, loaded at a speed of 1.0MPa/s, and then the average value of the strength of 3 specimens was taken as the compressive strength value. As shown in Figure 2.

Figure 2:PCECM Compressive Strength Test

III. RESULT AND DISCUSSION

Nine mixing ratios were determined according to the factor levels of the orthogonal test in Table 1, and the flow rates and compressive strengths at different curing ages were obtained under the conditions of each mixing ratio, and the test results are shown in Table 2. The results of the orthogonal tests are now analyzed.

Table 2: Orthogonal test fluidity, compressive strength results.

Specimen Group Number	3d compressive strength(MPa)	7d compressive strength(MPa)	28d compressive strength(MPa)	Fluidity (mm)
Group 1	74.18	91.83	122.16	740
Group 2	77.96	102.09	117.69	755
Group 3	88.52	110.23	126.27	755
Group 4	72.16	97.51	108.35	770
Group 5	83.09	103.16	119.00	720
Group 6	74.57	103.35	125.10	830
Group 7	76.35	101.12	123.60	755
Group 8	74.55	101.55	130.18	690
Group 9	75.68	89.46	121.37	765

3.1 Effect of test factors on PCECM fluidity

The effects of ultrafine composite powder dosage, silica fume dosage, and steel fiber aspect ratio on the flowability of PCECM are shown in Figures 3, 4, and 5.

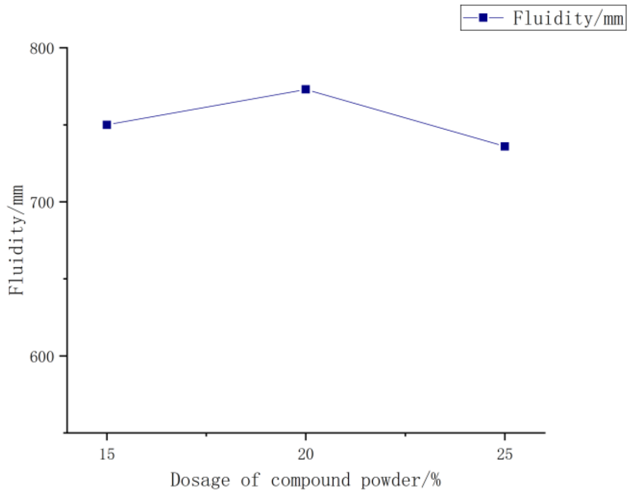

Figure 3: Effect of ultrafine composite powder dosage on flowability

From Figure 3, it can be seen that the flowability with the increase of ultrafine composite powder dosage shows a trend of increasing and then decreasing. For ultrafine composite powder, its form is round spherical particles, can be filled in between the cement particles, as a "ball" to play a lubricating effect, so as to improve the fluidity of the slurry [6]. When the dosage is higher than 20%, the fluidity begins to decline.

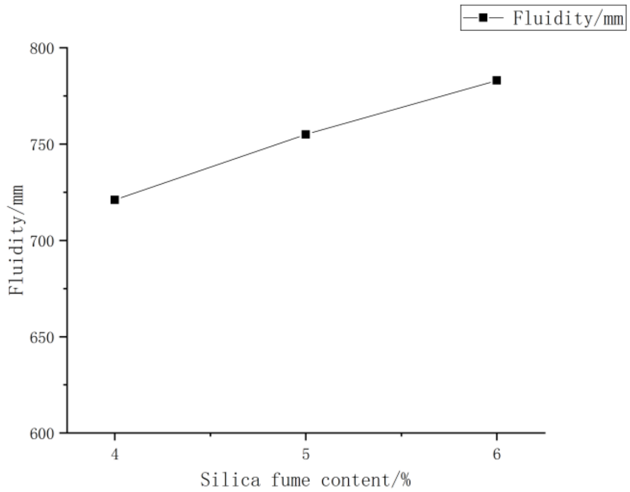

Figure 4: Effect of silica fume dosing on flowability

From Figure 4, it can be seen that the flowability has been increasing with the increase of silica fume dosage. This is because a small amount of silica fume plays the role of "ball" in the slurry, which effectively reduces the yield stress of the slurry, and produces a "composite water reduction effect" when silica fume is used together with high-efficiency water reducing agent [7]. Under the action of the water reducing agent, a layer of active substance is wrapped on the surface of silica fume, which generates electrostatic repulsion between silica fume particles and cement particles, and thus improves the fluidity of the slurry.

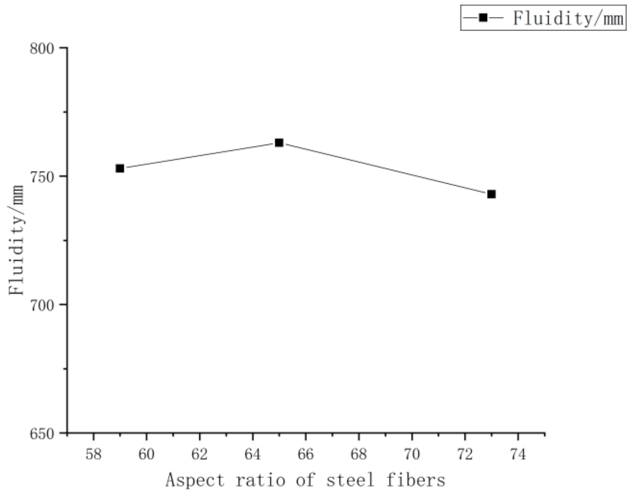

Figure 5: Effect of steel fiber length-to-diameter ratio on flowability

From Figure 5, it can be seen that the flowability shows a tendency to increase and then decrease with the aspect ratio of steel fibers. For steel fibers, the length of steel fibers in the mix increases with the increase of steel fiber aspect ratio, which leads to the increase of adhesion as well as friction between steel fibers and mix, so it has a greater effect on the extension resistance and makes the flowability decrease [7].

3.2 Effect of test factors on the compressive strength of PCECM

The effects of ultrafine composite powder dosage, silica fume dosage, and steel fiber aspect ratio on the compressive strength of PCECM are shown in Figures 6, 7, and 8.

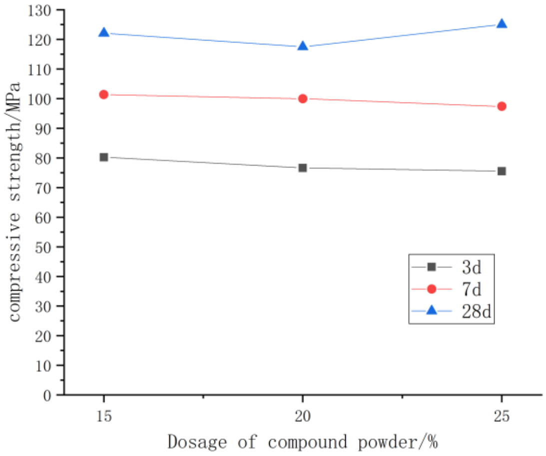

Figure 6: Effect of ultrafine composite powder dosage on compressive strength at different ages

As can be seen from Figure 6, for 3d, 7d compressive strength is reduced with the increase of ultrafine composite powder dosing, for 28d compressive strength, the later shows an increasing trend, which is because the ultrafine composite powder later mainly plays the role of volcanic ash activity. Volcanic ash reaction products in the role of cementation to provide strength at the same time can also play a role in filling the pore space, which is conducive to the improvement of strength.

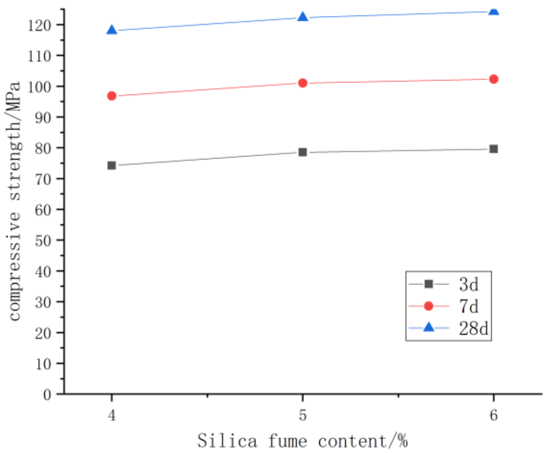

Figure 7: Effect of silica fume dosing on compressive strength at different ages

As can be seen from Figure 7, for different ages the compressive strength increases with the increase of silica fume doping. On the one hand, the volcanic ash effect of silica fume, its active ingredient SiO_2 can be with the cement hydration product $Ga(OH)_2$ secondary hydration reaction, generating high strength and high stability of low alkaline hydrated calcium silicate; On the other hand, the silica fume particles of small particle size, can maximize the filling to the pore space of the cement particles, improve the densification of the cementitious material, and then improve the strength.

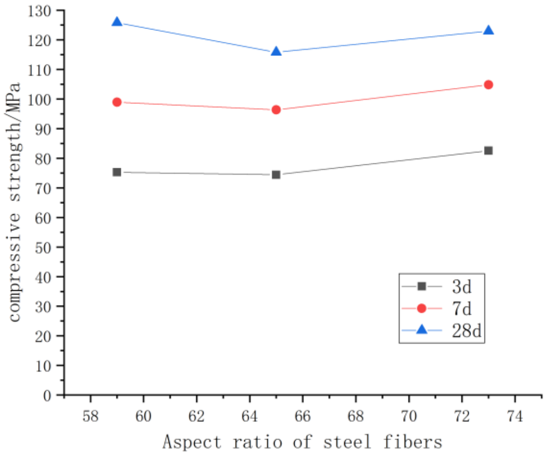

Figure 8: Effect of steel fiber length-to-diameter ratio on compressive strength at different ages

As can be seen from Figure 8, for different age compressive strength are with the increase of steel fiber L/D ratio shows a trend of first decrease and then increase. When the length is the same, the smaller the diameter of the steel fiber, the greater the L/D ratio, the same mixing ratio, the greater the number, the greater the total specific surface area of the steel fiber, the denser the internal network structure of steel fibers, further improving its compressive strength; but at the same time, it will have a certain effect on the material's denseness, so it will also be to a certain extent, the compressive strength of the material is reduced. But the dominant role is still the length of the steel fiber, generally speaking, the longer the length, the higher the compressive strength.

IV. CONCLUSION

Based on the orthogonal test, this paper obtained the trend and degree of influence of the dosage of ultrafine composite powder, silica fume dosage, and steel fiber diameter ratio on the flowability and 3, 7, 28d compressive strength of PCECM. The silica fume dosage has the greatest influence on the fluidity of PCECM, and the steel fiber aspect ratio has the greatest influence on the compressive strength. At 25% of ultrafine composite powder, 4% of silica fume, and 73 steel fiber aspect ratio, the dosage of silica fume can be minimized while ensuring excellent fluidity to prepare PCECM with suitable strength.

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