

Effect of Curing Temperature on Activity Index of Silica Fume

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Abstract. The compressive strength of the contrast mortars and test mortars at different curing temperatures at different ages were tested. Effect of curing temperature on the strength of the test mortars and the contrast mortars was analyzed. The relative activity index and absolute activity index of the silica fume were studied. The mercury porosimetry method was used to test the pore structure of mortar specimens, and the improving effect of silica fume on the pore structure of mortar specimens under different curing temperatures was analyzed. The results show that with the increase of age, the decrease of curing temperature will cause the strength of mortar specimens to slow down. At the 3d and 7d ages, with the decrease of curing temperature, the absolute activity value of silica fume gradually increases. After 7 days of age, with the decrease of curing temperature, the absolute activity of silica fume gradually decreases. With the increase of curing age, the relative activity of silica fume decreases at first and then increases at 20 °C and 10 °C. The relative activity value of silica fume under the maintenance of 5 °C and -3 °C increased first and then decreased gradually. The addition of silica fume in the concrete improved the internal pore structure of the specimen, and the effect of curing temperature on the specimen was consistent.

1. Introduction

Silica fume is a kind of fly ash collected from soot when ferrosilicon plant and metal factory smelt alloy or metal silicon [1]. The high quality silica fume obtained through a certain quality control or preparation technology is used in concrete, which not only can reduce the cost and protect the environment, but also can improve the durability and workability of concrete, extend the service life of concrete and improve the quality of the project. The contribution of silica fume to the compressive strength of concrete was studied, it is pointed out that the contribution of silica fume to the strength under standard curing conditions is larger, and the enhancement effect of silica fume under hot water and high temperature curing is further increased [2]. The effect of silica fume on the mechanical properties of reactive powder concrete was studied, the results show that the increase of silica fume content effectively improves the mechanical properties of concrete, but exists an optimal mixing amount [3]. Use of silica fume as a cement mixed material was pointed out, the changes in the variety of the cement properties of the change basically no significant impact, and the amount of change will cause differences in cement properties [4]. The curing temperature can promote the enhanced role of silica fume in advance to make the concrete to obtain a higher early strength, but 28 days after the strength of the continuous development of the magnitude of decline in long-term strength of wet curing concrete lower than room temperature curing concrete [5]. The influence of silica fume content



on concrete chloride ion binding ability was studied, results show that with the increase of silica fume content, concrete chloride ion total binding capacity, chemical binding capacity and physical binding capacity trends are linearly reduced. The hydration characteristics of silica fume mixed with silica fume under low temperature curing conditions were studied, it is pointed out that the addition of silica fume to concrete can improve the hydration characteristics of concrete, however, the curing conditions of low temperature affect the activity of pozzolanic silica fume[7]. The reactivity of silica fume in silica fume-mixed concrete was studied by using nuclear magnetic resonance (NMR) method, the reactivity of silica fume was determined by the amount of silica fume and the ratio of water to binder[8]. The dosage of silica fume usually based on the activity of silica fume to choose for concrete mix design. The capacitance of concrete was measured to understand the activity of mineral admixtures in concrete[9]. Based on the calculation of the activity index of mineral admixture using the percentage of mortar strength, a test method for measuring the activity index of concrete composite mineral admixture is introduced, the composite mineral admixture is replaced by an equal volume of cement to test the concrete composite mineral admixture activity index, this method can solve the composite mineral admixture due to density fluctuations on the composite mineral admixture activity index[10]. At present, in the test method for testing the activity of mineral admixture, the application of activity index method is more common.

The activity index of silica fume is usually calculated based on the intensity ratio of the mortar under standard conditions. However, in high altitude or high latitudes, the concrete under construction is usually affected by the low temperature, and the cold climate makes the concrete at low or even negative temperature curing environment, but less research on the effect of low or negative temperature on the activity of silica fume. The compressive strength of the test mortar and the comparative mortar under the curing conditions of 20 °C, 10 °C, 5 °C and -3 °C were tested, the relative activity index and absolute activity index of the silica fume were calculated. The influence of temperature on the silica fume activity was analyzed, in order to provide basis for the design of concrete mix ratio and the selection of silica fume content under the influence of low and negative curing temperature.

2. Experiment

2.1 Raw materials in the experiment

Cement uses P O42.5 grade cement produced by Gansu Qilian Mountain Cement Group Co., Ltd., and Silica fume(SF) is produced by Li Xinyuan Silica Powder Co., Ltd., with a specific surface area of 20,000 m² / kg. The water used for mixing is PH 7.6. The chemical composition of the cement and mineral admixtures tested by X-ray fluorescence is shown in Table 1.

Table 1. Chemical components of cement and mineral admixture

| Raw materials | Chemical component $\omega/\%$ | | | | | | | | |
|---------------|--------------------------------|------------------|--------------------------------|--------------------------------|------|-----------------|------------------|------------------|------|
| | CaO | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | MgO | SO ₃ | K ₂ O | TiO ₂ | ZnO |
| Cement | 76.70 | 9.90 | 2.01 | 7.01 | 0.30 | 1.61 | 1.06 | 0.57 | 0.11 |
| SF | 1.17 | 89.10 | 0.15 | 3.56 | 0.13 | 1.91 | 3.17 | - | 0.10 |

2.2 Experiment method

2.2.1 Activity index test method. According to the method specified in "Application Technical Specification for Mineral Admixtures" (GB/T51003-2014) and "Test method for cement mortar strength (ISO method)" (GB/T17671) to prepare mortar specimens, specimens using 40mm×40mm×160mm prism, mix proportion shown in Table 2. The compressive strength of test mortar samples and comparative mortar samples was measured at 3d, 7d, 14d and 28d curing at different temperatures, the activity index is expressed in the form of compressive strength ratio. The activity index of each mineral admixture defines the compressive strength value of the test mortar under the different temperature curing and the compressive strength ratio of the mortar sample cured

at the temperature as the absolute activity index at the age, the compressive strength of the test mortar under different temperature curing and the compressive strength ratio of the mortar under the standard conditions were the relative activity index at that age.

Table 2. Mortar mix proportion

| Raw materials | Contrast mortar | Test motor |
|-----------------------|-----------------|------------|
| | | SF |
| Cement (g) | 450±2 | 405±1 |
| Mineral admixture (g) | - | 45±1 |
| ISO sand (g) | 1350±5 | 1350±5 |
| Water (g) | 225±1 | |

2.2.2 Pore structure test method. The pore structure of concrete was tested by mercury intrusion method. Absolute ethyl alcohol was used to stop the hydration of concrete. Before the experiment, the test piece is dried, weighed and placed in a mercury porosimeter for testing.

2.2.3 Curing method. Mortar specimens were cured in 20 °C, 10 °C, 5 °C, -3 °C constant temperature environment. Among them, when the curing conditions of 20 °C are adopted, the specimens are molded and the molds are cured together for 24 hours in an environment of a temperature of $(20 \pm 1) ^\circ \text{C}$ and a relative humidity of not less than 90% and then released at a temperature of $(20 \pm 1) ^\circ \text{C}$ and water conservation to the prescribed age. When the curing conditions of 10 °C, 5 °C and -3 °C are adopted, the specimens are molded and wrapped in plastic film and directly put into low or negative temperature curing environments of 10 °C, 5 °C and -3 °C, low and negative temperature maintenance environment is realized by artificial climate simulation box produced by China Academy of Building Research. The temperature of the simulation system can be controlled between -20 ~ 80 °C, the temperature fluctuation is not more than 0.5 °C and the relative humidity can be controlled at 10% ~ 98 %.

3. Test results and data analysis

3.1 Effect of temperature on the Strength of Mortar

Shown in Figure 1 the strength test values of contrast mortar samples at 3d, 7d, 14d, 28d age the different curing temperature. Shown in Figure 2 the compressive strength test values of test mortar in the 3d, 7d, 14d, 28d age the different curing temperature strength.

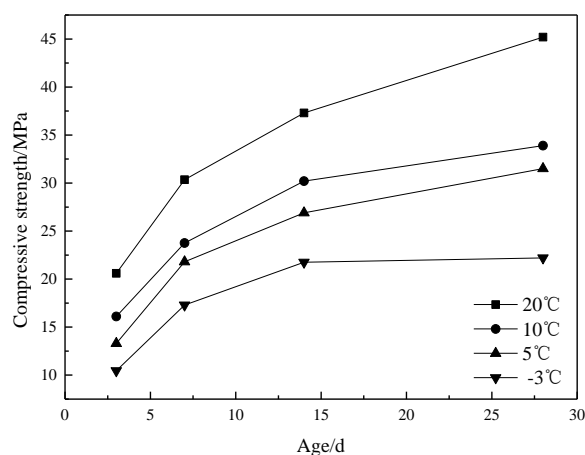


Figure 1. Measured compressive strength of contrast mortar

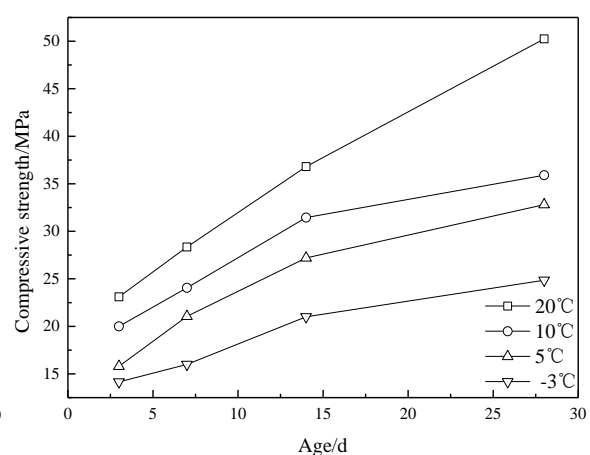


Figure 2. Measured compressive strength of test mortar

As can be seen from figure 1, with the increase of age, the decrease of curing temperature will cause the strength growth rate of the comparative mortar to slow down. Under the negative temperature curing of -3°C , the strength of the mortar will also grown, but the growth rate was slow. With the decrease of curing temperature at the same age, the compressive strength value of the specimens decreased gradually. At the age of 7d, the strength of the contrast mortar under 10°C , 5°C and -3°C reached 78.25%, 71.83%, 57.00% compared to curing under the maintenance of 20°C . When they reached 28d, the proportion became 75.00%, 69.69%, 49.12%. It can be seen from figure 2, under 20°C curing temperature, with the increase of age, the test mortar strength almost linear increase, but the curing temperature will also cause the strength of the test mortar growth rate slowed; the same age with the decrease of curing temperature, the compressive strength of the specimens decreased gradually. At 7 days, the strength of test mortar under the curing conditions of 10°C , 5°C and -3°C reached 84.83% , 74.25% and 56.44% compared to curing under the maintenance of 20°C , respectively, and reached 28.44%, 65.27% and 49.45% at the age of 28 days.

A series of complicated physico-chemical reactions occur after the cement is added with water, and the hydration products generated have the characteristics of condensation and hardening. Any chemical reaction has the characteristics of material changes, energy changes and reaction rates. The same proportion of the specimen at different curing temperature, the curing temperature decreases caused the chemical reaction rate decreased, resulting in the strength of the mortar sample growth rate slowed. At the same age, with the decrease of curing temperature, the hydration rate and degree of hydration of cement decreased, and the hydration products generated by hydration were less, which resulted in the decrease of compressive strength of specimens. Under -3°C continuous negative curing temperature, the specimen is in a freezing environment, the water in the large pores of the cement slurry will freeze, but the moisture in the gel pores still exists in the form of supercooled liquid water, so under the environment of negative curing temperature, hydration reaction between water and cement will still occur, and the strength of the specimen will continue to increase. However, the temperature will affect the growth rate slowly. Silica fume has very fine particle morphology and contains a very high proportion of amorphous SiO_2 with good volcanic ash effect and micro-aggregate filling effect. It can fill the pores in concrete and improve the pore structure of concrete, making the structure of the slurry more compact , While silica fume can react with $\text{Ca}(\text{OH})_2$ generated by cement hydration. While reducing $\text{Ca}(\text{OH})_2$, the content of C-S-H is increased and the interfacial bond between slurry and aggregate is enhanced, so mortar strength at the same age was improved.

3.2 Effect of temperature on the activity index of silica fume

Figure 3 shows the effect of different curing temperatures on the absolute activityindex of silica fume at 3d, 7d, 14d and 28d. Figure 4 shows the effect of different curing temperatures on the relative activity index of silica fume at 3d, 7d, 14d and 28d.

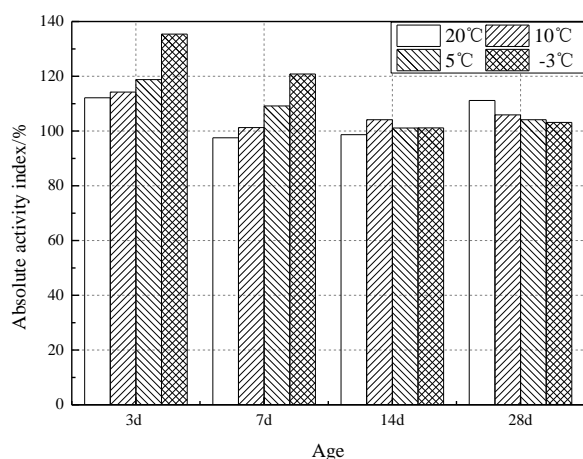


Figure 3. Absolute activity index of SF

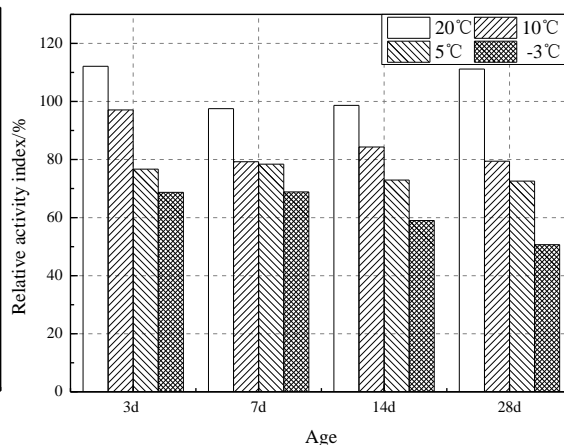


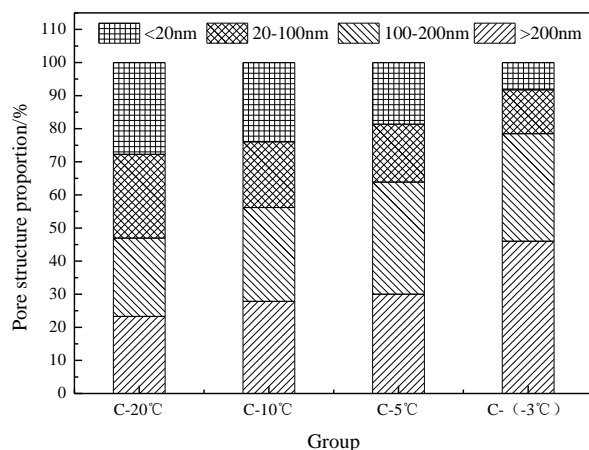
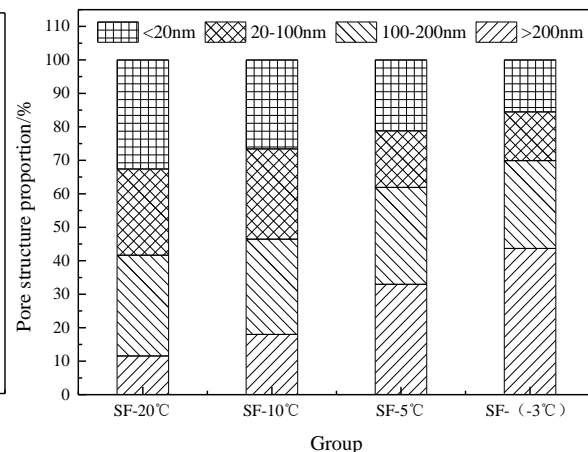
Figure 4. Relative activity index of SF

As can be seen from figure 3, with the increase of age, the absolute activity index of silica fume decreases and then increases at each curing temperature. At 3d and 7d, with the decrease of curing temperature, the absolute activity index of silica fume increased gradually. At 28 days, the absolute activity index of silica fume decreased with the decreasing of curing temperature. At 3d, the absolute activity index of silica fume at 10 °C, 5 °C and -3 °C was 102%, 106% and 120% compared to curing under the maintenance of 20 °C, and reached to 103%, 112%, 123% at the age of 7d., and this ratio becomes 105%, 102%, 103% at the age of 14d. By the 28d age, the proportion becomes 95%, 94%, 93%. As can be seen from figure 4, with the increase of curing age, the relative activity index of silica fume first decreases and then increases at 20 °C and 10 °C, while at 5 °C and -3 °C, relative activity index increased first and then decreased. At the same age, with the decrease of curing temperature, the relative activity index of silica fume decreased gradually. The relative activity index of silica fume at the temperature of 10 °C, 5 °C and -3 °C was 86%, 68% and 61% compared to curing under the maintenance of 20 °C at the age of 3d., and the proportion reached 81%, 80%, 70% at the age of 7d, the proportion becomes 85%, 74%, 60% at the age of 14d., and the proportion becomes 71%, 65%, 46% at the age of 28d.

Silica fume is a kind of highly active admixture. The high free energy of the surface and the presence of a large amount of ultrafine particles, silica fume mixed with water, the hydration reaction is intense in the cementitious cement paste. The setting time will be shortened; silica fume incorporation will increase the gelling system 3d and 7d hydration heat. At 3d and 7d, due to silica fume incorporation, the hydration heat of the test mortar increased compared with the control group, and the increased heat of hydration promoted the hydration process of the cement. The formation of Ca(OH)_2 in the pore fluid of cement slurry will further increase the content of C-S-H, the pore structure is more compact, and the compressive strength of mortar will also increase. At the age of 3d and 7d, the compressive strength of the control mortar and the test mortar decreased with the decrease of the curing temperature, but the strength of the mortar under the influence of hydration heat increased with the curing temperature, this explains why the compressive strength ratio reflects the absolute activity of silica fume and the absolute value of silica fume increases gradually at 3d and 7d when the curing temperature decreases. After 7 days, the influence of hydration heat on the strength of the mortar decreased gradually. The influence of curing temperature on the strength of mortar gradually increased. Therefore, the absolute value of silica fume decreased gradually with the decrease of curing temperature.

3.3 Effect of temperature on the pore structure of the specimen

The effect of curing temperature on the strength of mortar can be reflected by the pore structure of the specimen, as shown in Figure 5, which shows the variation of pore size distribution of mortar under different curing temperatures tested by mercury intrusion at 28 days, As shown in Figure 6, the variation of pore size distribution of test mortar under different curing temperatures tested by mercury intrusion method at 28d age.

**Figure 5.** Pore structure of contrast mortar**Figure 6.** Pore structure of test mortar

The concrete pore structure was divided into four categories [11], which are harmless pores ($\leq 20\text{nm}$), fewer harmful pores ($20\text{-}100\text{nm}$), harmful pores ($100\text{-}200\text{nm}$) and multiple harmful pores ($\geq 200\text{nm}$). As can be seen from figure 5, with the decrease of curing temperature, the proportion of harmless holes and harmless holes in the contrast mortar gradually increases, and the proportion of harmless holes and fewer holes decreases. As can be seen from figure 6, with the decrease of curing temperature, the proportion of harmless holes and many harmful holes in mortar mixed with silica fume increased gradually, and the proportion of harmless holes and fewer harmful holes gradually changed small. It can be seen that the curing temperature on the impact of comparative mortar specimens and test mortar specimens are the same. However, as can be seen from the comparison between figure 5 and figure 6, the proportion of innocuous pores in test mortar doped with silica fume is higher than that without silica fume at the same curing temperature compared with the mortar, the proportion of the former is much lower than that of the latter, that is, the pore structure of the specimen is improved by adding silica fume to the specimen.

4. Conclusion

With the increase of age, the decrease of curing temperature will result in the decrease of the strength growth rate.

At 3d and 7d, with the decrease of curing temperature, the absolute value of silica fume increased gradually. After 7 days, the absolute value of silica fume decreased with the decrease of curing temperature. With the increase of curing age, the relative activity of silica fume under the conservation of 20°C and 10°C decreased first and then gradually increased. The relative activity of silica fume under the conservation of 5°C and -3°C increased first and then decreased gradually.

Adding silica fume in concrete improves the internal pore structure of the specimen, and the influence rule of curing temperature of specimen is consistent.

5. References

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