Research on influence of admixtures to the plastic shrinkage cracking of mortar

Yiping Ma¹, Han Zhang¹, Shaotong Yu¹, Chang Tan¹,² and Xiaojie Yang¹

¹ Key Laboratory of Advanced Civil Engineering Materials of Education Ministry, Tongji University, Shanghai, China
² Wuhan Chengxing United Technology Development Co., Ltd., Wuhan, China
E-mail: ypma1239@sina.com

Abstract. In this paper, the influence of admixture on plastic shrinkage cracking was studied. The results show that the plastic tensile strength increases while plastic shrinkage stress decreases as the content of air-entraining agent grows to 150×10⁻⁶ wt.%, and the anti-cracking index increases as a whole. Water reducing agent, water retaining agent, and shrinkage reducing agent all have the effect of improving plastic shrinkage cracking of fresh cement mortar. The constitutive relations between the admixtures content and anti-cracking index have been built.

1. Introduction
Plastic shrinkage cracking of cement-based materials is a common engineering construction problem which has a great impact on its performance. As an important influencing factor for plastic shrinkage and cracking of cement-based materials, admixture has also been studied [1-2]. Andreas Leemann [1] had studied the effect of shrinkage reducing admixture and paraffin-based curing compound to fresh concrete in plastic state, the results showed that the effectiveness in reducing plastic shrinkage cracking. On the other hand, it has been noted that the addition of SRA delays the time of cracking. Many researchers have proposed models to simulate plastic shrinkage and try to predict the plastic shrinkage cracking. A model called PShC Severity Model was proposed by Boshoff et al [3]. The model was based on the volume of water that evaporates from the concrete between the placing and the initial setting time of the concrete. The author [4] has studied the plastic shrinkage and cracking mechanism of cement-based materials and established the correlation between the cracking index and the plastic shrinkage cracking of cement-based materials.

Based on the existing research methods of the plastic shrinkage constitutive relationship of cement-based materials, this study explores the influence of the types and contents of various commonly used cement admixtures on the plastic shrinkage constitutive relationship of cement-based materials.

2. Experiment
2.1. Raw materials
Ordinary Portland Cement (P·O 42.5) was used in this experiment. The fineness modulus of sand with a 5 mm maximum particle size was 2.6, and the water used in the experiment was tap water. Air-entraining agent and water retaining agent were sodium dodecyl benzene sulfonate and methyl cellulose, respectively. These reagents were manufactured by Sinopharm Chemical Reagent Co., Ltd and all of their purity levels were analytical. The polycarboxylate water reducing agent (powder agent) was used. The composition of the shrinkage reducing agent was fatty alcohol-polyoxyethylene ether.
2.2. Research methods of constitutive relations in plastic shrinkage cracking
The flat method was used to test the cement mortar plastic capillary shrinkage stress and the plastic tensile strength of mortar was tested in this experiment using briquette mould designed by the authors. The schematic diagram of the test device is shown in figure 1, figure 2 and figure 3. The specific operation method of this device can be found in the author’s previous article [5].

![Figure 1. Sketch of measuring principle for plastic shrinkage stress](image1)

![Figure 2. Schema of the briquette mould](image2)

![Figure 3. Schema of the test set-up of plastic tensile strength of mortal](image3)

3. Results and discussion
3.1. Effect of air-entraining agent on plastic shrinkage cracking of mortar[6]
The mortar consists of cement, sand and water in a weight ratio of 1: 1: 0.5. Adding air-entraining agent in a ratio of 0.005 wt.%~0.025 wt.% to the mortar according to GB50119-2013.

![Figure 4. Relationship between plastic shrinkage index and air-entraining agent](image4)

![Figure 5. Relationship between anti-cracking index K and content of air-entraining agent](image5)

The effect of air-entraining agent content on plastic shrinkage index and air-entraining agent is presented in figure 4. The correlation coefficients (R^2) of plastic shrinkage stress and plastic tensile strength fitting are respectively 0.83 and 0.74. It is shown that the shrinkage stress will decrease with the increase of air-entraining agent content in the initial stage. The minimum of shrinkage stress is 0.0108MPa when the dosage is 200×10^-6 wt.%. After that, the shrinkage stress will increase with the increase of air-entraining agent content. As can be seen from figure 4, the tensile strength of mortar will increase first and then reduces with the air-entraining agent content increased.
The relationship between the anti-cracking index $K$ and the dosage of the air-entraining agent is shown in figure 5. The correlation coefficient ($R^2$) is 0.68. It is seen that with the increase of the amount of air-entraining agent, the anti-cracking index $K$ of the mortar increases first and then decreases, which is similar to the trend of the tensile strength. The maximum value of $K$ will achieve when the air-entraining agent dosage is $200\times10^{-6}$ wt.%.

We believe that the phenomenon mentioned above after introduction of air-entraining agent can be explained in the following three aspects. (1) As a surfactant, the air-entraining agent reduces the surface tension of water which leads to the reduction of the shrinkage stress of capillary concave surface. At the same time, the bubbles introduced by air-entraining agent impede the rate of moisture migration, resulting in a decrease in the rate of capillary concave surfaces formation. (2) The increase in tensile strength is due to the increase of viscosity in the internal porosity of the liquid caused by the air-entraining agent. In addition, the micro-bubble introduced by air-entraining agent has a certain mechanical strength. When the dosage of air-entraining agent exceeds a certain amount, the original micro-bubbles connect with each other to form a large air bubble, which reduces the overall mechanical strength, thereby decreasing the tensile strength. (3) The moisture migration is impeded by the bubbles and the formation rate of capillary concave surface reduced owing to the introduction of air-entraining agent, which resulting in the extension of cracking time.

3.2. Effect of water reducing agent on plastic shrinkage cracking of mortar

The mortar consists of cement, sand and water in a weight ratio of 1:1:0.45. The temperature, humidity and wind speed are set to 23°C, 45% and 3.5m/s, respectively. Adding water reducing agent in a ratio of 0.01 wt.%~0.08 wt.% to the mortar.

The influence of the water reducing agent content on plastic shrinkage stress and tensile strength of mortar is presented in figure 6. The correlation coefficient ($R^2$) of tensile strength fitting is 0.75. With the increase of the amount of water reducing agent, the plastic tensile strength tends to decrease gradually, while the plastic shrinkage stress is basically unchanged. Figure 7 is the fitting curve of water reducing agent content and anti-cracking index. It is known that the anti-cracking index tends to decrease as the amount of water reducing agent increases. The fitting equation of water reducing agent content and the mortar anti-cracking index is shown in equation (1). $J$ indicates the amount of water reducing agent, and the correlation coefficient ($R^2$) is 0.58.

\[
K = 2.28 + 1.05J - 1.05 \quad (1)
\]

In order to verify the reliability of the equation, we still choose a new content of water reducing agent for verification. The temperature, humidity and wind speed are set to 23°C, 45% and 3.5m/s, respectively. The water reducing agent dosage is 0.06 wt.%. The value of the anti-cracking index calculated by equation (1) is 0.91, so we predicted that the mortar will crack. In the verification experiment, the mortar cracked at 218min and the actual anti-cracking index was 0.85. The relative error between the actual measured value and the theoretical calculated is 7.1%.
3.3. Effect of water retaining agent on plastic shrinkage cracking of cement mortar

Adding water retaining agent in a ratio of 0.02 wt.%, 0.05 wt.% and 0.1 wt.% to the mortar (Water-cement ratio is 0.45, Cement sand ratio is 1:1). The temperature, humidity and wind speed are set to 23℃, 60% and 3.5m/s, respectively.

The effect of water retaining agent on the plastic shrinkage stress and plastic tensile strength is presented in figure 8. The correlation coefficient ($R^2$) of tensile strength fitting is 0.77. Figure 9 is the relationship between the water retaining agent dosage and anti-cracking index $K$. As shown in figure 8, the plastic shrinkage stress of the mortar decreases with the addition of water retaining agent while the plastic tensile strength increases gradually. From figure 9, the anti-cracking index increases with the addition of water retaining agent. The plastic shrinkage cracking of mortar specimens occurs if the content of water retaining agent is less than 0.05 wt.%. The fitting equation of water retaining agent content and mortar anti-cracking index is shown in equation (2). $B$ indicates the water retaining agent content, and the correlation coefficient ($R^2$) is 0.69.

$$K = 5.18 + 1.25B$$

A new experiment was carried out to verify the equation (2). The temperature, humidity and wind speed are set to 23℃, 60% and 3.5m/s, respectively. The dosage of water retaining agent is 0.07 wt.%. The value of the anti-cracking index calculated by the equation (2) is 1.61. In the verification experiment, the mortar did not crack and the actual anti-cracking index is 1.55. The relative error between the actual measured value and the theoretical calculated value is 3.9%.

3.4. Effect of shrinkage reducing agent on plastic shrinkage cracking of cement mortar

Adding shrinkage reducing agent in a ratio of 0.01 wt.%–0.1 wt.% to the mortar (Water-cement ratio is 0.45, Cement sand ratio is 1:1). The plastic shrinkage stress and tensile strength of the test mortar are presented in figure 10. The correlation coefficients ($R^2$) of plastic shrinkage stress and plastic tensile strength fitting are respectively 0.92 and 0.91. Figure 11 is the relationship between the anti-cracking index and the amount of shrinkage reducing agent. The correlation coefficient ($R^2$) is 0.86. From figure 10, we can see that the plastic shrinkage stress and the plastic tensile strength decrease with the addition of the shrinkage reducing agent. As is shown in figure 11, the anti-cracking index increases linearly with the increase of the shrinkage reducing agent content.

On one hand, the incorporation of shrinkage reducing agent reduces the surface tension of the water on the mortar surface, thereby reducing the capillary shrinkage stress caused by water evaporation. In addition, due to the incorporation of shrinkage reducing agent, the mortar mixture has a certain expansion, which compensates for the plastic shrinkage of mortar. So, the plastic shrinkage stress would reduce with the addition of shrinkage reducing agent. On the other hand, the solidification and hardening process of the mortar is delayed owing to the water retention and retarding effect of shrinkage reducing agent which leads to the reduction of plastic tensile strength. A certain amount of bleed air was observed in the experiment that resulted in a certain expansion of the specimen, increased porosity in the slurry.
and decreased the cohesiveness of the mortar, which can also be seen as a cause of a significant reduction in plastic tensile strength.

Figure 10. Linear fit chart of plastic shrinkage index and content of shrinkage reducing agent

Figure 11. Linear fit chart of anti-cracking index and content of shrinkage reducing agent

4. Conclusions

(1) With the increase of air-entraining agent dosage, the anti-cracking index of mortar increases first and then decreases. In the range of experimental parameters, the best anti-cracking effect can be achieved with about the dosage of 200×10⁻⁶ wt.%, while the more accurate value should be further studied.

(2) The anti-cracking index of mortar decreases with the addition of water reducing agent.

(3) With the increase of the amount of water retaining agent, the anti-cracking index shows an increasing trend, and shrinkage cracks can be significantly reduced.

(4) After the addition of shrinkage reducing agent, the anti-cracking index increases significantly, which indicates the improvement of anti-cracking performance about the mortal.

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