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# Analysis of the Influence of Mixed Chemical Additive on Concrete Shrinkage and Cracking Behaviors

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This paper adopts laboratory test method in analyzing influence of the different kinds of chemical additives on early concrete shrinkage and cracking behaviors. The research results indicate that: tensile strength and compressive strength of concrete can all be promoted somewhat by adding chemical additive, expanding agent has the most obvious influence on strength and elastic modulus of concrete, the next is air entraining agent, and water reducing agent has the minimum influence on basic performance of concrete. According to the test results, mixing proportions of expanding agent, water reducing agent and air entraining agent are 8%, 1.5% and 0.4% respectively, and anti-shrinkage performance of the concrete is best in the early stage. When mixing expanding agent and water reducing agent in concrete simultaneously, anti-cracking effect of concrete shall be worse by comparing with that when adding only one chemical additive. In practical engineering application, the optimum chemical additive mixing proportion can be obtained in continuous tests.

## 1. Introduction

Concrete has become the building material with the maximum use and the most extensive applications. In recent years, along with emergence of the new concrete with higher strength and lighter quality, concrete material has been used in such sophisticated fields as super high-rise building and military defense (AïTcin 2000; AïTcin 2003; Samman et al., 1996; Chang et al., 2001).

Early shrinkage and cracking of concrete building is the neck for formation of the concrete with higher strength. As limited by various restraint functions in curing process, there is greater tensile stress existed in concrete, which can result in tensile fracture. Simultaneously, quicker moisture evaporation of concrete can also result in cracking (Levesque et al., 2013; Zhutovsky and Kovler, 2012; Thomas and Folliard, 2007). Currently, concrete cracking is mainly divided into load cracking and non-load cracking (Bentz et al., 2001; Bentz 2006; Hover 1998). Adding of chemical additive is an effective method of restraining early cracking of concrete. By adding different kinds of additives in concrete appropriately early cracking of concrete can be restrained, and concrete strength can be promoted. However, excessive or little adding of additives can result in such problems as excessive shrinkage and durability declining (Neville, 2001; Lura et al., 2001; Shen et al., 2016; Li and Yao, 2001).

According to the analysis above, this paper adopts laboratory test method in analyzing influence of the different kinds of chemical additives on early shrinkage and cracking behaviors of concrete. The research conclusion can provide theoretical reference for early curing of concrete.

## 2. Influence of chemical additive on concrete shrinkage performance

When concrete shows excessive shrinkage, the tensile stress received by concrete shall exceed the extreme tensile stress, and there shall be cracking shown in surface of concrete. Concrete shrinkage performance is mainly affected by such factors as mixing proportion and construction aggregate. Different chemical additives have different restraints on concrete shrinkage.

Concrete strength used in test is C55, and chemical additives mainly include water reducing agent, expanding agent and air entraining agent. There are five groups set for each additive, and P-0, P-1, P-2, P-3 and P-4 are the codes for the five samples of expanding agent, with mixing proportions P-0=8%, P-1=6%, P-2=7%, P-3=9%

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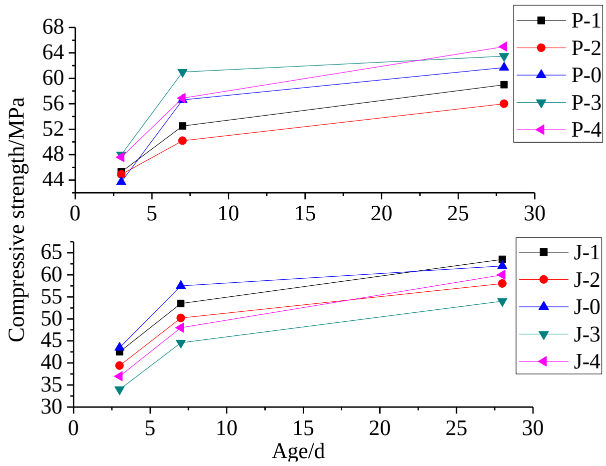
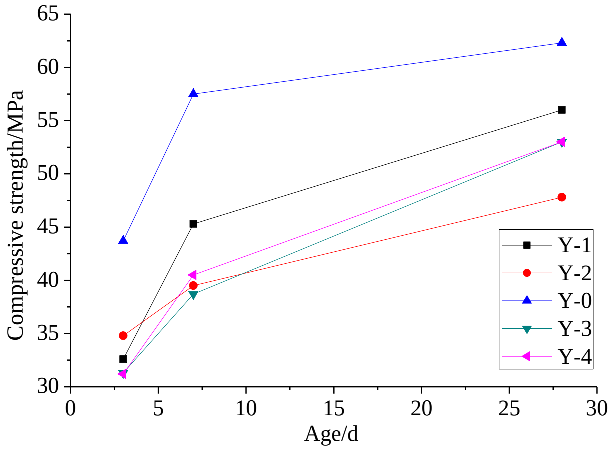
and P-4=10% respectively; similarly, mixing proportions of the fives samples of water reducing agent are J-0=1.5%, J-1=1.2%, J-2=1.4%, J-3=1.6% and J-4=1.8% respectively; mixing proportions of the fives samples of air entraining agent are Y-0=0.4%, Y-1=0.2%, Y-2=0.3%, Y-3=0.5% and Y-4=0.6% respectively. During laboratory process, the three chemical additives shall be added solely or be mixed together according to the different conditions.

Figure 1 refers to the influence curve of concrete strength on curing time when adding three kinds of chemical additives simultaneously. In the upper part of figure 1(a), it shows change of concrete strength under mixture of five groups of expanding agents when J-0=1.5% and Y-0=0.4%, and it can be seen in diagram that concrete strength basically increases along with increment of mixing proportion of expanding agent; the figure below figure 1(a) refers to influence of water reducing agent on concrete strength when P-0=8% and Y-0=0.4%, and it can be seen that concrete strength and water reducing agent mixing amount show no obvious linear characteristics after 28d of curing; it can be seen from figure 1(b) that concrete strength obtained by selecting Y-0=0.4% is far greater than that obtained in the other four mixing proportions when P-0=8% and J-0=1.5%. In practical application, mixing proportion of air entraining agent can be selected as 0.4%, while that of expanding agent and water reducing agent can be determined according to practical situation.




(a) J-0=1.5%, Y-0=0.4%, P-0=8%, Y-0=0.4%




(b) P-0=8%, J-0=1.5%

*Figure 1: Influence curve of compounded additive on high performance concrete strength*

Figure 2 shows concrete shrinkage under mixture of five groups of expanding agents when J-0=1.5% and Y-0=0.4%. During test, concrete shall be put in solution environment and air environment respectively, and concrete shrinkage performance shall be tested after 3, 7 and 14 days respectively. In the figure, the front 14 days refer to concrete shrinkage value in solution environment, and the later 14 days refer to concrete shrinkage value in air environment.

It can be seen from figure 2 that the larger mixing proportion of expanding agent shall result in higher concrete expansion rate in solution environment. On 14th day, if mixing proportion of expanding agent is 10%, concrete expansion rate shall reach 0.018%. In the first 3 days, if mixing proportion of expanding agent is 8%, concrete expansion rate shall be fastest. During 3-14 days, if mixing proportion is 10%, the expansion rate shall be fastest. However, concrete shows obvious shrinkage characteristic in air, and the smaller mixing proportion of expanding agent shall result in greater concrete shrinkage. As indicated by test results, when adding appropriate expanding agent during concrete curing process, and when there is sufficient water in ambient environment, concrete shrinkage can be restrained effectively. It is known from test analysis that anti-shrinkage performance of concrete is best when mixing proportion of expanding agent is 8% and 9% respectively.

Figure 3 refers to concrete shrinkage under different contents of water reducing agent when P-0=8% and Y-0=0.4%. As indicated in the Figure, concrete still shows expansion trend in solution environment; however, when mixing proportion of expanding agent is fixed at 8%, the expansion rates obtained by adding different proportions of water reducing agent shall all be less than the expansion rate obtained when mixing proportions of expanding agent are 9% and 10%. After curing in air for 14 days, concrete shrinkage rate is almost zero when J-0=1.5%, while it reaches 0.019% when J-4=1.8% and 0.012% when J-3=1.6%. It indicates that water reducing agent has certain incompatibility with expanding agent and air entraining agent. When mixing proportion of water reducing agent is selected as 1.5%, the better anti-shrinkage effect of concrete can be reached.

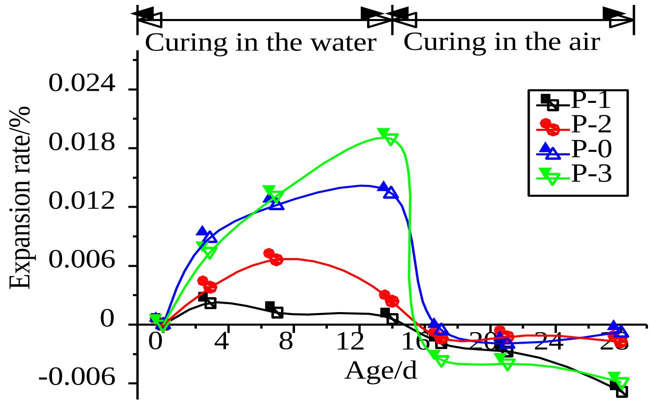



*Figure 2: Influence curve of compounded additive system on HPC shrinkage property (J-0=1.5%, Y-0=0.4%)*

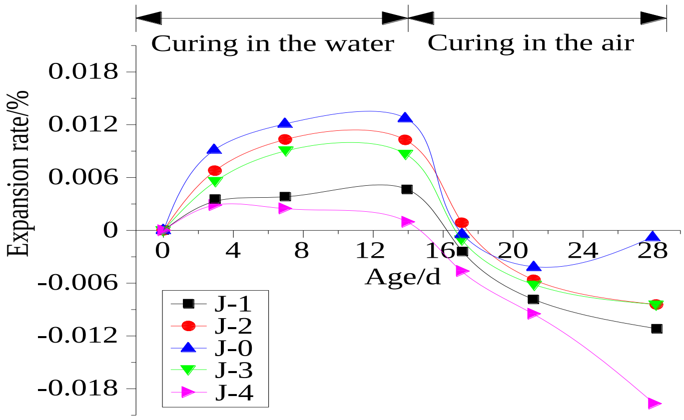



*Figure 3: Influence curve of compounded additive system on HPC shrinkage property (P-0=8%, Y-0=0.4%)*

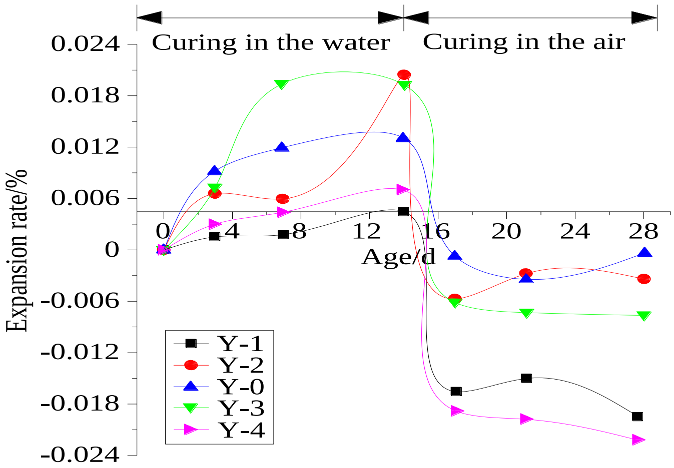



*Figure 4: Influence curve of compounded additive system on HPC shrinkage property (P-0=8%, J-0=1.5%)*

Figure 4 refers to concrete shrinkage under different contents of air entraining agent when P-0=8% and J-0=1.5%. As indicated in figure, concrete expansion and shrinkage characteristics show greater difference under different contents of air entraining agent. When Y-1=0.2% and Y-4=0.6%, concrete shall be in shrinkage state both in solution environment and air environment. After curing in air environment for 14 days, shrinkage rate shall reach 0.024% when Y-4=0.6%, which is very easy to cause concrete cracking. When Y-0=0.4%, concrete shrinkage rate is basically zero in air environment.
According to the analysis above, it finally determines that mixing proportions of expanding agent, water reducing agent and air entraining agent are 8%, 1.5% and 0.4% respectively. When giving spectral component analysis to this mixed chemical additive, composition of the main component c of this chemical additive is as shown in Figure 5. It can be seen from the Figure that Ca content of the mixed reagent is the highest and reaches 70.23%, Si content is 13.95%, and proportion of the two components reaches 84.18%, for there are more Si in expanding agent, and Ca and Si can generate gel with higher hardness in concrete, which contributes to the denser concrete structure. There are also such minor components as Fe, Al, S, K and Ti contained in mixed reagent.

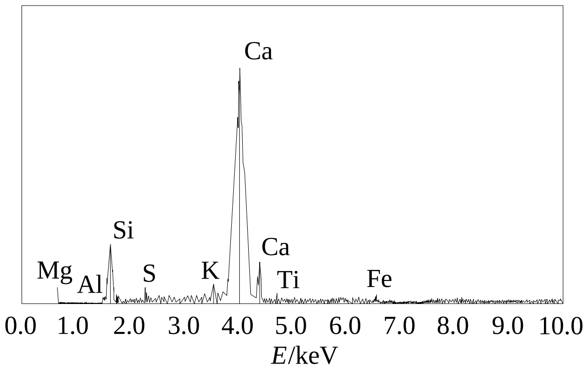



*Figure 5: Energy spectrum analysis of mixed chemical admixtures*

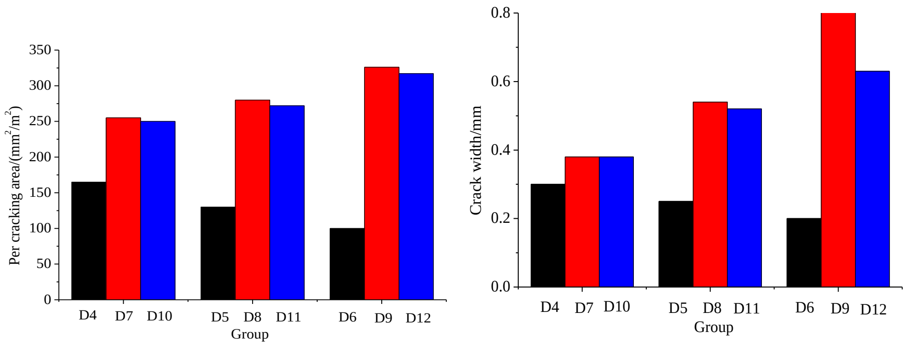
## 3. Influence of chemical additive on anti-cracking performance of concrete

Analysis is given to influence of the three chemical additives on anti-cracking of concrete further. Strength grade of the concrete sample selected is C30, chemical additives in different kinds are added in sample respectively, there are total 12 conditions divided, and compressive strength and tensile strength of the concrete for test are as shown in table 1. C1-C3 refers to the condition of adding water reducing agent solely, C4-C6 refers to the condition of adding water reducing agent and shrinkage reducing agent with different proportions, C7-C9 refers to the condition of adding water reducing agent and expanding agent with different contents, and C10-C12 refers to the condition of adding the three chemical additives together. It can be seen from table that tensile strength and compressive strength of concrete can all be promoted somewhat by adding chemical additive.

*Table 1: Concrete design mix proportion and basic performance*

| Number | Admixture amount (/(kg/m$^3$) | | | Compressive strength/MPa | | Splitting tensile strength/MPa | |
|---|---|---|---|---|---|---|---|
| | Water reducing agent | Shrinkage reducing agent | Expansive agent | 3d | 28d | 3d | 28d |
| C0 | 3.5 | 0 | 0 | 23.7 | 42.0 | 1.4 | 2.6 |
| C1 | 4.5 | 0 | 0 | 24.5 | 49.5 | 1.4 | 2.7 |
| C2 | 5.5 | 2.8 | 0 | 24.0 | 42.5 | 1.4 | 2.6 |
| C3 | 3.5 | 0 | 0 | 22.8 | 40.0 | 1.4 | 2.6 |
| C4 | 3.5 | 0 | 0 | 24.1 | 45.8 | 1.3 | 2.7 |
| C5 | 3.5 | 3.8 | 0 | 23.0 | 46.6 | 1.3 | 2.7 |
| C6 | 4.5 | 5.6 | 0 | 23.2 | 46.1 | 1.3 | 2.6 |
| C7 | 5.5 | 7.3 | 22.4 | 25.7 | 44.2 | 1.4 | 2.8 |
| C8 | 4.5 | 0 | 27.9 | 25.9 | 48.9 | 1.5 | 3.0 |
| C9 | 3.5 | 0 | 35.6 | 24.5 | 52.0 | 1.4 | 2.7 |
| C10 | 3.5 | 2.8 | 22.8 | 23.4 | 47.7 | 1.3 | 2.6 |
| C11 | 3.5 | 0 | 29.3 | 22.9 | 47.5 | 1.3 | 2.5 |
| C12 | 4.5 | 0 | 35.8 | 22.6 | 24.0 | 1.3 | 2.5 |

Figure 6 refers to comparison of cracking area and cracking width of different test concretes after mixing with shrinkage reducing agent and expanding agent. As indicated in figure, when mixing with two chemical additives, presentation of cracking area and cracking width of concrete shall be better than the condition when mixing in expanding agent solely, while it shall be worse than the condition when mixing in shrinkage reducing agent solely. It indicates that mixing of shrinkage reducing agent can restrain anti-cracking performance of concrete when expanding agent should have been mixed in concrete.




(a) Cracking area (b) Crack width

*Figure 6: Influence of expansive agent and shrinkage reducing agent on cracking performance*

## 4. Conclusions

This paper adopts laboratory test method in analyzing influence of different kinds of chemical additives on early shrinkage and cracking behaviors of concrete. Research conclusions are as follows:

(1) Tensile strength and compressive strength of concrete can all be promoted somewhat by adding chemical additive, expanding agent has the most obvious influence on strength and elastic modulus of concrete, the next is air entraining agent, and water reducing agent has the minimum influence on basic performance of concrete.

(2) According to test results, when mixing proportions of expanding agent, water reducing agent and air entraining agent are 8%, 1.5% and 0.4% respectively, early anti-shrinkage performance of concrete shall be best.

(3) When mixing expanding agent and water reducing agent in concrete simultaneously, anti-cracking effect of concrete shall be worse than the effect when adding one chemical additive solely. In practical engineering application, the best mixing proportion of chemical additive can be obtained in continuous tests.

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