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A Study on Influence of Chemical Admixtures on Early Cracks of Concrete

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The influence of chemical admixtures on early shrinkage cracking of concrete with different water cement ratio was studied by using flat shrinkage die. Plate method is an excellent way to investigate the effect of admixture on the shrinkage crack of fresh concrete from the early state to hardening, which is in line with the actual engineering situation. Early shrinkage cracking of concrete is influenced by the factors of early shrinkage and strength. When the water cement ratio is lower, the early shrinkage of concrete dominates the early cracking resistance of concrete. On the contrast, when the water cement ratio is higher, the strength development of concrete is the dominant factor affecting the cracking. The effect of high efficiency water reducing agent on the early shrinkage and cracking resistance performance of concrete is depend on its water cement ratio; when the water cement ratio is high, more high efficiency water reducing agent would correspond to a better early shrinkage and cracking resistance properties of concrete; when the water cement ratio is low, more high efficiency water reducing agent would correspond to a worse early shrinkage and cracking resistance properties of concrete.

1. Introduction

Recently, more and more commercial concrete is applied. With a large dose of cement and sand ratio, small coarse aggregate size and large slump, commodity concrete is prone to shrinkage cracking(Guo, 2014), which seriously affects the durability of the concrete structure and service life. With the development of economy, a larger scale of concrete engineering and the higher performance of concrete materials are required, what's more, the technology of concrete is also develop into high strength and high performance. It has been proved that concrete with high strength and high performance is more prone to cracking than others because its lower water binder ratio and greater self-shrinkage (Chia et al., 2002), and with the decrease of water binder ratio, the early cracking of concrete would be more serious. The study on shrinkage cracking of concrete by expansion agent, shrinkage reducing agent or various kinds of fiber has attracted many people's attention both at home and abroad (Meddah et al., 2011).

The development of modern concrete science cannot be separated from the use of chemical admixtures. Chemical admixture has become the essential fifth component of modern concrete (Plank et al., 2015), and has been widely used in Engineering. However, the research on the influence of chemical admixtures on the early shrinkage cracking of concrete is relatively lacking. It is a blind spot for preparing high performance concrete and studying the concrete shrinkage cracking performance. As the quality of concrete chemical admixtures varies greatly, there are also different methods of using and drying shrinkage, and the results obtained by scholars at home and abroad are quite different. When using water reducer to reduce the water consumption of concrete or reducing the amount of cement in the same water cement ratio, the test shows that the dry shrinkage value of concrete with high efficiency water reducing agent is smaller than or close to the dry shrinkage value of blank concrete. However, some experiments show that the polymer superplasticizer can increase the dry shrinkage of concrete. When water reducing agent is used to improve the workability and slump of concrete, Boroks's research (1989) shows that adding water reducer agent makes dry shrinkage increase by 20%, The result of research by Qian et al., (2004), a scholar of China, is that adding water reducer can make a sligt increase of concrete shrinkage. Dr Yang Yibo from the South China University of Technology, carried out cracking tests on the mortar using park ring method by keeping the the volume of

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water and aggregate quantity is the same, and he results showed that the addition of water reducing agent made the cracks appear earlier and greatly increased the total width of the cracks. Ma Baoguo from Wuhan university investigated the influence of water reducing agent on the crack of concrete and proved that the addition of superplasticizer is beneficial to the shrinkage cracking of concrete (Qi et al., 2002). With the development of concrete technology, especially the development of large fluidity and self-compacting concrete, water reducing agent is mainly used to maintain the cement paste volume unchanged and increasing liquidity instead of learning its effects on dry shrinkage of concrete (Mollah et al., 2000). Although the hardened concrete in the condition of restricted shrinkage cracking admixtures are studied, the influence of additives on the performance of concrete shrinkage limit from the fresh state to the hardening of this period of time is rarely investigated. Considering the performance of concrete during this period, the durability of concrete is directly affected, it is necessary to be studied.

After pouring, surface moisture evaporation rate of concrete is greater than the internal bleeding rate in the initial few hours of the maintenance phase, which would make it contraction. At this stage the strength of concrete is quite low, so plastic cracks begin to appear on the exposed surface of the concrete when the contraction stress produced by the negative pressure of the capillary is greater than the tensile strength of the concrete. In the first few hours, cracks in the concrete constantly causing and expanding, the number of cracks increased, the the width and crack length of cracks are increased. This kind of early crack has very unfavourable influence on concrete's impermeability, corrosion resistance, frost resistance, melting cycle and other durability, then reduce the durability of concrete, so it is of great significance to study the cracking of concrete in early stage (<24h). In view of this situation, the effect of superplasticizer and other components on the early cracking behavior of concrete when the mixture ratio of cement and concrete is kept and water cement ratio is different studied in this paper. The influence of amount and kind of chemical admixtures on the early cracking behavior of concrete was discussed.

2. Experimental section

2.1 Design of experiments

This paper deals with the shrinkage cracking of concrete in the early stage from the mixing to the initial hardening stage. Plate method is used to test the early-age cracking resistance of concrete (Qian et al., 2012; Gentile et al., 2016).

The plate mold shown in Figure 1 is used to investigate the effect of admixtures on early cracking resistance of concrete.

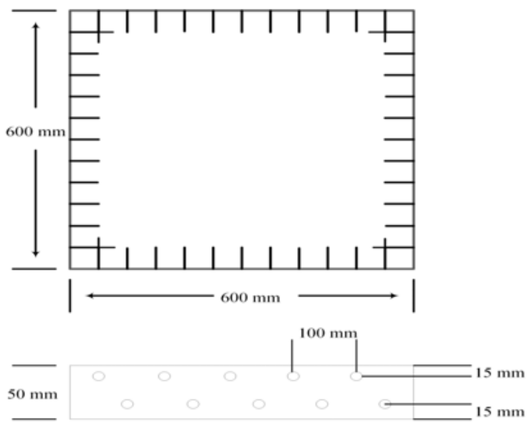

Figure 1: Flat shrinkage cracking test device

In the test, a rubber pad is spread on the bottom board, and a polythene film is spread on the rubber cushion to prevent the loss of the cement slurry and the evaporation loss of the water from the bottom. A ceiling fan with a speed of 3 m/s is hang 35 cm above the plate. Place a plastic box (area is 540 cm2) with the same height as plate to measure water loss rate of concrete. A electronic scale with an accuracy of 1 g, a range of 20 kg were used to measure the water loss rate after 4h, 12 h and 24 h (the water loss rate of water evaporation is the mass ratio of the loss water and concrete). At the same time, 2 sets of (10*10*10) cm coagulation specimens were placed around the mold to test the splitting tensile strength and compressive strength of the concrete under the same condition after 24 h (20-23 °C).

During the test, the concrete mixture is poured into the mold in vibrating molding, smooth surface, the specimens were placed in the mold with the wind environment, tracking observation of the cracking of concrete slab with special measuring crack width gauge. In the beginning, the concrete was observed every 5 min, when a crack was found, it was observed every 10imn. In the wind blowing condition, the specimens were observed 24 h. After the test, the main record of each plate includes initial crack time (the time it start to crack), crack size (maximum crack width and length in 24 h) length and crack number (the total number of cracks in 24 h). The number of cracks is based on the visible fracture. The length is determined by the length of the yarn along the direction of the crack, its value is measured by a steel tape measure and record as L. The maximum crack width (d) is tested through the combination of 50 times reading microscope and feeler. Then the total area of fracture and cracking is calculated as follows:

$$A = \sum d_{i\max} L_i \tag{1}$$

where A means the total area of fracture and cracking, d_imax means the maximum crack width of crack i, L_i means the length of crack i. The total area of fracture and cracking is used to evaluate properties of early plastic shrinkage. Parameters and test flow are shown below:

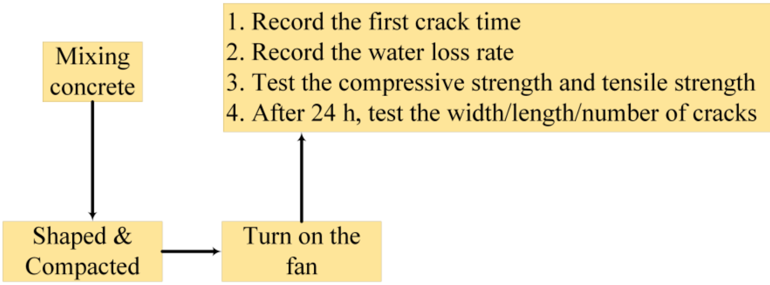

Figure 2: Flow chart of plate shrinkage cracking test

All the experiment are carried out as steps shown in the Figure 2.

2.2 Material

2.2.1 Cement

The cement is provided by anhui conch cement company. Its main components are CaO and SiO_2. The chemical and Physical proerties of it were shown in Table 1 and Table 2 respectively.

Table 1: chemical and mineral composition (%)

CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	SO_3	Na_2O.eq	C_3S	C_3A	f-CaO	LOI(S)
61.08	23.10	2.12	5.06	2.48	2.86	0.61	53.88	7.21	1.10	2.02

Table 2: Physical performance index

Fineness (%)	specific surface area (m^2/kg)	Standard consistency (%)	Stability	Setting time (h:min)		Flexural strength (Mpa)		Compressive strength (Mpa)	
				Initial	Final	3 d	28 d	3 d	28 d
1.3	341	26.7	Qualified	3:26	4:31	5.7	9.8	37.8	56.2

2. 2.2 Chemical admixture

Chemical admixture used here is high Efficient Naphthalene Water Reducing Agentprovied by Shanghai pre construction coating company. (Abbreviated NWR).

The water reducing rate is 20%, the conventional mixing amount is about 0.75%

2.2.3. Others

Sand (specific weight 2.66, fineness modulus is 3.1, with excellent particle size distribution, washed by water) and Stone (particle diameter is 5-20 mm) are provided by Shanghai pre construction coating company.

2.3 Concrete proportioning

In this study, three different water cement ratio (0.3, 04 and 05) were used, other materials used in concrete keep unchanged. Then change the amount of admixture and investigated the influence of the amount of admixture on the early cracking behavior of concrete with different water cement ratio. Mix proportion of concrete in this experiment was shown in table 3.

Table 3: Mix proportion of concrete in this experiment

Number	Cement (kg/m^3)	Sand (kg/m^3)	Stone (kg/m^3)	Water (kg/m^3)	Chemical admixture
D1	368	810	1026	192	0.3% NWR
D2	368	810	1026	192	0.5% NWR
E1	425	801	1042	171	0.5% NWR
E2	425	801	1042	171	0.3% NWR
F1	508	722	1088	152	0.75% NWR
F2	508	722	1088	152	1.0% NWR

3. Result and discussion

3.1 The influence of superplasticizer dosage on early shrinkage cracking of concrete

Under different water cement ratio, the test results of different dosage of superplasticizer (NWR) are shown in table 4.

Table 4: The test results of different dosage of superplasticizer (NWR)

Number	Slumps (mm)	Strength (Mpa)			Water loss rate (%)		Setting time (h:min)		First crack time (h:min)	Maximum crack width (mm)	Total Cracks	Crack area (mm^2)
		R1	R28	R1s1	4h	24h	Iniyial	Final				
D1	145	12.9	54.3	0.95	0.73	2.71	8:56	11:23	3:55	0.09	4	33
D2	187	12.1	55.9	0.90	0.80	2.88	10:15	12:45	3:42	0.12	13	178
E1	145	19.1	62.1	2.2	1.10	2.57	8:36	10:37	3:30	0.74	15	950
E2	205	18.2	66.2	2.1	1.23	2.92	9:59	12:33	3:16	0.42	5	530
F1	168	32.9	77.3	2.8	0.55	1.89	8:07	10:23	2:53	1.52	11	4598
F2	205	31.6	82.7	2.5	0.65	1.98	9:48	11:55	2:48	1.17	10	3190

As shown in table 4, for D1(with 0.3% NWR) and D2(with 0.5% NWR), E1(with 0.5% NWR) and E2(with 075% NWR),F1(with 075% NWR) and F2(with 1.0% NWR), With the increase of superplasticizer content, the initial crack time of concrete has become earlier. However, after 24h the maximum crack width and crack area do not coincide with the cracking time, but vary with the change of water cement ratio. The cracking area of concrete in each group is shown in Figure 3.

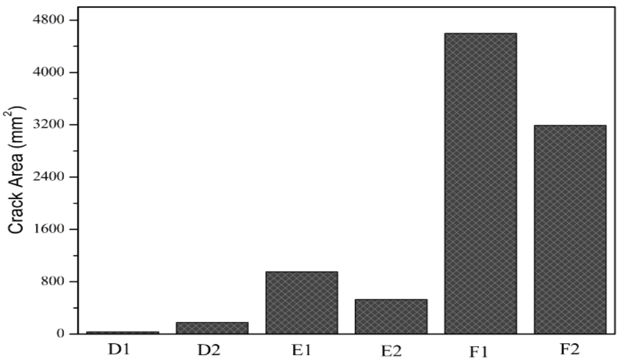

Figure 3: The cracking area of concrete in each group with different dosage of water reducing agent (NWR)

According to Table 4 and Figure 3, after 24 h the water loss rate of D2 is greater than D1, the initial crack time of D2 is earlier than that of D1; while the maximum crack width, the number of crack bars and the cracking area of D2 are all higher than that of D1. Then we can draw a conclusion that when water cement ratio is 0.5, after 24 h the number of cracks in the cracking area and the maximum crack width is increasing with the increase of its superplasticizer dosage, and that is to say too many superplasticizer is not good for improving the early cracking resistance of concrete. after 24 h the water loss rate of E2 is greater than E1, the initial crack time of E2 is earlier than that of E1; while the maximum crack width, the number of crack bars and the cracking area of E2 are all lower than that of E1, indicate that when water cement ratio is 0.4, with the increase amount of superplasticizer, after 24 h the concrete crack ahead of time while the maximum crack width, crack number and cracking area decreases, the early cracking resistance of concrete is improved. After 24 h the water loss rate of F2 is greater than Fl, the initial crack time of F2 is earlier than that of F1, and cracks number of F2 is almost the same as that of F1, while the maximum crack width and cracking area of F2 are smaller than those of F1, which shows that when water cement ratio is 0.3, with the increase of superplasticizer content, the initial cracking time of concrete is earlier while the early crack resistance is improved.

3.2 Mechanism study

The water reducing agent can increase the dispersity of cement agglomerate, change the proportion of adsorbed water and free water, increase the amount of free water, and improve the fluidity and stability of cement slurry. The mechanism is as follows (Li, 2009; Westmoreland and Fahey, 2016.): Calcium ions released by hydration of cement (positively charged) are adsorbed on the surface of cement particles (negatively charged) so that the cement particles are positively charged, the negatively charged water reducing agent molecules are adsorbed on calcium ions, thus forming a negatively charged solvation film on the surface of the cement particles. The existence of a solvent film with negatively charged polymers have many advantages: 1) It can reduces the surface energy of the cement particles, reduces the thermodynamic instability of the cement dispersions, and achieves relative stability; 2) The dynamic electric potential of cement particles is increased, and the electrostatic repulsion between cement particles is increased, thus the flocculating structure of cement particles is destroyed, and the cement particles are dispersed; 3) The solvation film prevents formation of condensed structures and produces spatial protection; 4) Because of the existence of the solvation film, the hydration of the cement at the initial stage is inhibited, thereby increasing the free water content and improving the fluidity of the cement slurry

With the formation and development of concrete strength, cracks are caused by both factors of shrinkage and strength. As the water reducing agent is adsorbed on the surface of cement particles to form an electrostatic repulsion or a solvent film to disperse the cement particles, adding water reducing agent will slow down the hydration of cement at the initial stage of adding water. The greater the amount of superplasticizer, the more slowly the concrete condenses.

After adding water reducing agent, the water reducing agent will adsorb on the surface of the hydrated cement to form the adsorption layer, thereby increasing the electrokinetic potential, making the cement particles dispersed, and this adsorption also allows the water to enter the rate of slowing down then make hydrate slowly, that is to say uperplasticizer in concrete mixing has some retarding effect, so as to increase the amount of superplasticizer, the hydration degree of concrete decreases relatively early, unhydrated cement grains increased relatively, so that the pores become coarse.

In the case of low water cement ratio, the particle spacing in concrete is small, that means small pore diameter and small loss of free water in the pores. Therefore, the early shrinkage of concrete is very important when the water cement ratio is low, which may dominant the early cracking resistance of concrete. So although the concrete compressive strength and splitting tensile strength of E1 is higher than E2(the compressive strength and splitting tensile strength strength of F1 is also higher than the F2), the early anti cracking performance of E2 is better than El (the early anti cracking performance of F2 is better than F1). This shows that the formation and development of concrete cracks are more affected by shrinkage at low water cement ratio, and the high dosage of superplasticizer is beneficial to the early crack resistance of concrete.

When water cement ratio is 0.5, the situation is different. In this moment, the early crack resistance of concrete with low amount of water reducing agent is better than that of high dosage. Under a higher water cement ratio, the autogenous shrinkage of concrete is smaller. Therefore, in the case of relatively high water cement, the early drying shrinkage and autogenous shrinkage of the aggregate is smaller. Then early shrinkage on the concrete cracking performance is less affected, it may cause that concrete strength become the main factor affecting the development of early cracks under high water cement ratio. As shown in Table 2, the compressive strength and splitting tensile strength of D2 are less than Dl. It can be explained as below: in a high water cement ratio, with the dosage of superplasticizer increases, early strength of concrete is low because of the retarding effect, make an increase of concrete cracks total number, maximum crack width and the crack area, so, in this case, the increase of superplasticizer admixture is not conducive to the improvement of early crack resistance of concrete.

4. Conclusion

Plate method not only can study the early shrinkage cracking behavior of concrete rapidly and effectively but also similar to actual engineering structure. What's more, the plate mold can make cracks easy to measure and compare. In this paper, plate mold method was used to study the influence of admixture on shrinkage cracking during mixing from early mixing to early hardening (<24 h), the test results has certain reference value to engineering practice. The shrinkage cracking behavior of concrete is affected by early shrinkage and strength development. At low water cement ratio (0.3 and 0.4), the early shrinkage value of concrete dominates the early crack resistance of concrete. In the high water cement ratio (0.5), the development of concrete strength is the main factor affecting the development of early cracks.

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