Experimental Study On Properties Of High-Early-Strength Cementitious Grout

S M Huang¹, W Zhu¹, L L Yu¹, S Zhang³, D H Lu²

¹ Guangzhou Testing Centre of Construction Quality & Safety Co., Ltd., 833 Baiyun Avenue North, Guangzhou, 510440, China
² Guangzhou Construction Engineering Co., Ltd. 4 Guangwei Road, Guangzhou, 510030, China
³ Guangzhou Institute of Building Science Co., Ltd. 833 Baiyun Avenue North, Guangzhou, 510440, China

* Corresponding author. E-mail: wenzi311@163.com

Abstract. This paper studied the influences of mineral admixture content on the fluidity, compressive strength and vertical expansion rate of the cementitious grout, which based on a ternary composite cementitious material system of sulfoalminate cement, portland cement and gypsum. The influences of fly ash, slag powder and silica fume were investigated respectively. It was shown that: (1) The initial fluidity grew as the addition of fly ash content in the cementitious grout, 1 d compressive strength and 3 d compressive strength were reduced. (2) The slag powder had great impact on the fluidity, when the content of slag powder more than 18%, initial and 30 min fluidities declined. With the slag powder increased, 1 d, 3 d and 28 d compressive strengths decreased slightly, while 3 h vertical expansion rate increased. (3) The increased of silica fume content made the compressive strengths rised first and then fell. 1 d, 3 d and 28 d compressive strengths could reach their maximum values, when the amount of silica fume was 3.0%.

1. Introduction
Precast concrete structure is a type of structure composed of prefabricated components and the connections between them. It has been rapidly promoted and widely used in China, due to its advantages of highly industrialized level, fast construction speed and excellent overall performance. Currently, grouting coupler has been usually used as a connection technology in the construction of the precast concrete structure, which could enhance the ability to absorb the energy at the joint among components, relieve the stress concentration, and improve the construction efficiency, compared with traditional connection technology (welded connection and bolt connection). The behavior of the cementitious grout is the main guarantee for the reliability of grouting coupler connection technology, and it also plays a significant role in structure safety and durability simultaneously[1-3].

The grouting material for reinforcement splicing sleeve is a dry powdery mixture composed of cement, fine aggregate, chemical admixture, etc. It should have good fluidity, high-early strength, and micro expansion after mixing with water[4,5]. And then the mixture could be used as the gap filler between the sleeve and ribbed bars. However, the cementitious grout used in practical construction usually has problems such as poor fluidity, large loss of fluidity, low early compressive strength and...
volume shrinkage, which is difficult to meet the requirements of grouting coupler connection, also restricts the development of precast concrete structure.

In this regard, this paper seeks to optimize the mix ratio of the cementitious grout by adjusting the dosage of fly ash, slag powder and silica fume to improve the fluidity, mechanical properties and vertical expansion rate of the grouting material, based on a ternary composite cementitious material system of sulfoaluminate cement, portland cement and gypsum. Finally, an optimal mixing amount of fly ash, slag powder and silica fume is obtained.

2. Experimental Program

2.1. Materials

P.II 42.5 cement (portland cement according to Chinese standards) is from Yingde Conch Cement Co., Ltd., of which the chemical composition and physical parameters are shown in Table 1 and Table 2. A commercial sulfoaluminate cement is produced by Tangshan Polar Bear cement Co., Ltd. with the oxide composition and physical properties being listed in Tables 3 and 4. The mineral admixtures, S95 slag powder, fly ash and silica fume, are provided by Tangshan Caofeidian Dun Shi New Building Materials Co. Ltd. The performances of slag powder is shown in Table 5. The sodium gluconate as a retarder is from Beijing Chemical Works Co., Ltd. The polycarboxylate superplasticizer is provided by Sica Co., Ltd. In order to eliminate bubbles caused by SP during the process of mixing, the defoamer tributyl phosphate (TBP) is applied, which is also supplied by Sica Co., Ltd.

| Table 1. Chemical composition of portland cement. |
|-----------------------------------------------|
| Composition | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | other |
| Proportion (%) | 22.77 | 5.58 | 3.71 | 58.84 | 1.98 | 2.20 | 0.23 | 0.36 | 2.31 |

| Table 2. Physical parameters of portland cement. |
|-----------------------------------------------|
| Setting time (min) | Compressive strength (MPa) | Flexural strength (MPa) |
| Initial | Final setting | 3 d | 28 d | 3 d | 28 d |
| 187 | 231 | 27.3 | 51.9 | 5.6 | 9.1 |

| Table 3. Chemical composition of sulfoaluminate cement. |
|-----------------------------------------------|
| Composition | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | other |
| Proportion (%) | 8.94 | 26.12 | 2.51 | 45.73 | 3.73 | 11.96 | 2.09 | 0.50 | 0.78 |

| Table 4. Physical parameters of sulfoaluminate cement. |
|-----------------------------------------------|
| Setting time(min) | Compressive strength (MPa) | Flexural strength (MPa) |
| Initial | Final setting | 3 d | 28 d | 3 d | 28 d |
| 7 | 39 | 44.3 | 50.4 | 7.4 | 8.7 |

| Table 5. Chemical composition of slag powder. |
|-----------------------------------------------|
| Composition | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | K₂O | Na₂O | other |
| Proportion (%) | 34.16 | 15.21 | 1.71 | 36.08 | 10.2 | 0.58 | 0.41 | 1.65 |

2.2. Experimental methods

The fluidity, mechanical properties, and vertical expansion rate of the cementitious grout with different contents of fly ash, slag, and silica fume were tested in this study. Experiments were conducted according to Chinese standard "Cementitious grout for coupler of rebar splicing" JG/T 408-2013[4].

In order to study the optimum amount of fly ash in the cementitious grout, the mix ratios of fly ash were set at 3%, 6%, 9%, 12% and 15%, meanwhile the binder/sand and water/binder ratios were maintained at 0.8 and 0.24, respectively. Proportions of the compositions in the grouting material are shown in Table 6.
Table 6. Test matrix (different fly ash contents) (w%).

| Number | F-3  | F-6  | F-9  | F-12 | F-15 |
|--------|------|------|------|------|------|
| Portland Cement | 56.80 | 54.40 | 52.00 | 49.60 | 47.20 |
| Sulphoaluminate cement | 14.20 | 13.60 | 13.00 | 12.40 | 11.80 |
| Gypsum | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Slag powder | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| **Fly ash** | **3.00** | **6.00** | **9.00** | **12.00** | **15.00** |
| Silica fume | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Superplasticizer | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Defoamer | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Expansion agent | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Sodium gluconate | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |

The effect of slag powder on properties of cementitious grout were studied in this experiment. The mix ratios of the slag powder in the designed cementitious grout were 12%, 15%, 18%, 21%, and 24%, respectively, with the binder/sand ratio being 1.2, and water/binder ratio being 0.22. The compositions are listed in Table 7.

Table 7. Test matrix (different slag powder contents) (w%).

| Number | K-12  | K-15  | K-18  | K-21  | K-24  |
|--------|-------|-------|-------|-------|-------|
| Portland cement | 60.80 | 58.40 | 56.00 | 53.60 | 51.20 |
| Sulphoaluminate cement | 15.20 | 14.60 | 14.00 | 13.40 | 12.80 |
| Gypsum | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **Slag powder** | **12.00** | **15.00** | **18.00** | **21.00** | **24.00** |
| Fly ash | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| Silica fume | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Superplasticizer | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Defoamer | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Expansion agent | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Sodium gluconate | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |

In this part, the binder/sand and water/binder ratios were kept at 0.8 and 0.24, respectively, while the proportions of silica fume ranged from 1% to 10%. Table 8 gives the mix ratios.

Table 8. Test matrix (different silica fume contents) (w%).

| Number | G-1  | G-3  | G-5  | G-7  | G-10 |
|--------|------|------|------|------|------|
| Portland cement | 56.00 | 54.40 | 52.80 | 51.20 | 48.80 |
| Sulphoaluminate cement | 14.00 | 13.60 | 13.20 | 12.80 | 12.20 |
| Gypsum | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Slag powder | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| Fly ash | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| **Silica fume** | **1.00** | **3.00** | **5.00** | **7.00** | **10.00** |
| Superplasticizer | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Defoamer | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Expansion agent | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Sodium gluconate | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |

3. Experimental results and discussions

3.1. Influence of fly ash on the performance of cementitious grout
In this part, the performances of cementitious grouting material were optimized by adjusting the content of fly ash, and the test results are listed in Table 9.

**Table 9.** Test results of the cementitious grout with different fly ash contents.

| Test parameters                  | F-3  | F-6  | F-9  | F-12 | F-15 |
|----------------------------------|------|------|------|------|------|
| Fluidity (mm)                   | initial          | 320  | 319  | 326  | 330  | 333  |
|                                  | 30 min          | 227  | 250  | 302  | 288  | 297  |
| Compressive strength (MPa)      | 1 d             | 46.7 | 38.4 | 37.3 | 38.1 | 34.3 |
|                                  | 3 d             | 72.2 | 71.5 | 69.1 | 69.8 | 68.5 |
|                                  | 28 d            | 105.3| 109.9| 110.2| 107.4| 103.2|
| 3 h vertical expansion rate (%) | 0.068           | 0.057| 0.061| 0.048| 0.116| 0.116|
| Difference between expansion rates of 24 h and 3 h (%) | 0.068 | 0.072 | 0.177 | 0.144 | 0.126 |

As can be seen in Table 9, the initial fluidity grew as the increasing of fly ash content. However, the 30 min fluidity increased first and then decreased. The micromorphology of fly ash is a spherical glass body with a smooth surface, which can reduce the friction between fine aggregate and the grout, also known as the effect of ball lubrication\(^6,7\), so to increase the fluidity. However, when the fly ash was overused, the slurry amount increased significantly due to the low density of the fly ash, wrapped around the surface of the fine aggregate, then the lubricating film became thicker, which resulted in the decay of 30 min fluidity of cementitious grout.

With the increase of fly ash content, 1 d compressive strength and 3 d compressive strength of the cementitious grout were reduced in different degrees. While the 28 d compressive strength was increased, in the case that the fly ash is less than 9%. Fly ash contains some vitreous, and its main component is active silica, which participates in the later period of hydration reaction. Also, it can be seen from Table 9, the variation laws of the 3 h vertical expansion rate and difference between expansion rates of 24 h and 3 h of the cementitious grout were not obvious.

### 3.2. Influence of slag powder on the performance of cementitious grout

It can be seen from Table 10, that with the increase of the slag powder content, the initial fluidity and 30 min fluidity of the cementitious grout both grew initially and then experienced a drop. Fluidity of cementitious grout depends on its yield stress to some extent. A certain amount of slag powder can reduce the yield stress of the grouting material significantly, so as to improve the fluidity. In addition, the particle size of slag powder is smaller than that of cement, and the roundness of the former is larger, which induces a lubricating effect that can increase the fluidity. However, when the content of the slag powder was more than 18%, initial fluidity and 30 min fluidity diminish with the addition of slag powder. As the slag powder content reached 24%, initial fluidity and 30 min fluidity were 352 mm and 287 mm, respectively. The large specific surface area of the slag powder leads to an increasing demand of water in the cementitious grout, which also affects the fluidity negatively.

**Table 10.** Test results of cementitious grout with different slag powder contents.

| Test parameters                  | K-12 | K-15 | K-18 | K-21 | K-24 |
|----------------------------------|------|------|------|------|------|
| Fluidity (mm)                   | initial          | 359  | 361  | 363  | 356  | 352  |
|                                  | 30 min          | 287  | 283  | 319  | 258  | 287  |
| Compressive strength (MPa)      | 1 d             | 53.0 | 49.7 | 47.8 | 48.7 | 46.9 |
|                                  | 3 d             | 76.0 | 80.3 | 74.7 | 76.1 | 75.2 |
|                                  | 28 d            | 110.3| 109.1| 108.2| 108.2| 102.6|
| 3 h vertical expansion rate (%) | 0.081           | 0.080| 0.089| 0.109| 0.143| 0.167|
| Difference between expansion rates of 24 h and 3 h (%) | 0.150 | 0.082 | 0.095 | 0.224 | 0.167 |

With the increase of the slag powder content, 1 d compressive strength, 3 d compressive strength and 28 d compressive strength decreased slightly, while 3 h vertical expansion rate increased. When
the content was 24%, 3 h vertical expansion rate had the maximum value of 0.143%. Slag powder is an active admixture because of its active ingredients such as SiO₂, Al₂O₃ and CaO, which can react with the hydration product (Ca(OH)₂) to form hydrated calcium silicate product, filling in the porosity of the cementious material. However, a large amount of slag powder could dilute the volume ratio of the hydration product in the cementitious system. Therefore, as the slag powder content increased, 1 d compressive strength, 3 d compressive strength and 28 d compressive strength of the grouting material reduced.

3.3. Influence of silica fume on the performance of cementitious grout

Properties of the grouting materials with different silica fume contents were obtained at table 11. As the results show, with the increase of the silica fume content, the initial fluidity and 30 min fluidity decreased similarly. The reason could be that when the mix ratio of silica fume was low, water between the cement particles could be squeezed out, due to filling effect of the silica fume, which could improve the fluidity. Meanwhile, the micro particles of silica fume can adsorb polycarboxylate superplasticizer molecules. Under the synergistic effect of polycarboxylate superplasticizer molecules, the double electric layer potential formed on the particle surface could generate electrostatic repulsion, which is beneficial to the dispersion of cementitious material. In addition, the dispersion of silica fume contributes to the dispersion of cement particles, which is good for fluidity[2, 8-9]. Besides, silica fume has smaller particle size, and plays a role of ball lubrication in cement materials, which could also improve the fluidity. However, excessive incorporation of silica fume could cause the growth of specific surface area of cementitious material, making a high water demand, also increasing the viscosity of the cementitious material, which is the reason for the decline of fluidity.

Table 11. Test results of cementitious grout with different silica fume contents.

| Test parameters       | G-1  | G-3  | G-5  | G-7  | G-10 |
|-----------------------|------|------|------|------|------|
| Fluidity (mm)         | initial | 356 | 350 | 323 | 329 | 313 |
|                       | 30 min | 303 | 297 | 234 | 225 | 215 |
| Compressive strength (MPa) | 1 d  | 37.0 | 38.5 | 35.5 | 30.1 | 27.6 |
|                       | 3 d  | 66.9 | 68.9 | 68.5 | 62.4 | 57.5 |
|                       | 28 d | 107.1 | 110.8 | 108.9 | 102.1 | 100.6 |
| 3 h vertical expansion rate (%) | 0.069 | 0.318 | 0.023 | 0.022 | 0.107 |
| Difference between expansion rates of 24 h and 3 h (%) | 0.010 | 0.422 | 0.046 | 0.047 | 0.005 |

As silica fume ratio increased, 1 d compressive strength and 3 d compressive strength both risen first and then fell. When the content of silica fume was 3%, the 1 d, 3 d and 28 d compressive strengths reached their maximum values, which were 38.5 MPa, 68.9 MPa, and 110.8 MPa, respectively. Moreover, the 3h vertical expansion rate and the difference between expansion rates of 24 h and 3 h also went up at the beginning and drop afterwards. Silica fume with small particle size, plays the role of filler in the grout, reduces porosity of it after hydration reactions, makes the cementitious material more dense, and improves the compactness and mechanical strength of the hardened grout[10-12]. Furthermore, in the case of overuse, it is not easy for silica fume to disperse uniformly because of its large specific surface area, which may induce surface float and result in the decrease of the compressive strength.

4. Conclusion

This paper investigated the effect of mineral admixtures on the fluidity, mechanical properties and vertical expansion rate of cementitious grout, based on the ternary composite cementitious material system of sulfoalminate cement, protland cement and gypsum. From the previous experimental results, the following conclusions could be made:

1) Generally, the initial fluidity increases along with fly ash content in the grouting material. As fly ash content increases, 1 d compressive strength and 3 d compressive strength of the cementitious
grout are reduced in different degrees, while the 28 d compressive strength increases, in the case that the fly ash is less than 9%.

2) Slag powder has a significant impact on the fluidity of grout. When the ratio of slag powder in the cementitious grout increases and even exceeds 18%, the initial and 30 min fluidities decline. As the slag powder increases, 1 d, 3 d and 28 d compressive strengths all shrink slightly, while 3 h vertical expansion rate increases.

3) The initial and 30 min fluidities decrease with the increasing silica fume ratio. The increase of silica fume content makes the compressive strengths rise first and then falls. When the content of silica fume is 3%, the 1 d, 3 d and 28 d compressive strengths could reach their maximum values.

Acknowledgements
The research reported was financially supported by China Postdoctoral Science Foundation (No. 2020M672584), Guangzhou Science and Technology Project (Grant No. 201902010072) and Science and Technology Project of Guangzhou Municipal Construction Group Co., Ltd. (Grant No. [2019]-KJ022, [2019]-KJ024). The financial supports are highly appreciated.

References
[1] Zhu W, Huang S M and Gao Z X 2017 Guangzhou Architecture Research status and development trend of the rebar sleeve grouting materials for prefabricated concrete strture 45 22-26
[2] Wang X S, Yang Z L and Wu Z X 2015 China Concrete and Cement Products Experimental research on performance of high-strong cementitious grouting for prefabricated concrete structures 65-68
[3] Anonymous. Standard GB/T 51231-2016. Technical Standard for assembled buildings with concrete structure. Press in China, 2017
[4] Anonymous. Standard JGJ 355-2015. Technical specification for grout sleeve splicing of rebars. Press in China, 2015
[5] Anonymous. Standard JG/T 408-2013. Cementitious grout for coupler of rebar splicing. Press in China, 2013
[6] Huang W R and Guo G X 2015 Concrete Dosage of fly ash on properties of C30 self-compacting concrete 4 119-122
[7] Liu X M The influence of admixture on the performance of self compacting concrete, Kunming University of Science and Technology, 2019, Master Thesis
[8] Dong J J Development and properties of high performance cementitious grout coupler, Hefei University of Technology, 2016, Master Thesis
[9] Huang S M, Zhu W and Wang Y Y 2019 New Building Materials Preparation and properties of high performance cementitious grout for prefabricated concrete structure 46 10-13
[10] Li J Q, Xu H S, Xie H B and Li G Z 2006 Bulletin of the Chinese Ceramic Society Microstructural Investigation of Silica Fume Modified Cement/Lime Mortar 25 66-70
[11] Guo Y Z, Li P Y and Li Q Y 2008 Concrete Performance comparation between micron-sized super-fine slag powder and siliceous dust 10 67-69
[12] Ma B G, Han L, Zhu Y C and Tian Z 2014 New Building Materials Impact of mineral admixture on the performance of sulphate aluminum cement 41 19-21