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The Effects of Water-reducer on early-age plastic Shrinkage of Concrete

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Abstract. Water-reducer is one of the dispensable components in modern concrete, can improve the workability and mechanical performance of concrete, and also has an important influence on the plastic cracking resistance of concrete. In this paper, the flat cracking test was used to evaluate the effect of water reducer on the plastic cracking resistance of concrete, meanwhile, capillary pressure; plastic settlement and evaporation rate were also tested. The results showed that water-reducer could improve the plastic cracking resistance of concrete significantly, and the effectiveness of polycarboxylate water reducer were o better than that of wood calcium and naphthalene water reducer.

Introduction

In RILEM TC 181-EAS, plastic shrinkage of concrete was defined as: shrinkage in the plastic stage of concrete, which happened before the initial structure formation. It was roughly defined as shrinkage before concrete sets. Plastic shrinkage crack has very disadvantageous influence on the properties such as permeability, chemical attack, anti-freeze, which can speed up the process of concrete degradation and reduce the durability of concrete construction[1,2]. Water reducer is one of the dispensable components in modern concrete, can improve the workability and mechanical performance of concrete, and also has an important influence on the early plastic cracking resistance of concrete. Therefore, it is necessary to study the effects of water reducer on the early plastic cracking performance of concrete.

Materials and concrete mix proportion

1.1 Materials

Cement: P•II 52.5, produced by Jiangnan-Onoda Cement.Co.,Ltd. Coarse aggregate: well-graded crushed limestone with particle size of 5-25mm. Fine aggregate: medium sand fineness modulus of 2.60. Water: running water. Water-reducer: calcium lignosulfonate superplasticizer (M3), two kinds of naphthalene-based superplasticizer (N3, N4) and two kinds of polycarboxylate-based superplasticizer (J1, J2). The performance of water-reducer is shown in Table 1.

Table 1 The performance indicators of the superplasticizer

Variety	Category	Alkali content (%)	Na_2SO_4 Content (%)	Cl^- content (%)	pH	Surface tension (mN/m)	Solid content(%)	Density (g/cm^3)	Fineness (%)	fluidity of cement paste (mm)
M3	CL	3.65	/	0.44	12.98	58.9	88.65	/	7.5	97
N3	N	3.82	2.20	0.02	6.70	67.1	35.00	1.186	/	225
N4		3.59	2.15	0.04	6.67	67.0	34.20	1.178	/	215
J1	PCA	1.41	/	0.01	7.77	37.6	20.80	1.057	/	260
J2		1.38	/	0.19	6.36	54.8	21.49	1.061	/	255

1.2 Concrete mix proportion

The design strength of concrete is C40. The mix proportions of six concrete mixtures, which are designed by JGJ 55, are shown in Table 2. The mixtures have the same water to cement ratio of 0.45 and similar. Furthermore, the cement content of control mixture (C40) that without superplasticizer is larger than that of mixture with superplasticizer, in order to archive the similar workability.

Table 2 Mix of concrete C40

Number	Concrete mix（kg/m^3）				
	Cement	Sand	Stone	Water	Superplasticizer /（%）
C40	500	645	970	225	none
C40-M3	378	750	1102	170	0.3
C40-N3	378	750	1102	170	1.2
C40-N4	378	750	1102	170	1.2
C40-J1	378	750	1102	170	1.0
C40-J2	378	750	1102	170	1.0

Test methods

A modified restrained slab referred to CCES01-2004 and ASTMC1579-06[3] was designed to evaluate the plastic shrinkage cracking to concrete. The size of the concrete slab specimen is is 900mm×620mm×80mm.

After casting, the concrete slab was covered with plastic film for 2h. Then, plastic film was removed and the slab was exposed to ambient temperature of 30℃, relative humidity of 50% and wind paralleled to the surface of the slab with speed of 2m/s.

Concrete surface evaporation rate was test by the weight loss rate of 150×300×50mm3 containers filled with concrete. And the test frequency was 10-15min. The settlement of the slab was continuously monitored every 1 min by three Microtrak II high resolution laser displacement sensors. The measuring range of the sensors is ±1 mm and the resolution is 0.1 μm. Furthermore, The capillary pressure of the concrete surface and bottom was test by the special mini-type ceramic heads that designed by Tian Qian[4,5].

Experimental results and disscussion

3.1 Effects of water-reducer admixture on the plastic cracking

Mixture proportion data are given in Table 2. Plastic crack testing is proceeded accord to the experiment method in the above. The results are shown in Table 3.

Table3 The influence of water-reducing admixture to concrete plastic crack

Mix designation	C40	C40-M3	C40-N3	C40-N4	C40-J1	C40-J2
Mix crack width (mm)	1.1	0.85	0.95	0.9	0.6	0.45
Crack area（mm^2）	763	645	754	603	368	488

The results of plastic cracking of concrete mixture listed in Table 2 are shown in Table 3.

Table 3 indicates that the crack width and crack area of concrete mixture with water-reducing is less than that of control mixture. Furthermore, the effectiveness of polycarboxylate based water is better than that of Wood calcium and Naphthalene.

3.2 Effects of water-reducer admixture on the settlement of concrete

Effects of water-reducing admixture on the settlement of concrete are shown in figure 1. (Numbers before “/” represent concrete admixture, while values after “/” represent shrinkage value when testing is ended).

3.3 The effect of water-reducer on evaporation rate of concrete

The evaporation rate of concrete is one of the important effects on the plastic shrinkage of concrete. As shown in Figure 2, the evaporation rate of concrete was calculated by the linear fitting between evaporation（g/cm2）and time(h). The results of the evaporation rate of concrete mixture listed in Table 2 are shown in Table 4.

Table4 The effect of Water-reducer on evaporation rate of concrete surface

Groups	Fitting straight line	Correlation coefficientR^2	Water evaporation($g/cm^2/h$)
C40	y=0.2758x	0.9873	0.2758
C40-M3	y=0.2468x	0.9966	0.2468
C40-N3	y=0.2564x	0.9989	0.2564
C40-N4	y=0.2627x	0.9995	0.2627
C40-J1	y=0.2227x	0.9933	0.2227
C40-J2	y=0.2235x	0.9975	0.2235

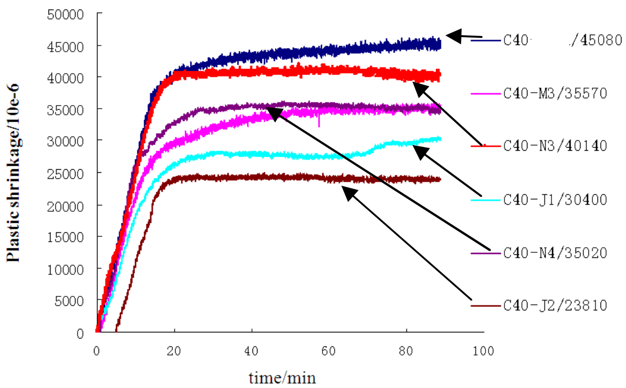


Fig.1 The influence of water-reducing admixture to concrete early plastic sedimentation

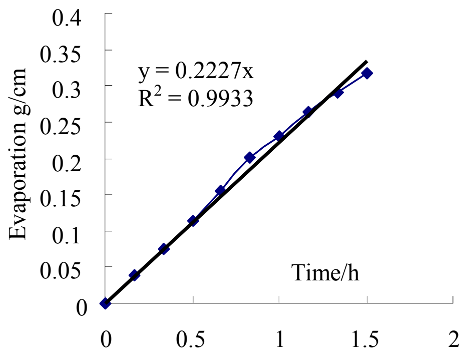
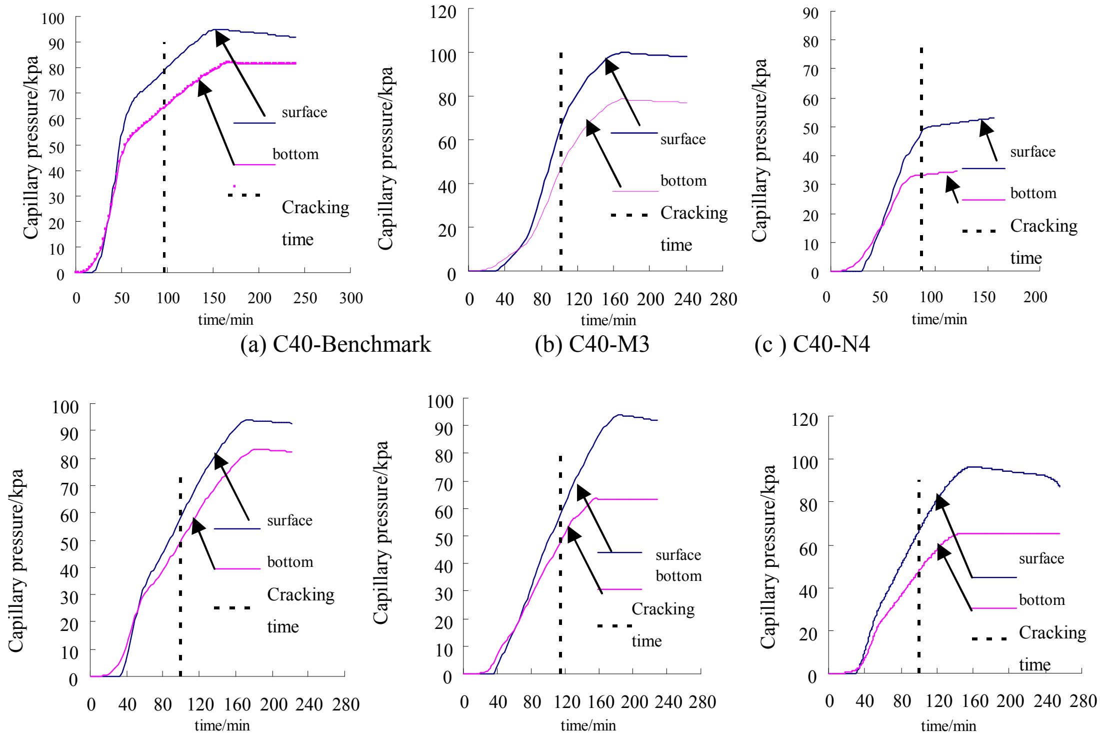


Fig.2 The effect of water-reducer on evaporation rate of concrete C40-J1

3.4 Effects of water-reducer admixture on capillary pressure of concrete

The effects of water-reducer on capillary pressure of concrete are shown in figure 4.



(a) C40-Benchmark (b) C40-M3 (c) C40-N4

（d）C40-N3 （e）C40-J1 （f）C40-J2

Fig.4 The effect of Water-reducer on early pore negative pressure of concrete

3.5 Disscussion

The plastic settlement and capillary contraction stress in concrete are major causes of concrete plastic cracking. The value of plastic settlement and water evaporation rate and other parameters are listed in table 5 when concrete plastic cracking occurs.

Figure 2 and table 5 indicate that the incorporation of water-reducer can reduce the plastic settlement remarkably. The control mixture (C40) shows the maximum plastic settlement shrinkage, which is followed by concrete with naphthalene-based water reducer and calcium lignosulfonate superplasticizer. Furthermore, Concrete with polycarboxylate-based water reducer shows the least plastic settlement shrinkage in the test. The influence of water reducer on the plastic settlement is mainly affected by its effects on the hydration of cement and viscosity of concrete. The incorporation of polycarboxylate-based water reducer increases the viscosity of concrete and reduces the water evaporation of concrete surface, which leads to less settlement shrinkage. The incorporation of calcium lignosulfonate superplasticizer retains more entrained air than does the naphthalene-based water reducer， which leads to smaller apparent density of fresh concrete and reduction of settlement caused by gravity.

The mixture C40-J2 has the least plastic settlement shrinkage and the least cracking width (0.45mm), while control mixture (C40) shows the maximum settlement shrinkage of 45080×10-6 and the maximum cracking width of 1.1mm. In addition, the settlement shrinkage of “C40-N4” and “C40-M3” are 34310×10^{-6} and 35440×10^{-6} respectively，and cracking width of them are 0.95mm and 0.85mm respectively. As results, although obvious corresponding relation is not found between the value of plastic settlement and the cracking time, the value of plastic settlement presents shows a clear association with cracking width and cracking area.

Table 5 Effect of water reducers on cracking parameters

group	cracking time /min	plastic settlement /10^{-6}	rate of water evaporation /g/cm^2/h	quantity of water evaporation /g/cm^2	capillary pressure /kPa	
					surface	inner side
C40	96	45080	0.2758	0.446	75	65
C40-M3	102	35440	0.2468	0.349	66	50
C40-N3	99	40140	0.2627	0.384	62	51
C40-N4	100	34310	0.2564	0.395	49	33
C40-J1	119	30400	0.2227	0.318	59	47
C40-J2	100	23810	0.2235	0.334	59	49

The incorporation of water reducer can effectively reduce the rate of water evaporation, and different water reducer present different effects. The sample control concrete (C40) shows the fastest the evaporation rate (0.446g/m2) and the shortest cracking time (1.5h). The incorporation of water reducer obviously prolongs the cracking time. Concrete with polycarboxylate-based water reducer presents the slowest water evaporation, and the cracking time and evaporation rate of it are 2.0h and 0.32g/m2 respectively when crack occurs. Furthermore, the cracking time of the mixture with naphthalene-based water reducer is 20min than that of the mixture with polycarboxylate-based water reducer. Moreover, due to the entrained air caused by the incorporation of calcium lignosulfonate superplasticizer, the evaporation rate reduces by 11% than that with naphthalene-based water reducer.

From section 3.4, it can be obviously seen that the curve of capillary negative pressure in concrete usually shows an induction period of about 40min, during which water evaporation leads no increase in capillary pressure. After then, a rapid increase will occur following the end of induction period, and macroscopic plastic cracking will happen.

Concrete with polycarboxylate-based water reducer (J1) presents a surface capillary pressure of 59kPa when it cracks after 2h， while the capillary pressure of concrete with naphthalene-based water reducer (N3) is 62kPa at 1.65h. According to these, higher values of capillary pressure of control concrete and concrete with calcium lignosulfonate superplasticizer can be observed when cracking occurs, they are 66kPa and 75kPa. Results indicate that although the relationship between cracking time and capillary pressure are not the same when the cracking occurs, the cracking occurs during the process of rapid increases of capillary pressure, which indicates capillary negative pressure are the one of the most important driving forces inducing cracking. Furthermore, although surface capillary pressure of concrete with water-reducer is smaller than the control concrete when cracking occurs, the cracking time is longer than the control concrete. So, water-reducer can decrease the increasing rate of capillary pressure, which further explains the effectiveness of water-reducer to decrease plastic cracking of concrete.

Conclusion

The incorporation of water reducers can significantly improve the plastic cracking resistance of concrete. And the effectiveness of polycarboxylate-based water is better than that of Wood calcium and Naphthalene.

The incorporation of water-reducer can reduce the plastic settlement and evaporation rate of concrete remarkably. Polycarboxylate-based water reducer shows a better effectiveness than do the lignosulphonate water reducer and naphthalene-based water reducer. Although obvious corresponding relation is not found between the value of plastic settlement and the cracking time, the value of plastic settlement presents shows a clear association with cracking width and cracking area.

The cracking all occurs during the process of rapid increases of capillary pressure, which indicates capillary negative pressure are the one of the most important driving forces inducing cracking. Water-reducer can decrease the increasing rate of capillary pressure, and then deceases the plastic cracking of concrete.

References

[1]Q.Tian. Research for the contraction and its mechanism of low water-binder ratio cement-based materials with high-content mineral admixtures, Nanjing, Southeast University, 2005.

[2] L.Li, W.Sun, Z.Y.Liu.Concrete 12 (2003), pp.33-36.

[3]ASTM C l579-06, ASTM International, United States.

[4]C.W.Miao, Q.Tian, J.P.Liu, W.Sun.Journal of the Chinese Ceramic Society, Vol.35-4(2007) pp.509-516

[5] Q.Tian, Y.J.Wang, J.P.Liu, C.W.Miao. “An Initial Curing Procedure Based on Pore Water Under Pressure Measurement of Cementitious Materials” in Proceedings for the 13th fiber reinforced concrete and the second conference cross-straits three concrete technology seminar,Oct.28-29,2010, pp.659-667.