Study on the preparation and properties of new sleeve grouting material for prefabricated building

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Abstract. The control variable method was used to determine the reasonable amount of cementitious system, water reducing agent and early strength agent in the grouting material. Through orthogonal test, the effect of water-binder ratio, cement-sand ratio and desulfurized building gypsum content on the fluidity, compressive strength and vertical expansion rate of grouting material was studied. The experiment determined the optimal ratio of grouting material. The test results show that the main factor affecting the fluidity of grouting material is the cement-sand ratio; the main factor affecting the 1d and 3d compressive strength is the gypsum, and the main factor of the 28d compressive strength is the water-binder ratio; the main factor affecting the vertical expansion rate of 3h and 24h is the gypsum content. The optimal ratio of grouting material is: water-binder ratio of 0.23, cement-sand ratio of 1.0, the mass ratio of cement to mineral admixture is 4:1, polycarboxylate superplasticizer of 0.3%, calcium formate early strength agent of 0.7%, silicone defoamer of 0.2%, desulfurized building gypsum of 9%.

1. Introduction

Compared with traditional construction methods, concrete prefabricated buildings have many advantages such as stable component quality, safe construction process, increased labor productivity, and reduced life cycle costs. It is one of the architectural models that our country is currently vigorously developing[1-3]. The key to affecting the quality of concrete prefabricated buildings is the connection between the nodes of the structure. The "Technical Specification for Fabricated Concrete Structures" (JGJ 1-2014) recommends the use of reinforced sleeve grouting technology at the longitudinal connection of components. The performance of the grouting material is the key factor affecting the quality and force transmission performance of the joint, which directly determines the integrity and seismic resistance of the architectural structure system[4-6]. To this end, domestic experts and scholars have done a lot of research on how to improve the working performance, mechanical properties and volume stability of the grouting material. But the current research still has room for deepening, especially in the application of desulfurized building gypsum in the grouting material.

Incorporating industrial by-product desulfurization building gypsum into the grout is an effective way to prepare low-energy, low-cost, environmentally friendly grout.

The experiment adopts the controlled variable method to study the influence of the change of the amount of cementitious system, water reducing agent and early strength agent on the fluidity and compressive strength of the grout. And on this basis, use the principle of orthogonal design to optimize
the formula, study the influence of water-binder ratio, cement-sand ratio, and desulfurization building gypsum content on the fluidity, compressive strength and vertical expansion rate of the grouting material, and determine the optimal ratio of grouting material.

2. Test

2.1. Raw materials

(1) Cement: P·O 52.5 cement produced by a cement plant in Chongqing.

(2) Mineral admixtures: fly ash, slag powder and silica fume are selected in the test.

(3) Desulfurized building gypsum: hereinafter referred to as "gypsum", which is light yellow. See Table 1 and Table 2 for main chemical composition and physical performance indexes.

(4) Fine aggregate: quartz sand with fineness modulus of 2.4, particle size range of 0.08-2.36mm, and mud content less than 0.1%.

(5) Admixtures: polycarboxylate superplasticizer, calcium formate early strength agent and silicone defoamer are selected in the test.

Table 1. Chemical composition of gypsum /%

| Component | SO₃ | CaO | SiO₂ | MgO | Fe₂O₃ | Loss |
|-----------|-----|-----|------|-----|-------|------|
| Content   | 41.5| 32.9| 1.24 | 1.84| 0.15  | 15.78|

Table 2. Physical property indexes of gypsum

| Water consumption for standard consistency/% | Setting time/min | 2h/MPa | 7d/MPa |
|---------------------------------------------|------------------|--------|--------|
|                                             | Initial setting  | Final setting | Flexural strength | Compressive strength | Flexural strength | Compressive strength |
| 60                                          | 3                | 9      | 3.50   | 6.94   | 2.85   | 6.35   |

2.2. Test method

Fluidity and vertical expansion rate of grouting material: Test according to Appendix A and Appendix C in "Cementitious grout for sleeve of rebar splicing" (JG/T 408-2019).

Compressive strength test of grouting material: the test is conducted according to Appendix B in "Cementitious grout for sleeve of rebar splicing" (JG/T 408-2019) and “Method of testing cements--determination of strength” (GB/T 17671-1999).

3. Results and analysis

3.1. Single factor influence of raw materials on properties of grouting material

3.1.1. The influence of cementitious system on the workability and mechanical properties of grouting material. The cementitious system of grouting material is composed of cement and mineral admixtures. Mineral admixtures replace part of cement as a part of the cementitious system of grouting material, which can not only save resources, benefit environmental protection, meet the national energy saving and waste recycling policy, but also have the potential hydraulic properties and pozzolanic activity, which can effectively improve the performance of grouting material [7-8]. Based on the preliminary experimental research, the mineral admixture is composed of fly ash, slag powder and silica fume in a mass ratio of 1:1:1, and the effect of the cementitious system on the fluidity and compressive strength of the grouting material is studied. The grouting material were prepared with water-binder ratio of 0.25, cement-sand ratio of 0.96, water reducing agent of 0.25%, early strength agent of 1%, defoamer of 0.25%, and mineral admixture of 15%, 20%, 25% and 30% of the cementitious system.

It can be seen from Figure 1 that with the increase of the proportion of mineral admixtures in the cementitious system, the initial fluidity and 30min retention value of grouting material both increase at first and then decrease, and meet the requirements of specifications. This is because mineral
admixtures are spherical particles with smooth surface and large specific surface area. In the mixture of grouting material, the micro spherical body can play the role of lubrication and water locking, which is beneficial to increase and maintain the fluidity of grouting material. It can be seen from Figure 2 that as the proportion of mineral admixtures in the cementitious system increases, the 1d compressive strength of the grouting material decreases, and the 3d compressive strength first increases and then decreases, and both are lower than the full cement cementitious system. The 28d compressive strength also appears to increase first and then decrease, but it is higher than that of the full cement cementitious system in the range of 15%-25% by mass. It can be seen that the mineral admixture weakens the early compressive strength of grouting material, and in the later stage, the secondary reaction between the mineral admixture and the cement hydration product Ca(OH)₂ increases the amount of C-S-H gel in the system. At the same time, Ca(OH)₂ crystals are reduced, which is more conducive to the increase of the compressive strength of the grout.

Considering the fluidity and compressive strength of grouting material, the mass ratio of mineral admixture to cementitious system is determined to be 20%, that is, the mass ratio of cement to mineral admixture is 4:1.

3.1.2. The influence of water reducing agent on the workability and mechanical properties of grouting material. The amount of water reducing agent is a key factor affecting the fluidity and compressive strength of the grouting material. In the experiment, 530P polycarboxylate superplasticizer was selected to study its influence on the workability and mechanical properties of grouting material under different dosages. Based on the above experimental results, when the water-binder ratio is 0.25, the cement-sand ratio is 0.96, the mass ratio of cement to mineral admixture is 4:1, the early strength agent is 1%, and the defoamer is 0.25%, the influence of water reducing agent dosage on the relevant performance of grouting material is studied when its dosage is 0.1%, 0.3%, 0.5% and 1% of the cementitious system mass.

It can be seen from Figure 3 that with the increase of water reducing agent content, the initial fluidity and 30min retention value of grouting material show an increasing trend, and the range of 0.3% - 1% can meet the requirements of the specification. It can be seen from Figure 4 that with the increase of the amount of water reducing agent, the compressive strength of each age increases first and then slightly decreases, but they all meet the requirements of the specification. The compressive strength reaches the peak value when the dosage of water reducing agent is 0.3%. The compressive strengths of 1d, 3d and 28d are 45MPa, 75MPa and 104MPa respectively.

The test takes into account both the fluidity and compressive strength of grouting material, and considering the economy, it is determined that the content of the water reducing agent is 0.3% of the cementitious system mass.
3.1.3. The influence of early strength agent on the workability and mechanical properties of grouting material. Ordinary Portland cement itself does not have early strength properties. In order to meet the standard requirements for the early strength of grouting material, the early strength agent was added to improve the early strength of grouting material[10]. In the experiment, calcium formate organic early-strength agent was selected to study its influence on the workability and mechanical properties of the grout under different dosages. Based on the above experimental results, when the water-binder ratio is 0.25, the cement-sand ratio is 0.96, the mass ratio of cement to mineral admixture is 4:1, the water reducing agent is 0.3%, and the defoamer is 0.25%, the influence of early strength agent on the relevant performance of grouting material is studied when its dosage is 0.5%, 0.7%, 1% and 1.2% of the cementitious system mass.

It can be seen from Figure 5 that calcium formate early strength agent has a certain water reducing effect. With the increase of the early strength agent content, the initial fluidity and the 30min retention value of the grouting material increased slightly compared with the benchmark group, and both met the requirements of the specification. It can be seen from Figure 6 that the early strength agent can significantly improve the 1d and 3d compressive strength of grouting material. When the dosage is 0.7%, the compressive strengths of 1d and 3d are 50MPa and 78MPa respectively, which are increased by 56% and 20% sequentially compared with the benchmark group, while there is basically no effect on the 28d compressive strength of the grout. This is because calcium formate early strength agent can lower the pH value of the grouting system, promote the hydration of cement clinker C3S, and speed up the dissolution rate. At the same time, calcium formate can increase the concentration of Ca^{2+} in the system and accelerate the crystallization rate of cement, which is beneficial to increase the early strength of grouting material.

![Figure 3. Influence of water reducing agent on fluidity of grouting material](image1)

![Figure 4. Influence of water reducing agent on compressive strength of grouting material](image2)

![Figure 5. Influence of early strength agent on fluidity of grouting material](image3)

![Figure 6. Influence of early strength agent on compressive strength of grouting material](image4)
The test takes into account both the fluidity and compressive strength of grouting material, and considering the economy, it is determined that the content of the early strength agent is 0.7% of the cementitious system mass.

3.2. Determination of the mixing ratio of grouting material
The experiment adopts the principle of orthogonal design, and selects water-binder ratio, cement-sand ratio, and gypsum content as the research objects of orthogonal design. Through the systematic analysis of the orthogonal test data, the fluidity, compressive strength and vertical expansion rate under the action of three factors and three levels are studied to determine the optimal combination of grouting material. Based on the above test results, the reference mix ratio of grouting material is shown in Table 3, the design factors and levels of the orthogonal test are shown in Table 4, and the mean value and range analysis of the orthogonal test results are shown in Table 5.

It can be seen from Table 5 that the initial fluidity and the 30min retention value of grouting material exceed 300mm and 260mm at all levels of water-binder ratio, cement-sand ratio, and gypsum content, meeting the specification requirements. Therefore, the compressive strength and vertical expansion rate of the grouting material at different ages are mainly taken as the research objects in the mean and range analysis of orthogonal test results. By comparing the magnitude of the range of each factor, we can see that: The water-binder ratio has the greatest influence on the 28d compressive strength, followed by the 1d and 3d compressive strength, and the smallest influence on the 3h and 24h vertical expansion rate, and the A1 level is the best. The cement-sand ratio has the smallest impact on the compressive strength of the three ages, and the impact on the vertical expansion rate of 3h and 24h is the second. Taking into account the values of various indicators, it is recommended that the cement-sand ratio be set to B2. Except for the second impact on the 28d compressive strength, the content of gypsum is the most influential factor for other indicators, and most of the indicators have better effects when the C3 level is taken. However, during the test, it was found that when the gypsum content was C3 level, the hardened body of grouting material had slight cracking phenomenon. Therefore, it is not recommended that the content of gypsum is too high, and C2 level is the best.

By comprehensively analyzing the influence of the above three factors on the fluidity, compressive strength and vertical expansion rate of grouting material, the final mix ratio of grouting material is obtained as follows: water-binder ratio of 0.23, cement-sand ratio of 1.0, the mass ratio of cement to mineral admixture is 4:1, water reducing agent of 0.3%, early strength agent of 0.7%, defoamer of 0.2%, gypsum of 9%.
Table 5. Mean and range analysis of orthogonal test results

| Number | Initial fluidity/mm | 30min fluidity retention value/mm | Compressive strength/MPa | Vertical expansion rate/% |
|--------|---------------------|-----------------------------------|--------------------------|--------------------------|
|        | A                   | B                                 | C                        | A                        | B                        | C                        | A                        | B                        | C                        | A                        | B                        | C                        | A                        | B                        | C                        | A                        | B                        | C                        |
| k1     | 335.56              | 332.40                            | 338.42                    | 320.12                   | 316.78                   | 317.83                   | 53.61                    | 51.80                    | 53.68                    | 81.00                    | 78.72                    | 80.42                    | 108.35                   | 106.85                   | 106.37                   | 0.089                    | 0.090                    | 0.089                    |
| k2     | 338.60              | 346.72                            | 341.91                    | 323.42                   | 327.77                   | 324.60                   | 50.46                    | 54.67                    | 60.50                    | 80.24                    | 79.27                    | 81.74                    | 105.73                   | 108.15                   | 107.86                   | 0.054                    | 0.056                    | 0.051                    |
| k3     | 346.73              | 350.89                            | 336.21                    | 326.90                   | 339.56                   | 334.23                   | 48.01                    | 50.34                    | 58.22                    | 79.50                    | 79.53                    | 83.98                    | 103.36                   | 105.99                   | 109.24                   | 0.052                    | 0.052                    | 0.062                    |
| R      | 11.17               | 18.49                             | 5.70                      | 6.78                     | 22.78                    | 16.40                    | 5.60                     | 4.33                     | 4.32                     | 1.53                     | 0.81                     | 5.46                     | 1.99                     | 2.36                     | 2.87                     | 0.007                    | 0.011                    | 0.020                    |

Primary and secondary order: B > A > C, B > C > A, C > A > B, C > A > B, A > C > B, C > B > A

Optimal combination: A3B3C2, A3B3C3, A1B2C2, A1B3C3, A1B2C3, A1B3C3

Note: ki is the average value of the index, and R is the range.

4. Conclusion

(1) When the grouting material has a fixed content of cement, mineral admixtures, water reducing agent, early strength agent and defoamer, the main factor affecting the fluidity is cement-sand ratio; the main factor affecting the 1d and 3d compressive strength is desulfurized building gypsum, while the main factor affecting 28d compressive strength is water-binder ratio; the main factor affecting the vertical expansion rate of 3h and 24h is desulfurized building gypsum.

(2) The test takes into account the fluidity, compressive strength and economy of grouting material, the optimal mixing ratio is determined as follows: water-binder ratio of 0.23, cement-sand ratio of 1.0, the mass ratio of cement to mineral admixture is 4:1, polycarboxylate superplasticizer of 0.3%, calcium formate early strength agent of 0.7%, silicone defoamer of 0.2%, desulfurized building gypsum of 9%.

(3) Desulfurized building gypsum has no obvious effect on the workability of grouting material, but it has a great improvement on the early compressive strength and 3 h, 24 h vertical expansion rate of grouting material.

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