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Study on the preparation of cementitious grout for grout sleeve splicing of rebars based on a ternary composite material system

Wen Zhu[1], Shiming Huang[3,a,*], Shuo Zhang[1], Jiang Wu[1], Kun Luo[3], Mengxiong Tang[2]

[1] Guangzhou Institute of Building Science Co., Ltd. Guangzhou, 510440, China

[2] Guangzhou Construction Engineering Co., Ltd. Guangzhou 510030, China

[3] Guangzhou Testing Centre of Construction Quality & Safety Co., Ltd. Guangzhou, 510440, China

[3,a,*] huangshiming123@163.com

Abstract. In this study, through orthogonal experiments, a ternary composite material system of sulfoaluminate cement, Portland cement and gypsum with optimal proportions was developed for preparing cementitous grout for rebar sleeve splicing. The main factors affecting the performances of the grout were investigated. Also, the influences of water/binder ratio, Portland cement/sulphoaluminate cement ratio and gypsum content on the properties of the grout were studied. The experimental results show that: (1) The factors affecting the fluidity and compressive strength of the cementitious grout in order that from significant to non-significant were water/binder ratio, Portland cement/sulphoaluminate cement ratio and gypsum content. (2) To obtain comprehensive properties of good compressive strength and fluidity, it seems that the optimal ratio of the Portland cement to sulphoaluminate cement is 8:2. At this ratio, 1d compressive strength and 3d compressive strength were 35.7 MPa, 61.7 MPa, respectively, and the initial fluidity was 335 mm. (3) Gypsum is the main factor affecting the vertical expansion rate of the cementitious grout among the factors studied. The compressive strength and vertical expansion rate of cementitious grout both grew as the increase of gypsum content (from 0% to 3%), but the compressive strength experienced a drop, when the gypsum content even exceeds 3%.

Keywords: Cementitious grout; Portland cement/sulphoaluminate cement ratio; fluidity; gypsum; vertical expansion rate.

1. Introduction

The cementitious grout for grout sleeve splicing of rebars is a dry powdery mixture composed of cement, chemical admixture, fine aggregate, etc. It should have high-early strength, micro expansion and good fluidity after mixing with water[1-3]. Then the mixture as connecting material between sleeve and ribbed bars is the key to the quality and reliability of the connection in prefabricated concrete construction[4,5]. However, the cementitious grout used in practical construction usually has some problems such as low early mechanical strength, volume shrinkage, poor fluidity and large loss of fluidity, which is difficult to meet the requirement of grouting coupler connection, also restricts the development of precast concrete structures[3]. What`s more, the complexity of raw materials and admixtures can lead to unstable performance and high production costs[6-8], that is difficult to meet the requirement of economic benefits and performance.

In response to the problems of cementitious grout, this paper used a ternary composite material system of Portland cement, sulfoaluminate cement and gypsum to prepare the cementitious grout with high performance by orthogonal experiments, and optimized its components and properties. Also, the effect of water/binder ratio, Portland cement/sulphoaluminate cement ratio and gypsum content on performances of the cementitious grout were researched.

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2. Experimental Program

2.1 Materials

P.O 42.5R cement (Portland Cement according to Chinese standards) is produced by Yingde Conch Cement Co., Ltd., and the sulphoaluminate cement is from Tangshan Polar Bear cement Co., Ltd, of which the chemical composition are shown in Table 1. The sodium tetra borate, lithium carbonate and sodium gluconate as modifier are provided by Beijing Chemical Works Co., Ltd. And the super-plasticizer (SP) is from Sica Co., Ltd. The white silicone powder is used for remove bubbles generated by SP during the mixing process, which is also from Sica Co., Ltd.

Table 1. Chemical composition of cement (%)

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	other
Portland Cement	22.77	5.58	3.71	58.84	1.98	2.20	0.23	0.36	2.31
Sulfoaluminate cement	8.94	26.12	2.51	45.73	3.73	11.96	2.09	0.50	0.78

2.2 Experimental methods

In this study, mechanical properties, vertical expansion rate and fluidity of cementitious grout were tested according to Chinese standard "Cementitious grout for coupler of rebar splicing" JG/T 408-2019[1].

In order to obtain the cementitious grouting ratio, orthogonal experiments were devised with three levels of three factors, which were water/binder ratio, Portland cement/sulphoaluminate cement ratio and gypsum content. And the binder/sand ratio was 1.0, water reducer was 0.8%, silicone powder was 0.05%.The tests mix ratios of three levels of three factors were shown in Table 2, and the orthogonal experiments were shown in Table 3.

This research seeked to optimize the mix ratio of Portland cement/sulphoaluminate cement, the mix ratios of Portland cement/sulphoaluminate cement in the designed were 10:0, 8:2, 6:4, 4:6, 2:8 and 0:10, respectively, with water/binder ratio was 0.26, and binder/sand ratio was 1.0.

Table 2. Orthogonal experimental factors and level

Level	Factor A	Factor B	Factor C
	Portland cement/sulphoaluminate cement ratio	water/binder ratio	gypsum content
1	25:75	0.26	1%
2	50:50	0.28	4%
3	75:25	0.30	7%

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Table 3. The orthogonal experiments

NO.	Combination	Factor A	Factor B	Factor C
		Portland cement/sulphoaluminate cement ratio	water/binder ratio	gypsum content
CG-1	$A_1B_1C_1$	25:75	0.26	1%
CG-2	$A_1B_2C_2$	25:75	0.28	4%
CG-3	$A_1B_3C_3$	25:75	0.30	7%
CG-4	$A_2B_1C_2$	50:50	0.26	4%
CG-5	$A_2B_2C_3$	50:50	0.28	7%
CG-6	$A_2B_3C_1$	50:50	0.30	1%
CG-7	$A_3B_1C_3$	75:25	0.26	7%
CG-8	$A_3B_2C_1$	75:25	0.28	1%
CG-9	$A_3B_3C_2$	75:25	0.30	4%

The gypsum plays an important role in cementitious materials, also has an great impact on the strength and vertical expansion rate of the grout. In the third part of experiments, the water/glue ratio was 0.26, binder/sand ratio was 1.0, and the Portland cement/sulphoaluminate cement was 8:2, the mix ratios of the grout were designed with different gypsum content of 0%, 1%, 3%, 5%, and 7%.

3. Experimental Results and Discussions

3.1 Research on the cementitious grout mix proportion

In this part, the grout mix proportion were obtained by orthogonal experiments, and the results of orthogonal experiments were shown in Table 4, and the average value and range value of the results of orthogonal tests were listed in Table 5, Table 6, and Table 7, respectively.

Table 4. Results of orthogonal test

NO.	Fluidity (mm)		Compressive Strength (MPa)			Vertical expansion rate (%)	
	initial	30min	1d	3d	28d	3h	24h
CG-1	315	283	40.2	73.8	94.7	0.049	0.108
CG-2	337	308	33.7	61.5	86.8	0.068	0.129
CG-3	354	315	29.5	56.3	81.7	0.083	0.151
CG-4	321	289	35.2	70.4	97.4	0.058	0.131
CG-5	344	312	30.4	58.9	89.1	0.072	0.139
CG-6	359	318	25.3	54.7	84.2	0.044	0.111
CG-7	326	292	36.3	64.6	95.6	0.064	0.142
CG-8	345	309	32.7	56.9	90.7	0.039	0.098
CG-9	364	321	27.4	51.8	85.4	0.051	0.101

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Table 5. Average value and range value of fluidity test results

Level	Initial fluidity (mm)			30min fluidity (mm)		
	A	B	C	A	B	C
1	335.3	320.7	339.7	302.0	288.0	303.3
2	341.3	342.0	340.7	306.3	309.7	306.0
3	345.0	359.0	341.3	307.3	318.0	306.3
Range	9.7	38.3	1.7	5.3	30.0	3.0

Table 6. Average value and range value of compressive strength test results

Level	1d compressive strength (MPa)			3d compressive strength (MPa)			28d compressive strength (MPa)		
	A	B	C	A	B	C	A	B	C
1	34.5	37.2	32.7	63.9	69.6	61.8	87.7	95.9	89.9
2	30.3	32.3	32.1	61.3	59.1	61.2	90.2	88.9	89.9
3	32.1	27.4	32.1	57.8	54.3	59.9	90.6	83.8	88.8
Range	4.2	9.8	0.7	6.1	15.3	1.9	2.8	12.1	1.1

Table 7. Average value and range value of vertical expansion rate test results

Level	3h vertical expansion rate (%)			24h vertical expansion rate (%)		
	A	B	C	A	B	C
1	0.067	0.057	0.044	0.129	0.127	0.106
2	0.058	0.060	0.059	0.127	0.122	0.120
3	0.051	0.059	0.073	0.114	0.121	0.144
Range	0.015	0.003	0.029	0.016	0.006	0.038

It can be seen from Table 5 and Table 6, the range value of factor B (water/glue ratio) was greater than the factor A`s, and greater than the factor C`s. So the ratio of water/glue was the main factor affecting the fluidity and compressive strength of the grouting material, and followed by Portland cement/sulphoaluminate cement ratio and gypsum content. As shown in Table 7, the range value of factor C was the largest of the studied factors, that meaned gypsum content had the greatest impact on the vertical expansion rate of the grout. Therefore, the primary and secondary factors affecting the fluidity and the compressive strength of the grouting material were the water/glue ratio, Portland cement/sulphoaluminate cement ratio and gypsum content. And The factors affecting the vertical expansion rate of the cementitious grout in order that from significant to non-significant were gypsum content, Portland cement/sulphoaluminate cement ratio and water/glue ratio.

Taking into account the compressive strength, fluidity, vertical expansion rate, and cost of the grouting material, factor B adopted level 1, factor A adopted level 3, and factor C adopted level 2. So, the original mix ratio of the cementitious grout were get, which was shown in Table 8.

Table 8. The matrix of cementitious grout (w%)

Water/glue ratio	Binder/sand	Cementitious material			Admixture	
		Portland cement	sulphoalu-minate cement	gypsum	super-plasticizer	silicone powder
0.26	1.0	53.2	17.8	4	0.8	0.05

3.2 Influence of Portland cement/sulphoaluminate cement ratios on the performance of cementitious grout

As can be seen from Figure.1, 1d and 3d compressive strength grew as the increase of sulphoaluminate cement content. While the 28d compressive strength declined initially and then

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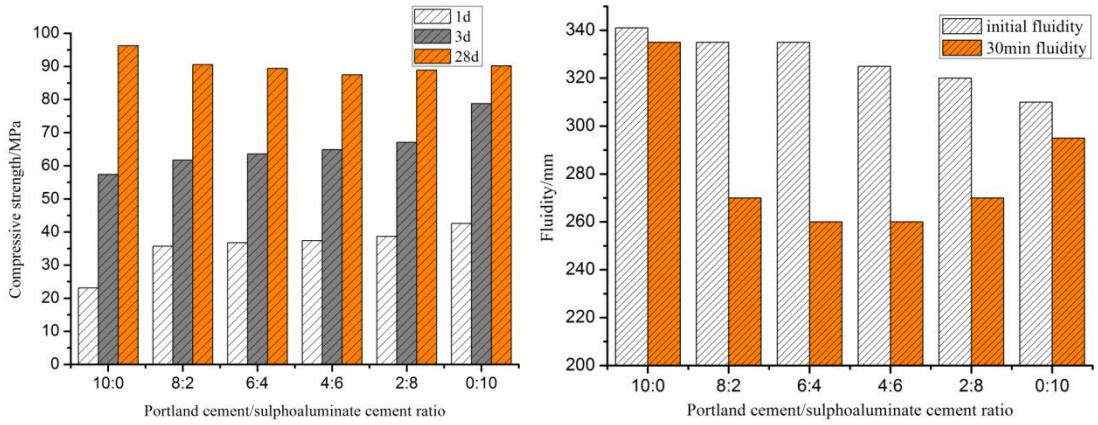
experienced a rise. The sulphoaluminate cement had high early hydration activity and fast hydration rate, that created a large amount of ettringite interlaceing each other in the cement paste to form a crystal frame (as shown in Figure.2), which could contribute to the early strength of grouting material. However, due to the slow hydration rate of Portland cement, the ettringite were produced continuously at the late stage of Portland cement hydration[9,10], that would cause uneven expansion,which resulted in micro-cracks. So, the 28d compressive strength of the composite cements system were lower than the single cement system`s.

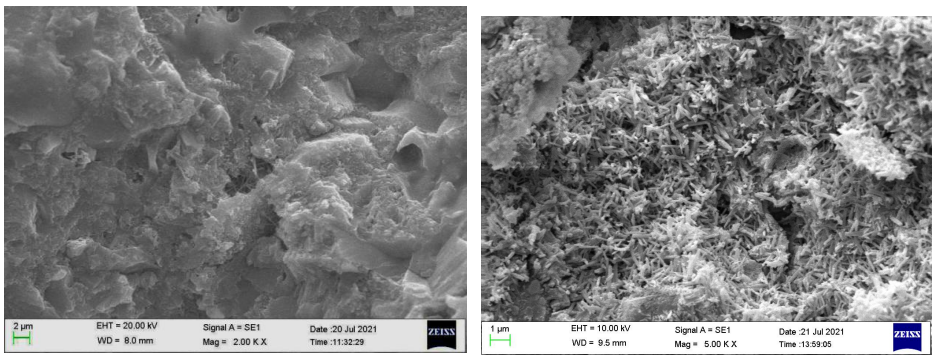


(a) compressive strength (b) fluidity

Figure 1. Compressive strength and fluidity of cementitious grout with different Portland cement/sulphoaluminate cement ratio

With the increase of sulphoaluminate cement content, the initial fluidity showed a downward trend, and the 30min fluidity decreased first and then increased. As the increase of sulfoaluminate cement, the content of anhydrous calcium sulphoaluminate (C4A3S), which has a fast hydration rate in the system, would increase, that could speed up the formation of ettringite and aluminum hydroxide gel and consume the hydration products calcium hydroxide (CH) at the same time. Those processes promoted the hydration reaction of C2S and C3S[11], then leaded to the decay of fluidity.

Therefore, considering the compressive strength and fluidity, the Portland cement/sulphoaluminate cement ratio was selected as 8:2. At this ratio, 1d and 3d compressive strengths were 35.7 MPa and 61.7 MPa, the initial fluidity and 30minfluidity were 335 mm and 270 mm, respectively.



(a) the ratio was 10:0 (b) the ratio was 8:2

Figure 2. Microscopic morphology of the slurry of different Portland cement/sulphoaluminate cement ratio(3d)

3.3 Influence of gypsum content on the performance of cementitious grout

It can be seen from Figure 3, that with the increase of the gypsum content, the 3h vertical expansion rate and 24h vertical expansion rate of cementitious grout both grew. The concentration of Ca2+ in the ternary composite cementitious material system would be rise, when gypsum content

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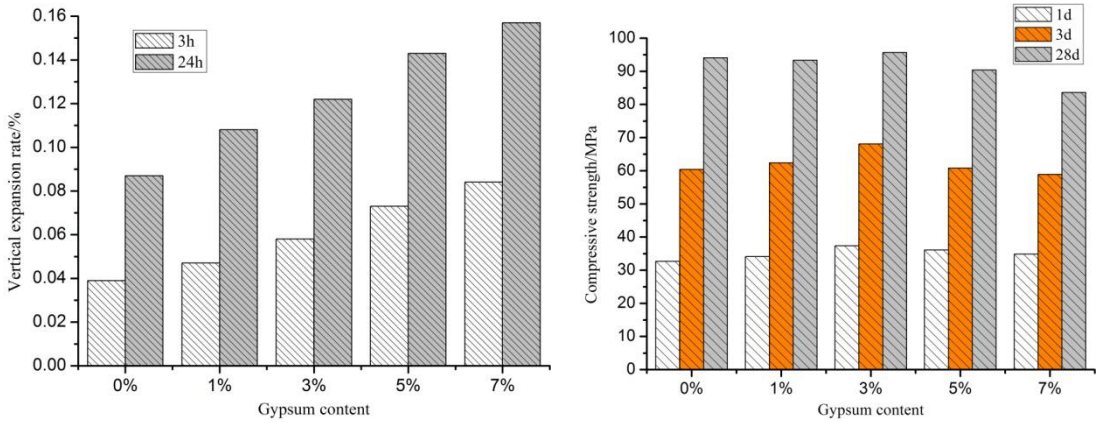
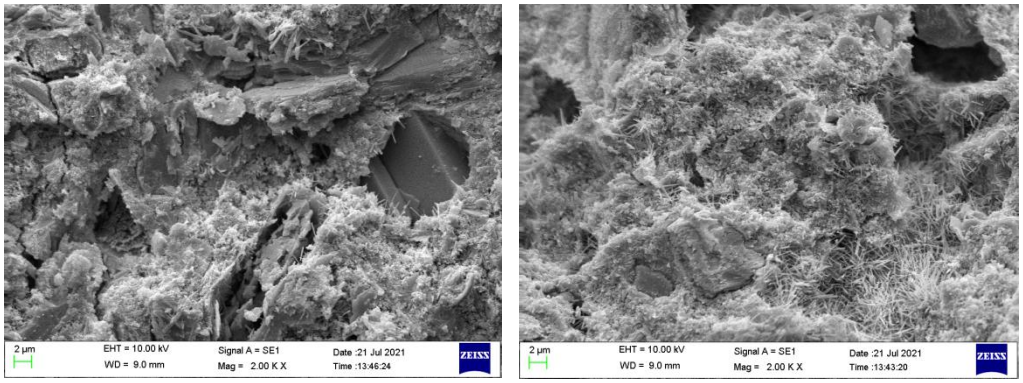
increased, that would not only increase the output of ettringite crystals, but also have a main influence on its morphology. When the concentration of Ca2+ exceeded the saturation, the ettringite crystals would be formed by a solid-phase reaction, and its morphology was agglomerated and radiating needle-like crystals(as shown in Figure 4), which had larger specific surface and cross-extrusion, playing an important role on the increase of vertical expansion rate of the grouting slurry after hardening. However, when the amount of gypsum were excessive, more ettringite would be generated, resulting in greater expansion stress, which would lead to cracks in the slurry eventually.



(a) vertical expansion rate (b) compressive strength

Figure 3. Vertical expansion rate and compressive strength of cementitious grout with different gypsum content

With the increase on the gypsum content, the compressive strength of the cementitious grout both grew initially and then experienced a drop. When the content of gypsum less than 3%, gypsum could increase the strength of cementitious grout. The addition of gypsum made the production rate and the diffusion of hydration products of the ternary composite cementitious material had a well matched. Also, gypsum could promote the hydration reaction of C4A3S and β-C2S. So, as the age increases, the space frame could be filled by reaction products, that would make the structure more compact and the strength higher (as shown in Figure 4). While, excessive blending of gypsum would result in an increase of ettringite, the main product of hydration reaction, which not only would cause volume expansion of the slurry, but also generate harmful stress and cause cracking. Therefore, a few amount of gypsum could increase the strength of the cementitious grout.



(a) gypsum content was 1% (b) gypsum content was 3%

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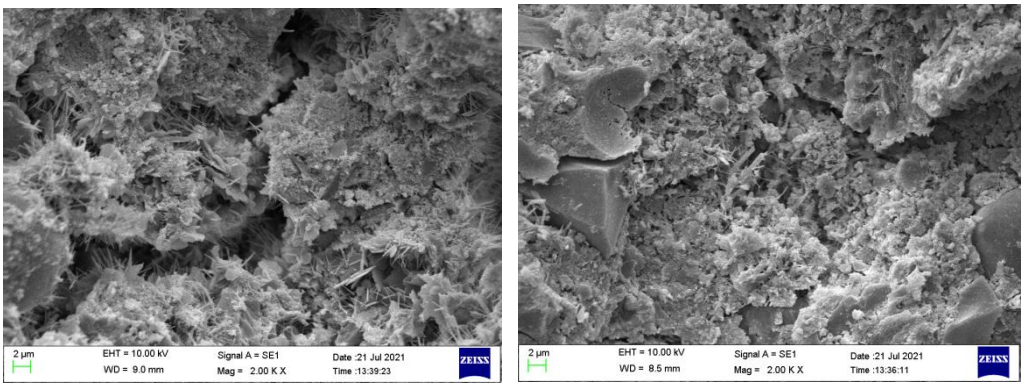

(c) gypsum content was 5% (d) gypsum content was 7%

Figure 4. Microscopic morphology of the slurry of different gypsum content(3d)

4. Conclusion

A cementitious grout based on the ternary composite material system was developed, and the influences of ratio of Portland cement to sulphoaluminate cement and gypsum content on the performances of it were investigated. Based on the experimental results, the following conclusions could be made:

(1) The factors affecting the fluidity and compressive strength of the cementitious grout in order that from significant to non-significant were water/binder ratio, Portland cement/sulphoaluminate cement ratio and gypsum content.

(2) Sulphoaluminate cement could improve the early compressive strength of the cementitious grout. To obtain comprehensive properties of good compressive strength and fluidity, it seems that the optimal raito of the Portland cement to sulphoaluminate cement is 8:2.

(3) Gypsum is the main factor affecting the vertical expansion rate of the cementitious grout among the factors studied. With the increase of gypsum content (from 0% to 7%), the vertical expansion rate increased, but the compressive strength grew initially and then experienced a drop.

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