STUDY ON OPTIMIZATION OF HIGH PERFORMANCE CONCRETE ADMIXTURES

Liu Junlong[1,2], *Ma Haiyan*[1], *Li Qiang*[1,2], *Chen Shudong*[2], *Zhang Yunqing*[1]

(1. College of Aerospace Engineering, NUAA, 29 Yudao Street, Nanjing, 210016, P. R. China; 2. Department of Architecture and Civil Engineering, Zhejiang College of Construction, Hangzhou, 311231, P. R. China)

Abstract: Influences of admixtures on the workability and strength of high performance concrete (HPC) are investigated. The types of investigated admixtures include naphthalene series high range water reducing agent, polycarboxlic series high range water reduce agent and sodium sulfate hardening accelerating agent. Two kinds of curing condition, namely steam curing condition and standard curing condition, are adopted. The result shows that HPC, added with polycarboxlic series of high performance water reducer, has high workability and strength, while sodium sulfate accelerating agent causes poor workability and low strength. Thus for vapor-cured HPC and its formulations, naphthalene series high range water reducing agent with less sodium sulfate should be given priority. Therefore, the differences of curing conditions should be considered when selecting HPC admixtures.

Key words: high performance concrete; high performance water reducer; hardening accelerating agent; slump; compressive strength

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INTRODUCTION

With the advancement of science and technology and the sustainable development, demands on high strength and excellent durability of concrete or concrete structure are increasing. High-strength concrete and high performance concrete (HPC) attract world-wide attention and serve as significant construction materials for many great buildings such as highway bridges, seafloor tunnels and dams[1-2]. Water reducing agent, especially high range water reducing agent is an important component of high-strength concrete and HPC[3-6]. However, in the selection of HPC admixtures, which one should be chosen, naphthalene-based water reducer or polycarboxylate-based water reducer? In prefabrication of concrete works, people always want to improve the concrete strength by using accelerating agent. But what is the effect?

The influences of naphthalene series high range water reducing agent and polycarboxlic series of high performance water reducer on the strength and the vapor-cured characteristics of concrete added with sodium sulfate hardening accelerating agent are discussed and specified.

1 EXPERIMENT

1.1 Raw materials

(1) Cement: Portland cement P. II 52.5R produced by Dongguan Huarun Cement Manufactory in Guangdong, whose physical and mechanical properties are tested and shown in Table 1. The chemical composition of cement clinker is listed in Table 2.

(2) Coarse aggregates: crushed granite, whose maximum particle size is 16 mm and packing density and apparent density are 1 410 kg/m^3 and 2 565 kg/m^3.

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E-mail: ljl94916@163.com

Table 1 Properties of cement

Specific surface/ ($m^2 \cdot kg^{-1}$)	Residue on 80 μm sieve/%	MgO/ %	SO_3/ %	Water requirement for normal consistence/%	Setting time		Flexural strength/ MPa		Compressive strength/ MPa	
					Initial	Final	3 d	28 d	3 d	28 d
375	1.3	2.78	0.73	24.2	2:12	2:58	6.4	9.6	33.0	58.0

Table 2 Chemical composition of cement clinker %(in weight)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	f-CaO	I. L	Total
21.70	5.22	3.56	64.79	2.78	0.58	0.05	0.73	1.14	0.18	100.73

(3) Fine aggregates: river sand, whose packing density and apparent density are 1 480 kg/m^3 and 2 605 kg/m^3. Its mud content is less than 1% and fineness modulus is 2.55, Gradation II, belonging to medium sand.

(4) Mineral admixtures: grade I fly ash produced by Shenzhen Shajiao Thermal Power Plant, S95 grade of ground blast furnace slag produced by Lianda Gaoxin Building Materials Factory in Pingxiang, and micro silicon powder (Aiken) produced in Shanghai, in which the content of SiO_2 is greater than 90%. The performance indexes of fly ash and fine-slag are shown in Table 3.

(5) Water reducing agents: Maidi MNF-3 accelerating water reducing agent (powder) produced in Shenzhen, JM-B Naphthalene series high range water reducing agent (powder) produced by Jiangsu Bote New materials Co. Ltd. and JM-PCA (I) polycarboxlic series of high range water reducing agent (aqueous solution agent) produced by Jiangsu Bote New materials Co. Ltd. The water reducing rate of the first one possibly achieves above 12%, and the content of sodium sulfate in it is more than 14.5%. This admixture is formed by Naphthalene series high range water reducing agent and anhydrous sodium sulfate which contains a large quantity of unevenly-mixed white aggregates of sodium sulfate. The water reducing rate of the second one is above 20%, and the content of sodium sulfate and the chloride ion in it are less than 3% and 0.05%. The last one contains low alkalinity and no chloride ion, and its water reducing rate is more than 35%.

(6) Hardening accelerating agents: anhydrous sodium sulfate, white powder.

(7) Water: Tap water.

1.2 Mix proportions

Table 4 shows the mix proportions of HPC, for different samples as No. 1,2,3,4,5, which are added with JM-B Naphthalene series high range water reducing agent, MNF-3 hardening accelerating and water reducing agent, JM-PCA (I) polycarboxlic series of high range water reducing agent and hardening accelerating agent. The test aims to find out the effects of naphthalene-based water reducer and polycarboxylate-based water reducer, analyze the harm of sodium sulfate hardening accelerating agent and determine the principles for selection of HPC admixtures.

Table 3 Performance indexes of fly ash and ground blast furnace slag

Material	Residue on 45 μm sieve/%	Specific surface/ ($m^2 \cdot kg^{-1}$)	Ratio of fluidity/%	Water content/ %	SO_3/ %	Loss/ %	Index of activity/%	
							7 d	28 d
Fly ash	10.6	—	≤95*	≤1	1.01	2.14	—	≥75**
Slag	2.9	543	100	0.3	1.10	0.70	86	105

* Ratio of water demand; ** Ratio of compressive strength.

Table 4 Mix proportions of HPC

No.	Mix proportions/(kg · m^{-3})							Water-reducing agent	Hardening accelerating agent/%	Water-to-binder ratio
	Cement	Fly ash	Slag	Silica fume	Sand	Coarse aggregate	Water			
1	400	70	0	0	747	1 175	150	0.7%JM-B	0	0.32
2	450	50	0	0	680	1 175	177	0.8%MNF-3	0	0.35
3	481	65	65	39	683	1 066	162	1.6%JM-PCA(I)	0	0.25
4	490	54	0	0	713	1 115	180	0.7%JM-B	0	0.33
5	517	57	0	0	697	1 091	207	0.9%JM-B	5	0.36

1.3 Test method

The raw materials are mixed by a compulsory mixer, then the fresh state slump and the 1 h slump are measured. Afterwards, concrete prisms with size of 100 mm×100 mm×400 mm are prepared and sealed with plastic sheets. They are then separated into two groups for different kinds of curing conditions. The steam cured group is firstly put into a tunnel kiln for steam curing, during which fast curing system is adopted, namely the specimens are put directly in steam curing at a constant temperature of 85—90℃ for 4 h, without the periods of increasing and decreasing temperature. Then the specimens are taken out of the kiln and demoulded, afterwards they are standardly cured for 28 d. The standard cured group is demoulded after 24 h in room temperature and then standardly cured for 28 d. The standard curing condition is saturated $Ca(OH)_2$ solution at the temperature of 20 ℃. The compressive strength is then determined by a 2 000 kN press machine, and the values are modified by a mutilation of 0.95 to be translated to the standard cubic compressive strength.

2 RESULTS AND DISCUSSIONS

2.1 Effects of admixtures on workability of HPC

Table 5 shows the initial and 1 h slump of concretes with different admixtures. The results demonstrate that for No. 1, 2, 4, 5 concretes, although the water-to-binder ratios are similar, the slump and slump loss are different. When naphthalene-based water reducer with high content of sodium sulfate or sodium sulfate hardening accelerating agent is added, the slumps of HPC are smaller and the speed of loss is faster. Although the water-to-binder ratio is relatively low, the workability of HPC with polycarboxlic series of high performance water reducer is superior to the one with naphthalene series high range water reducing agent and its initial slumps and slump loss are smaller. Therefore, when preparing for HPC, the priority should be given to polycarboxylate-based water reducer. If naphthalene series high range water reducing agent is added, the content of sodium sulfate must be limited.

Table 5 Initial and 1 h slumps of HPC mm

No.	Initial slump	1 h slump
1	30	0
2	5	0
3	90	60
4	185	65
5	40	0

2.2 Effects of admixtures on compressive strength of standard cured HPC

Fig. 1 shows the compressive strength of standard cured HPC which added with different admixtures. The results demonstrate that for No. 1, 2, 4, 5 concretes, which have the similar water-to-binder ratio, the strengths of HPC are quite different. When naphthalene-based water reducer with high sodium sulfate or sodium sulfate hardening accelerating agent is added, the compressive strength of HPC decreases. It is the reason why international bid was invited for concrete admixtures in the year when China introduced the complete sets of technology of Daya Bay Nuclear Power Station in Shenzhen from abroad. One of the key technical indexes for naphthalene series high range water reducing agent was that the content of sodium sulfate must be limited strictly. At that time, no admixtures in China could meet the bid demand, so investors had to import a large quantity of high range water reducing agents from foreign countries. And it has been an important event in the development of admixtures in China.

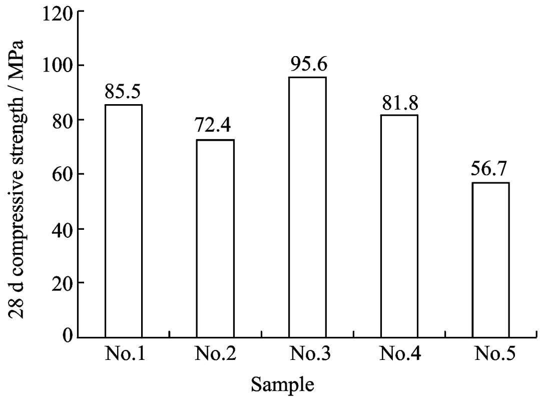

Fig. 1 Compressive strength of standard cured HPC

HPC with polycarboxlic series of high range water reducing agent can achieve a much lower water-to-binder ratio while its strength is higher. Therefore, for HPC polycarboxlic series of high performance water reducer should be given priority.

2.3 Effects of admixtures on compressive strength of steam cured HPC

Fig. 2 shows the compressive strength of steam cured HPC samples of No. 1, 3, 4 and 5. Results show that compared with strength of the standard cured specimens, as shown in Fig. 1, steam curing reduces the compressive strength of HPC. When concrete specimens are added with naphthalene series high range water reducing agent, the compressive strength decreases by 14%. When concrete specimens are added with polycarboxylate-based water reducer, the compressive strength reduces by 19%. When 5% sodium sulfate hardening accelerating agent is added, the compressive strength of steam cured HPC shows no enhancement compared with the corresponding standard cured specimens. It demonstrates that when preparing HPC, the use of hardening accelerating agent should be prudent and not used simultaneously with naphthalene-based water reducer. It is naphthalene-based water reducer with high concentration and low sodium sulfate content that is recommended. Therefore, for steam cured HPC naphthalene series high range water reducing agent with low sodium sulfate should be given priority, and polycarboxylate-based water reducer should not be added.

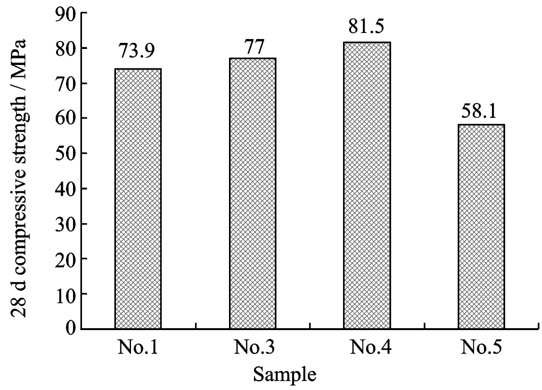

Fig. 2 Compressive strength of steam cured HPC

3 CONCLUSIONS

(1) In order to ensure the workability and high strength of HPC, polycarboxlic series of high performance water reducer should be given priority. If naphthalene series high range water reducing agent is added, the content of sodium sulfate in it should be strictly limited.

(2) For steam cured HPC, naphthalene series high range water reducing agent with low sodium sulfate should be given priority and polycarboxylate-based water reducer should not be added.

(3) Sodium sulfate hardening accelerating agent cannot increase the strength of HPC, but reduce it. So the use of this kind of early strength should be prudent.

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高性能混凝土的外加剂优化研究

刘俊龙[1,2] 麻海燕[1] 李 强[1,2] 陈树东[2] 张云清[1]

(1.南京航空航天大学航空宇航学院,南京,210016,中国; 2.浙江建设职业技术学院建筑工程系,杭州,311231,中国)

摘要:运用不同减水剂和早强剂配制高性能混凝土(High performance concrete,HPC),测定其工作性、标准养护强度和蒸汽养护强度,研究了HPC的外加剂选用原则。结果表明,掺加聚缩酸系高效减水剂有利于HPC获得高工作性和高强度。硫酸钠早强剂将导致工作性不好,强度降低。对于蒸汽养护的HPC制品,应该优先采用硫酸钠含量低的萘系高效减水剂。因此,HPC外加剂的选择应该考虑养护条件的差异。

关键词:高性能混凝土;高效减水剂;早强剂;坍落度;抗压强度

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