IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Experimental Investigation of the Material Performance of the Ultrahigh Early Strength Concrete

To cite this article: Dechao Qu *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 032069

IOP Conf. Series: Materials Science and Engineering 471 (2019) 032069 doi:10.1088/1757-899X/471/3/032069

Experimental Investigation of the Material Performance of the Ultrahigh Early Strength Concrete

Dechao Qu [1], Yang Zhao [2], Zheng Zhou [1]

[1] Harbin Institute of Technology, Harbin, China

[2] China Institute of Building Standard Design and Research, Beijing, China

zhouzhengra@163.com

Abstract. Aiming at some special working condition, the high performance concrete (HPC) is investigated by combining the ordinary concrete with the chemical additive or the active mineral admixture. The ultrahigh early strength concrete is one of the most popular HPC which has been extensively used in the construction of roads and tunnels, owing to the advantage of setting in a shorter time. Therefore, there is a growing need to investigate the material performance of the ultrahigh early strength concrete. In this study, several sets of contrast tests are well designed and conducted in order to experimentally investigate the material performance difference between the capability of the ultrahigh early strength concrete with specific mix proportion and the ordinary concrete such as the setting time, the workability, the impermeability and the compressive strength. The experiment results show that the ultrahigh early strength concrete works better than the ordinary concrete in most of the above material characteristics. To be specific, the ultrahigh early strength concrete appears the extremely higher compressive strength in the same curing time, the better permeability resistance and the slightly lower workability. Obviously, this kind of concrete is more prone to the application in the rapid construction of roads and tunnels.

1. Introduction

Ordinary concrete has been widely used in civil engineering for its good performance, high compressive strength and low cost. With the speedy development of urban construction, it has been an assured trend to enhance the concrete performance to meet the specific requirements. For example, in the issue of the quick repair and construction, there is an urgent demand for the ultrahigh early strength concrete to shorten the construction time and conserve resources.

In recent years, many scientific researchers have been carried out to investigate the engineering application potential of the ultrahigh early strength concrete. Since 1960s, high strength concrete(HSC) has been widely used in civil engineering with the development of chemical admixtures [1-5]. Some other scientists took advantage of fiber material to increase the tensile strength of the concrete [6-7]. Besides, the mixing and curing techniques are improved to meet the new requirements [8-9]. On the basis of former framework, it is necessary to keep on researching the performance of the ultrahigh early strength concrete.

Thus, the main characteristics of the ultrahigh early strength concrete are investigated in this article. The remainder of this article is composed of 3 sections, Section 2 covers the experimental materials and methods, and afterwards, the results and discussion will be put forward in Section 3. Finally, the conclusions of this paper will be drawn out in Section 4.

2. Materials and methods

2.1. Materials composition

In this experiment, the sulfate aluminate cement, whose strength grade is 42.5MPa, is adopted as the binder. The granite stone is chosen as the coarse aggregate with the bulk density of 1.71g/cm^3. The fineness modulus of the natural medium sand is 2.83, and the bulk density is 1.83g/cm^3. The mineral admixtures selected in this experiment is the silicon powder whose fluidity ratio is more than 95%. The HTPCA poly carboxylic acid and Sodium tripolyphosphate work as the water reducing agent and concrete retarder respectively in this trail.

The mixing proportion of the ultrahigh early strength concrete is designed by comparing the compressive strength at 3days. The influence factor of each composition is analyzed and considered, above all, the mixing proportion is shown in the Table 1. In comparison, the ordinary Portland cement concrete with the similar mixing proportion is adopted in this experiment.

Table 1. The mixing proportion of the concrete composition

The ultrahigh early strength concrete			
Water-cement ratio	Retarder (%)	Water reducing agent (%)	Sand coarse aggregate ratio (%)
0.36	0.8	1.2	37

The ordinary Portland cement concrete		
Water-cement ratio	Water reducing agent (%)	Sand coarse aggregate ratio (%)
0.36	1.2	37

2.2. Experimental methods

In order to investigate the material performance of the ultrahigh early strength concrete, several sets of contrast tests are carried out. In this experiment, the setting time, the workability, the impermeability and the compressive strength are considered as the main material characteristics

2.1.1. The setting time of the concrete. The experimental procedures are shown as follows: firstly, prepare the concrete mixture in accordance with the present mixing proportion; secondly, separate out the mortar with the standard sieve, and vibrate the mortar in the specimen barrel; thirdly, control the temperature in about 20 degrees, and record the time since the mortar is mixed with water; afterwards, measure the concrete strength by the concrete penetration resistance tester during the curing process until the concrete come into the final setting. Six specimens are produced in this test, three of which are made by the ordinary concrete.

The relationship between setting time and penetration resistance can be determined by linear regression method, as shown in equation (1):

$$\ln t = a + b \ln f_{PR} \tag{1}$$

where

t = the setting time of the concrete;

a,b = linear regression coefficients;

f_{PR} = the penetration resistance (MPa).

Respectively, the initial(t_s) and final(t_e) setting time of the concrete can be calculated in the following equations:

$$t_s = e^{(a+b\ln 3.5)} \tag{2}$$

$$t_e = e^{(a+b\ln 28)} \tag{3}$$

2.1.2. The workability of the concrete. The workability of the concrete generally includes cohesiveness, water-retaining capacity and mobility. Since the former two metrics are hard to quantify, only the performance of mobility is selected in this article.

The concrete mobility can be measured in the slump test, which is carried out using a metal mould called slump cone. During the test, the slump cone is placed on a hard non-absorbent ground filled with fresh concrete in three stages. Each layer should be tamped compactly, and at the end of the third layer, the fresh concrete fill to the full of the mould. Finally, the mould is carefully lifted vertically, and the slump of the concrete is measured from the top of the slumped concrete to the top of the mould.

2.1.3. The impermeability of the concrete. The impermeability of the concrete refer to the ability to resist the infiltration of internal and external material, which determines the water and erosive material can be kept out. Thus, the impermeability of the concrete is an important factor of the durability of the concrete.

In this test, HS 4.0 concrete anti permeability apparatus is adopted. At first, six concrete specimens with 28 days' age are prepared; second, the specimens are smeared with sealing material and pressed into a pre-heated metal mould; third, the specimens are placed in the testing instruments and applied with elevated hydraulic pressure until the third specimen starts to leak. The final pressure H is recorded, and the osmotic pressure S (MPa) of the concrete is calculated in the following equation:

$$S=10H\text{-}1 \tag{4}$$

2.1.4. The compressive strength of the concrete. In this test, the specimens are made into cubes with the size of 150×150×150mm. In each group of the experiment, three specimens are prepared in the same curing condition with the temperature of (20±2)℃. The compressive strength is tested with the curing age of 8h, 3d and 28d.

3. Results and discussion

3.1. The setting time of the concrete.

The results of the setting time of the ultrahigh early strength concrete and ordinary concrete are shown and analyzed in this part.

Table 2. The test data table of the ultrahigh early strength concrete

penetration resistance (MPa)	Curing time (min)	lnf_{PR}	ln$t$
1.3	184	0.262	5.217
2.5	206	0.916	5.327
3.3	217	1.194	5.382
5.6	242	1.723	5.490
9.2	264	2.219	5.578
14.2	282	2.653	5.644
17.6	292	2.868	5.679
30	328	3.401	5.794
a		5.1679	
b		0.1802	
$a+b\times\ln3.5$		5.393	
$a+b\times\ln28$		5.768	
Initial setting time（h）		3.6	
Final setting time（h）		5.3	

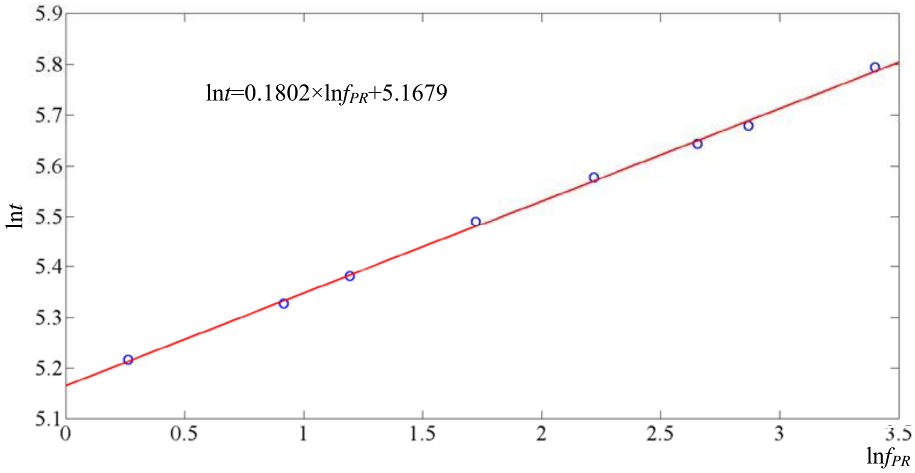

Figure 1. The regression diagram of the ultrahigh early strength concrete setting time

Table 3. The test data table of the ordinary concrete

penetration resistance (MPa)	Curing time (min)	lnf_{PR}	ln$t$
1.4	460	0.336	6.132
2.6	491	0.956	6.197
3.1	503	1.131	6.219
7.8	563	2.054	6.334
11	586	2.398	6.374
15.6	600	2.747	6.397
23	623	3.135	6.436
32.5	657	3.481	6.488
a		6.0929	
b		0.1129	
$a+b\times\ln3.5$		6.234	
$a+b\times\ln28$		6.469	
Initial setting time（h）		8.5	

Final setting time（h）	10.7

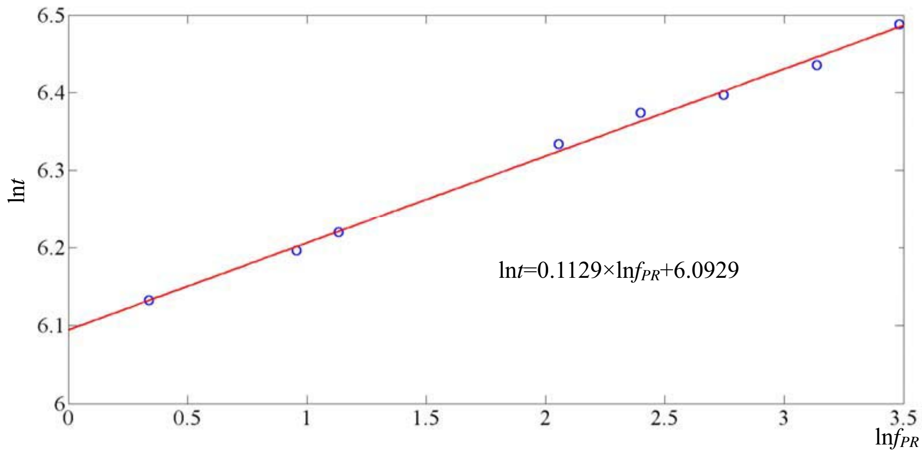

Figure 2. The regression diagram of the ordinary concrete setting time

The comparison diagram is displayed in the figure 3, it apparently shows that the ultrahigh has shorter initial and final setting time than the ordinary concrete. To be specific, the initial setting time of the early strength concrete is about 3h. This is because the ultrahigh early strength concrete is added with the retarder, which is absorbed by mineral component in the cement and forms a layer of shell on its surface, the layer of shell can work as a blocker to resist the process of the cement hydration. In actual construction, the retarder ratio can be changed to adjust the initial setting time.

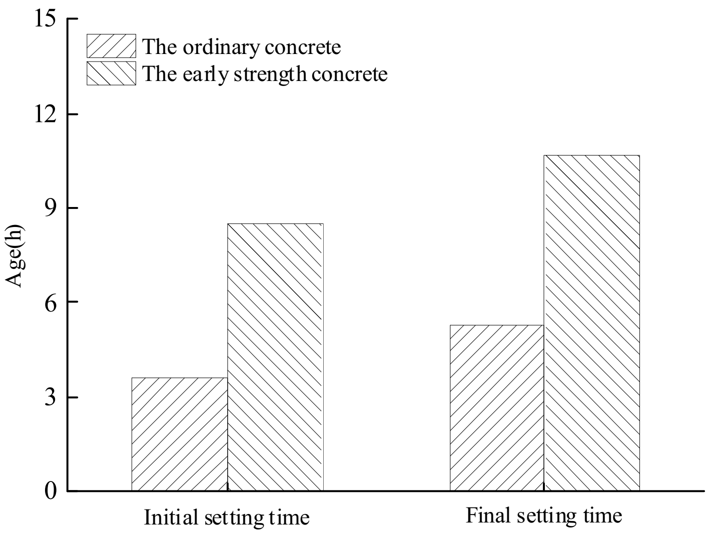

Figure 3. The comparison of the setting time

3.2. The workability of the concrete.

The results of the slump test are shown in the Figure 3, it is clear that the mobility of the ultrahigh early strength concrete is similar to the ordinary concrete. Besides, the slumped concrete comes to settle gradually after hitting by the side, which shows the ultrahigh early strength concrete has a good ability of cohesiveness. And there is no seeping water around the slumped concrete, indicating a good water-retaining capacity. From the above results, the ultrahigh early strength concrete is suitable for the quick construction.

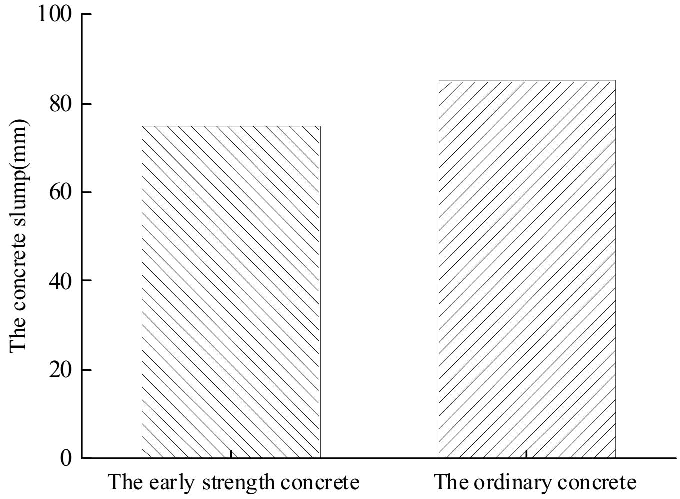

Figure 4. The comparison of the concrete slump

3.3. The impermeability of the concrete.

The results of permeability resistance test are shown in the Table 4, apparently the impermeability of the ultrahigh early strength concrete is better than the ordinary. This is because the ettringite produced by the hydration of the sulphoaluminate cement can overlap with C-S-H gel to form compact cement structure, which resists the water migration inside the concrete. Obviously, when working in humid condition, the ultrahigh early strength concrete is more adaptive than the ordinary concrete.

Table 4. The impermeability of the concrete

Specimen number	Concrete type	Osmotic pressure（MPa）	Impermeability level
1#	The ultrahigh early strength concrete	1.8	S16
2#		1.6	S14
3#		1.9	S18
4#	The ordinary concrete	1.2	S12
5#		1.5	S14
6#		1.3	S12

3.4. The compressive strength of the concrete.

As shown in the figure 5, the compressive strength of the the ultrahigh early strength concrete increases as the curing time grows. It is clear that the compressive strength of 8h has reaches the half the 28d. Sulphoaluminate cement is chosen as the raw material of the ultrahigh early strength concrete, because of its characteristics of fast hardening and early strength. Therefore, when added with water reducing agent and retarder, the kind of concrete can meet the design requirements.

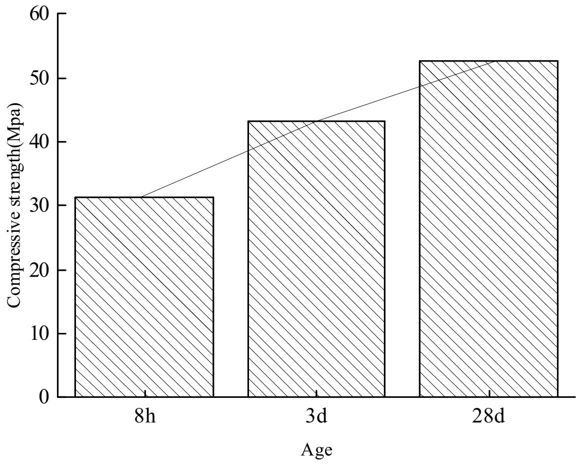

Figure 5. The growing trend of compressive strength

4. Conclusions

In this paper, sulphoaluminate cement, the water reducing agent and the retarder are chosen as the raw material of the ultrahigh early strength concrete. Using the orthogonal test methods, the following conclusion are drawn.

- The initial and final setting time of the ultrahigh early strength concrete are only 3.6h and 5.3h, nearly half of the ordinary concrete.
- The ultrahigh early strength concrete has a good performance in workability and impermeability, which can meet the requirements in complex environment.
- The compressive strengths of the ultrahigh early strength concrete reach 31.4Mpa, 43.2Mpa and 52.6Mpa when the curing times are 8h, 3d and 28d, which completely satisfies the design requirements.

References

[1] H. Shunsuke, and K. Yamada. “Interaction between cement and chemical admixture from the point of cement hydration, absorption behaviour of admixture, and paste rheology.” Cement & Concrete Research, vol. 29.8, pp. 1159-1165, 1999.

[2] P.C. Aïtcin. “Developments in the application of high-performance concretes.” Constr. Build. Mater., vol. 9(1), pp. 13–17,1995.

[3] Aiad, S.A. El-Aleem, and H. El-Didamony. “Effect of delaying addition of some concrete admixtures on the rheological properties of cement pastes.” Cement & Concrete Research, vol.32.11, pp. 1839-1843, 2002.

[4] N.M. Altwair, M. Johari, and S. Hashim.“Flexural performance of green engineered

cementitious composites containing high volume of palm oil fuel ash." Constr. Build. Mater.,vol. 37, 518–525, 2012.
[5] M. Khokhar, E. Roziere, and P. Turcry. "Mix design of concrete with high content of mineral additions: Optimisation to improve early age strength." Cement & Concrete Composites, vol. 32.5, pp. 377-385, 2010.
[6] O. Faruk, A.K. Bledzki, H.P. Fink, and M. Sain. "Progress report on natural fiber reinforced composites." Macromolecular Materials and Engneering, vol. 299, pp. 9-26, 2014.
[7] S. Fallah, M. Nematzadeh. "Mechanical properties and durability of high-strength concrete containing macro-polymeric and polypropylene fibers with nano-silica and silica fume." Contruction and Building Materials, vol. 132, pp. 170-187, 2017.
[8] Y.Z. Chen, G.P. Yan, and M.Z. An. "Research of influential factors on compressive strength of reactive powder concrete with normal mixing technology." Railway Engneering, vol. 03, pp. 44-48, 2003.
[9] Y.B. He, Y.H. Wu, Y.H. Yang, and et al. "Compounding technology and materials select for reactive powder concrete." Fujian Architechture & Construction, vol. 01, pp. 70-72, 2003.