Study on Properties of Binary Composite Cementitious Self-leveling Mortar

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Abstract: The binary composite cementitious self-leveling mortar is an important development direction of modern building construction. At present, there are great differences in opinions on the mixing proportion of Portland cement and aluminate cement or sulphoaluminate cement in binary system and there are few literatures comparing the fluidity and strength of the two kinds of mortar. In this paper, the fluidity, flexural strength and compressive strength of the two kinds of mortar with different dosages were compared. The research results showed that the addition of aluminate cement and sulphoaluminate cement could reduce the initial fluidity and 20min fluidity of mortars, but the decreasing degree was different. The influence of different dosages of aluminate cement and sulphoaluminate cement on the flexural strength and compressive strength of mortars was obviously different. When the dosage of aluminate cement was 0-10%, the flexural strength and 1d compressive strength of mortar could be improved remarkably. When the dosage was higher than 10%, the strengths were obviously reduced, even lower than the strengths of Portland cement mortar. The flexural strength of the mortar increased with the increase of sulphoaluminate cement in the range of test dosages, but the 1d compressive strength had little difference. When the dosage was 10%-20%, the influences of the two kinds of cement on the 28d compressive strength of mortars were basically consistent and both could improve the 28d compressive strength of mortars.

1. Introduction
Cementitious self-leveling mortar is composed of binding materials, fine aggregate, fillers and admixture, etc. It can flow and level with a little assistance after mixing with water. It has good fluidity, stability, early high strength and construction speed. It is the ideal material for large supermarkets, parking lots and warehouses. So it is an important development direction of modern building ground construction[1].

Binding materials generally include Portland cement (PC), aluminate cement (AC), sulphoaluminate cement (SAC) three kinds. In order to give full play to the advantages of all kinds of cement and restrain their own shortcomings, the scholars usually combine two kinds of cement together to prepare binary composite cementitious mortar. So the cementitious self-leveling mortar usually include Portland cement-aluminate cement binary composite mortar (PC-AC) and Portland cement-sulphoaluminate cement binary composite mortar (PC-SAC) two kinds. When PC is mixed with AC or SAC in an appropriate proportion, the system can not only retain the late strength of PC, but also take advantage of the higher early strength of AC or SAC to improve the early strength of the system and shorten the setting time. Therefore, how to mix the two kinds of cement properly and make
them complementary is the most important thing in the study. Many scholars have conducted relevant researches on this issue.

By comparing the effects of PC and AC on mortar performance in cementitious self-leveling mortar, Huo obtained that when PC increased continuously, but the dosage was still lower than AC, the 28d compressive strength and flexural strength gradually decreased. When the dosage exceeded AC, the 28d compressive strength gradually increased, the development of flexural strength was gentle[2]. Wang found that the setting time of the binary system composed of PC and AC shortened with the increase of AC dosage, but the compressive strength first increased and then decreased[3]. By studying the properties of PC and AC composite cement mortar, Shang got the best mixing ratio and found that the composite binding material had ideal early strength and late strength compared with the single cement within a small dosage range[4]. By the experiment, Dai found that with the increase of PC dosage, the loss of PC-AC mortar fluidity increased gradually, the setting time decreased and the strength of all ages decreased[5]. By comparing the fluidity of binary composite cement mortar with PC and AC in different mixing ratios, Zhou obtained that when m (PC) : m (AC) = 2:1, the fluidity loss was the minimum[6]. By using AC to replace PC, Ying analysed the compressive strength of the mortar under different substitution rates and found that the strength of the mortar in the binary composite system was the highest when the substitution rate was 5%[7]. Ren studied the influence of SAC on the working performance of binary composite mortar through experiments, the results showed that when the dosage of SAC was 15%-20%, the mortar had the best performance and the indexes were obviously better than the standard[8]. Li studied the strength development rule of composite system mortar which was compositied of PC and SAC with different proportions under different temperatures, it was concluded that with the increase of SAC, the setting time decreased quickly, early strength increased, but the excess of SAC could make strength development lagged behind, seriously affected the later strength[9]. Wang studied the fluidity, setting time and strength of composite mortar under the different dosage of PC, and concluded that when the dosage of PC was less than 50%, the setting time and fluidity of the PC-SAC composite system decreased with the increase of cement admixture, the strength decreased first and then increased[10]. Based on the experimental studying, Qin got that the setting time of PC-SAC blends decreased with the higher dosage of SAC, the compressive strength was increased by the higher incorporation of SAC (5-10%) at early ages, but it was decreased by SAC at late ages[11]. Trauchessec compared the compressive strength and hydration products of three blends and obtained that SAC percentage modified the hardening speed as well as the hydration mechanisms[12]. Based on the study of effects of PC on the early properties of SAC, Zhang obtained that the rapid setting and high early strength of SAC can be achieved by the addition of 10-20 wt% PC[13]. Chaunsali studied the influence of SAC dosage on expansion of PC-SAC blends and obtained that with the increase of SAC dosage, the expansion degree increased[14].

From the above, it can be seen that PC-AC and PC-SAC binary composite mortar can meet the requirements of fluidity and have high early strength and late strength at the appropriate ratio. However, opinions on the mixture ratio of binary system vary greatly in different literatures, and there are few literatures comparing the fluidity and strength of two kinds of binary composite mortars. Under certain conditions, it is necessary to compare the performance of the two kinds of binary composite mortar and select the appropriate binary composite mortar. Therefore, the fluidity, compressive strength and flexural strength of two kinds of binary composite mortars were studied in this paper, in order to meet the selection of cementitious mortar materials and determine the dosage under different conditions.

2. Materials & Methodology

2.1. Raw materials
The selection of raw materials is particularly important for the preparation of cementitious self-leveling mortar with good fluidity and high strength. The raw materials used in this experiment were as follows.
The cement used in this experiment included Portland cement (P.O 52.5), aluminate cement (CA-50) and sulphoaluminate cement (SAC 42.5). The chemical compositions and physics performance of cements were listed in Table 1 and Table 2.

Table 1. Chemical compositions of the cements (wt.%).

| Cement type | CaO  | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | SO$_3$ | MgO  | TiO$_2$ | R$_2$O |
|-------------|------|---------|-------------|-------------|--------|-------|---------|--------|
| P.O 52.5    | 64.95| 18.31   | 4.21        | 2.95        | 4.22   | 0.64  | 0.23    | —      |
| CA-50       | 37   | 7.82    | 52.4        | 2.41        | —      | —     | —       | 0.37   |
| SAC 42.5    | 39.25| 12.28   | 37.12       | 2.36        | 9.52   | —     | —       | —      |

Table 2. The physics performance of the cements.

| Cement type | 1d Flexural strength/MPa | 28d Flexural strength/MPa | 1d Compressive strength/MPa | 28d Compressive strength/MPa |
|-------------|--------------------------|---------------------------|-----------------------------|-----------------------------|
| P.O 52.5    | —                        | 4.0                       | 7.0                         | 23.0                        |
| CA-50       | 5.8                      | 6.7                       | 28d                         | 48.5                        |
| SAC 42.5    | 6.5                      | 7.5                       | 8.0                         | 38.0                        |

The fine aggregate included 30-100 mesh fine sand, 16-40 mesh coarse sand and coarse whiting. The admixture included polycarboxylic acid-enhanced water reducer, MT400 cellulose ether stabilizer, P803 antifoaming agents, UEA type expansion agent and redispersible powder.

The water used in this experiment met the requirements of standard.

2.2. Mix proportion design

The samples were divided into two types: PC-AC and PC-SAC binary composite cementitious mortars. The binary composite mortars were respectively prepared by using AC and SAC combined with PC (AC and SAC replace PC with five replacement rates of 0%, 5%, 10%, 15% and 20% respectively). The water-binder ratio was 0.24. The mix proportion of the specimens was shown in Table 3.

Table 3. The mix proportion of binary composite cementitious mortar.

| No. | Binding material (kg) | Admixture (%) | Coarse whiting (kg) | Coarse sand (kg) | Fine sand (kg) |
|-----|-----------------------|---------------|---------------------|-----------------|---------------|
|     | PC | AC | SAC  |                  |              |               |
| 0   | 480 | 0  | 0    | 3.45             | 60           | 214.5         | 212.5         |
| 1   | 456 | 24 | 0    | 3.45             | 60           | 214.5         | 212.5         |
| 2   | 432 | 48 | 0    | 3.45             | 60           | 214.5         | 212.5         |
| 3   | 408 | 72 | 0    | 3.45             | 60           | 214.5         | 212.5         |
| 4   | 384 | 96 | 0    | 3.45             | 60           | 214.5         | 212.5         |
| 5   | 456 | 0  | 24   | 3.45             | 60           | 214.5         | 212.5         |
| 6   | 432 | 0  | 48   | 3.45             | 60           | 214.5         | 212.5         |
| 7   | 408 | 0  | 72   | 3.45             | 60           | 214.5         | 212.5         |
| 8   | 384 | 0  | 96   | 3.45             | 60           | 214.5         | 212.5         |

2.3. Experimental methodology

In this paper, the fluidity (initial fluidity, 20min fluidity), flexural strength (1d, 28d), compressive strength (1d, 28d) of binary composite cementitious mortars were measured through the test. Since the maintenance method and test method were also important factors to affect the performance of cementitious self-leveling mortar, this experiment was prepared and tested in accordance with the requirements of standard JC/T 985-2017 Cementitious Self-levelling Compound for Floor. There were two groups of specimens. One group was used to measure the strength for 1d, and the other group was used to measure the strength for 28d.
2.4. Results & Discussion

2.4.1. Fluidity. The initial fluidity and 20min fluidity of the mortars when AC and SAC were mixed with different dosages were shown in Figure 1.

![Initial fluidity](a) Initial fluidity
![20min fluidity](b) 20min fluidity

Figure 1. The fluidity of binary composite cementitious mortars.

Based on Figure 1 (a), it can be seen that the variation tendency of initial fluidity for the two kinds of mortar was different. When the dosage increased from 0 to 5%, the fluidity of the two kinds of mortar decreased by the same degree and both decreased by 12.5%. When the dosage increased from 5% to 10%, the fluidity of PC-AC mortar decreased by 3.6%, the fluidity of PC-SAC mortar remained unchanged. When the dosage increased from 10% to 15%, the fluidity of PC-AC mortar decreased by 13.3%, the fluidity of PC-SAC mortar decreased by 3.6%. When the dosage increased from 15% to 20%, the fluidity of PC-AC mortar decreased by 14.5%, the fluidity of PC-SAC mortar increased by 1.5%. It could be concluded that when the dosage was 5%, the initial fluidity of the two kinds of mortar both decreased obviously. But when the dosage was higher than 5%, the larger the dosage was, the greater the reduction of PC-AC mortar would be, while the PC-SAC mortar basically showed a small fluctuations. When the dosage was 15% and 20%, the fluidity of PC-AC mortar was lower than 130mm, which could not meet the standard. The initial fluidity of the test dosages of PC-SAC mortar was all greater than 130mm, meeting the requirement of standard for fluidity.

Based on Figure 1 (b), it can be seen that the variation tendency of 20min fluidity for the two kinds of mortar was roughly same with the initial fluidity. When the dosage increased from 0 to 5%, the fluidity of PC-AC mortar decreased by 14.4% and that of PC-SAC mortar decreased by 15.6%. When the dosage increased from 5 to 10%, the fluidity of PC-AC mortar decreased by 3.6% and that of PC-SAC mortar decreased by 5.9%. When the dosage increased from 10 to 15%, the fluidity of PC-AC mortar decreased by 16.7% and that of PC-SAC mortar decreased by 3.1%. When the dosage increased from 15 to 20%, the fluidity of PC-AC mortar decreased by 22.7% and that of PC-SAC mortar did not change. It could be concluded that the 20min fluidity of the two kinds of mortar both decreased with the increase of the dosage of AC and SAC. But the decreasing degree was different. When the dosage was not higher than 10%, the decreasing degree of PC-AC mortar was lower than that of PC-SAC mortar. When the dosage was higher than 10%, the decreasing degree of PC-AC mortar was greater than that of PC-SAC mortar. When the dosage of AC was 15%-20% and SAC was 10%-20%, the 20min fluidity of mortar was lower than 130mm, which could not meet the standard.

Therefore, it can be seen from the above that the fluidity of mortars basically decreased with the variation of the dosage of AC and SAC, and when the dosage was higher than 10%, the fluidity of PC-AC mortar decreased more. In terms of fluidity, when AC was combined with PC, the dosage of AC should be 0-10%. When SAC was combined with PC, the dosage of SAC should be 0-5%.

2.4.2. Flexural strength. The flexural strengths of cementitious self-leveling mortar after 1d with different dosages of AC and SAC were shown in Figure 2. The maximum range of flexural strength of laboratory equipment was 12.4MPa, and the 28d flexural strength was beyond the range. Due to the limitation of the range, the 28d flexural strength could not be measured.
As can be seen in Figure 2, when the dosage increased from 0 to 5%, the 1d flexural strength of PC-AC mortar increased by 43.9% and that of PC-SAC mortar increased by 13.8%. When the dosage increased from 5% to 10%, the 1d flexural strength of PC-AC mortar decreased by 6.2% and that of PC-SAC mortar increased by 14.3%. When the dosage increases from 10% to 15%, the 1d flexural strength of PC-AC mortar decreased by 32.5% and that of PC-SAC mortar increased by 11.9%. When the dosage increased from 15% to 20%, the 1d flexural strength of PC-AC mortar increased by 1.8% and that of PC-SAC mortar increased by 2.8%. Therefore, it can be concluded that the 1d flexural strength variation trend of mortar mixed with different types of cement was different. With the increase of the AC dosage, the 1d flexural strength of mortar increased obviously at first, then decreased greatly, and finally increased slightly. With the increase of the SAC dosage, the 1d flexural strength increased gradually, but the increasing degree was smaller and smaller. When the dosage of AC or SAC was not higher than 10%, the 1d flexural strength of mortar both increased, but the 1d flexural performance of mortar mixed with AC was better. When the dosage was higher than 10%, the 1d flexural performance of mortar mixed with SAC was better.

Although the specific value of 28d flexural strength could not be measured, the flexural strength of all specimens was greater than 12.4MPa, which met the standard requirement. Therefore, the flexural strength of the two kinds of mortar was superior. In terms of flexural strength, when AC was combined with PC, the dosage of AC should be 0-10%. When SAC was combined with PC, the dosage of SAC should be 0-15%.

2.4.3. Compressive strength. The compressive strength of cementitious self-leveling mortar after 1d and 28d with different dosages of AC and SAC were shown in Figure 3.

According to Figure 3 (a), when the dosage increased from 0 to 5%, the 1d compressive strength of PC-AC mortar increased by 25.1% and that of PC-SAC mortar increased by 22.2%. When the dosage
increased from 5% to 10%, the compressive strength of PC-AC mortar increased by 17.4% and that of PC-SAC mortar increased by 1.0%. When the dosage increased from 10% to 15%, the compressive strength of PC-AC mortar decreased by 41.2% and that of PC-SAC mortar increased by 1.2%. When the dosage increased from 15% to 20%, the compressive strength of PC-AC mortar increased by 10.1%, and that of PC-SAC mortar decreased by 3.4%. Therefore, it could be concluded that the incorporation of two kinds of cement had a great difference in the impact of 1d compressive strength.

With the increase of dosage, the 1d compressive strength of PC-AC mortar first increased obviously, then decreased greatly and finally increased slightly. However, when the dosage of SAC was 0-5%, the 1d compressive strength of mortar could be effectively improved. When the dosage of SAC was 5%-20%, the 1d compressive strength was basically the same.

When the dosage was not higher than 10%, the 1d compressive strength of PC-AC mortar was greater than that of PC-SAC mortar. When the dosage was higher than 10%, the 1d compressive strength of PC-SAC mortar was greater than that of PC-AC mortar. In addition, the 1d compressive strength of PC-SAC mortar was always greater than that of PC mortar. When the dosage was higher than 10%, the compressive strength of PC-AC mortar was lower than that of PC mortar. The 1d compressive strengths of the two kinds of mortars were higher than the standard, the early mechanical properties were very superior. So in terms of 1d compressive strength, the dosage of AC should be 0-10%, the dosage of SAC should be 0-5%.

According to Figure 3 (b), when the dosage increased from 0 to 5%, the 28d compressive strength of PC-AC mortar increased by 26.9% and that of PC-SAC mortar increased by 5.1%. When the dosage increased from 5% to 10%, the compressive strength of PC-AC mortar decreased by 4.0% and that of PC-SAC mortar increased by 11.9%. When the dosage increased from 10% to 15%, the compressive strength of PC-AC mortar decreased by 4.4% and that of PC-SAC mortar increased by 1.2%. When the dosage increased from 15% to 20%, the compressive strength of PC-AC mortar increased by 2.2% and that of PC-SAC mortar increased by 1.1%. Thus, when the dosage was 5%, the incorporation of AC could significantly improve the 28d compressive strength of mortar. When the dosage of AC was higher than 5%, the 28d compressive strength of mortar decreased. However, the 28d compressive strength of the mortar increased with the increase of the dosage of SAC, especially when the dosage was 10%, the 28d compressive strength increased obviously.

When the dosage was not higher than 10%, the 28d compressive strength of PC-AC mortar was greater than that of PC-SAC mortar. It indicated that when the dosage was not higher than 10%, the AC had a better effect on improving the 28d compressive strength. When the dosage was higher than 10%, the 28d compressive strength of the two kinds of mortar was almost the same. The 28d compressive strength of the two kinds of mortar was greater than the standard and PC mortar. In general, the two kinds of cement had enhanced the later strength of mortars and achieved good results. So in terms of 28d compressive strength, the dosage of AC should be 0-5%, the dosage of SAC should be 0-10%.

3. Conclusion

Based on the experimental study on fluidity, flexural strength and compressive strength of PC-AC and PC-SAC composite cementitious self-leveling mortars with different dosages, the following conclusions were drawn.

The addition of AC and SAC both could reduce the initial fluidity and 20min fluidity of mortar, but the decreasing degree was different. When AC was combined with PC, the dosage of AC should be 0-10%. When SAC was combined with PC, the dosage of SAC should be 0-5%.

The influence of different dosages of AC and SAC on the flexural strength of mortar was obviously different. When the dosage of AC was 0-10%, the flexural strength of cementitious self-leveling mortar could be significantly increased, the maximum 1d flexural strength of mortar could be increased by 43.9%. When the dosage was higher than 10%, the flexural strength was obviously reduced, even lower than the 1d flexural strength of PC mortar. The 1d flexural strength of the mortar increased with the dosage of SAC increased in the range of test dosages.
For the 1d compressive strength of mortar, when the dosage of AC was not higher than 10%, it was significantly increased and the highest 1d compressive strength of mortar was increased by 46.82%. When the dosage was higher than 10%, it was obviously reduced, even lower than the compressive strength of PC mortar. When the SAC was added, the 1d compressive strength was increased obviously, but it was basically the same in the range of 5%-20%. For the 28d compressive strength of mortar, the AC and SAC both could increase its value. When the dosage of AC was 5% and the SAC was 10%, the increasing degrees were more obvious.

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