EFFECTS OF ANTI-FOAMING ADMIXTURE ON PROPERTIES OF ULTRA-HIGH PERFORMANCE CONCRETE

LING QIN[1] , XIAOJIAN GAO[1,2] *, HUAN YE[1], TIEFENG CHEN[1]
[1] *School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China*
[2] *Key Lab of Structure Dynamic Behavior and Control (Harbin Institute of Technology), Ministry of Education, Harbin 150090, China*

This paper aims to investigate effects of anti-foaming admixture (AFA) on air content, flowability, mechanical strength and microstructure of ultra-high performance concrete (UHPC). UHPC mixtures were prepared with two water-binder ratios of 0.17, 0.2 and three AFAs (XP1, XP2, XP3) were added by 0.05-0.4% of the mass of binder. Results reveal that the air content of fresh UHPC mixture decreases whit the incorporation of AFA and XP1 behaves the best decreasing effect. The compressive strength of UHPC added with AFA is increased and XP2 presents the best effect. The decrease of water-binder ratio from 0.2 to 0.17 doesn't lead to an increase in compressive strength due to the more air bubbles entrapped in very low water-binder ratio mixture. A good exponential relationship (f=a*x^b) can be found between compressive strength and entrapped air content. The incorporation of AFA decreases the coarse pore content (＞100nm) and air bubbles with diameter bigger than 100μm in hardened specimen, playing a positive role in optimizing pore structure and improving strength.

Keywords: *Ultra-high performance concrete; Workability; Compressive strength; Pore size distribution; Anti-foaming admixture*

1. Introduction

In recent years, more and more large-span spatial structures and super high-rise structures have been built all over the world. Such a tendency in construction forces cement concrete to develop toward higher strength, higher durability and higher reliability [1,2]. In the early 1980s, Bache developed Densified with Small Particles materials (DSP). The main idea is to mix concrete with high active volcanic ash and high efficient water reducing agent [3]. The tiny particles of high active volcanic ash fill the gap and increase the compressive strength of concrete to about 200 MPa. Birchall et al developed Macro Defect Free material (MDF) with similar level of strength [4]. The process involves mixing concrete with a low water-cement ratio with water-soluble polymer, adopting high speed stirring and pressure molding process. In the early 1990s, Bouygues company in France firstly developed Reactive Powder Concrete (RPC) with less internal defects, very high strength and durability [5,6]. RPC can be divided into two strength grades, RPC200 (compressive strength is less than 200 MPa) and RPC800 (compressive strength is between 200 and 800 MPa). In 1994, Larrard and Sedran [7] firstly proposed the concept of "Ultra High Performance Concrete" (UHPC), RPC and UHPC are the same concrete in essence. Until now, applications of UHPC in Europe, North America, Australia, Asia and New Zealand have been reported.

The preparation of UHPC is different from ordinary concrete [8], its raw materials including Portland cement, active volcanic powder, super fine aggregate (quartz sand), steel fiber (if needed) and high performance superplasticizer. Concrete is a typically porous and heterogeneous material, optimizing ingredients and preparation method to optimize pore structure is key for UHPC to obtain high strength and high durability [9]. It is well known that polycarboxylate superplasticizer has many advantages including low dosage, strong dispersion effect, small slump reduction, high early strength and excellent durability effect on concrete [10,11]. Nevertheless, some researches indicated that this type of superplasticizer presents air-entraining effect [12], resulting many bubbles in concrete mixtures [13,14]. Another research [15] indicated that the excessive air-entrainment in concrete is mostly caused by the reduction of surface tension of liquid phase in paste caused by superplasticizers. It becomes very important to eliminate the excessive air-entraining effect of superplasticizers [16] for preparing high strength concretes. Anti-foaming admixture (AFA) can eliminate the extra-large bubbles and adjust the air content in fresh concrete to an appropriate amount, improve the strength gain and the surface appearance of hardened concrete[17,18]. For normal strength concretes, anti-foaming admixtures have two aspects of effects [19,20]. On the one hand, it can inhibit the formation of air bubbles in

---

* Autor corespondent/*Corresponding author*,
E-mail: gaoxj@hit.edu.cn

Table 1

Physical and mechanical performances of quartz sand.

Quartz sand type	range of particle size (μm)	Constituent (wt.%)		apparent density (g/cm^3)	packing density (g/cm^3)
		SiO_2	Fe_2O_3		
Coarse	360~600	≥60~6	≤60~6	2.65	1.405
Fine	180~360	≥80~3	≤80~3	2.65	1.329

Table 2

Mixing proportion of two control UHPC mixtures.

w/b	Cement	Silica fume	Silica sand	SP
0.17	100	25	110	3.00
0.20	100	25	110	2.25

fresh mixture; On the other hand, it can break the bubbles that have already formed.

Until now, there is few literatures about the influence of anti-foaming admixture on UHPC. Therefore, the purpose of this research is to investigate the effects of different kinds of anti-foaming admixture on the fresh properties (air content, flowability), mechanical performance and microstructure of UHPC.

2. Experimental

2.1. Raw materials

The cement used is Portland cement with strength grade of 52.5 according to Chinese standard GB 175-2007. Silica fume (SF) was used as a mineral admixture with specific surface area of 2.1×105 cm2/g and a SiO_2 content of more than 92.8%. Two types of quartz sand produced by Harbin Jinghua Water Treatment Material Company were used as aggregates as shown in Table 1. A mixture of 60% coarse quartz sand and 40% fine quartz sand was used for preparing all the UHPC mixtures.

A polycarboxylate-based superplasticizer (SP) from Harbin Qiangshi Company was used. It has a water reducing efficiency of higher than 30% and a solid content of about 40%. Three types of anti-foaming admixtures were ALSCOAP W-181-S (XP1) as a yellowish transparent liquid from Japanese Toho Chemical Industry Company, Polyether (XP2) as a yellowish liquid from one company in China, XIAMETER®AFE-7610 organic silicon (XP3) as a milky white viscous liquid from American Dow Corning Corporation.

2.2. Mixing proportion and specimen preparation

Two control UHPC mixtures with water-binder ratio of 0.17 and 0.20 were designed as shown in Table 2. Three types of anti-foaming admixtures were added by 0.05~0.40% of total binder weight respectively.

All the mixtures were prepared by using a HOBART Mortar mixer with the same procedure. When UHPC mixtures were ready, prism specimens with size of 40×40×160mm3 were prepared by using a plastic mould. The mixture was casted in molds by two layers and vibrated for 90 seconds to consolidate the mixtures. The specimens in mould were covered with plastic sheet and placed under the room temperature (22 ± 3℃) for 24 h to minimize loss of water from the surface. Afterward, the specimens were taken out from their molds and stored in the standard curing room (22 ± 3℃, RH 90%) till the age of strength measurement.

2.3. Test methods

The fluidity of every fresh mixture was carried out by using the test method for flowability of cement mortar, in accordance with the Chinese National Standard GB/T 2419-2005. A mini cone mold was placed at the center of a jolting table. Firstly, the fresh mixture was poured into the cone mold in two layers and each layer is tamped 15 times uniformly. Then, the mold was lifted vertically and the sample on the jolting table was dropped 25 times. Finally, the mean value of two diameters, perpendicular to each other, was recorded as the final flowability. The air content in fresh mixture was measured by the water column method according to EN 12350. The compressive strength and flexural strength for every mixture were measured on the prepared prism specimens according to GB/T17671-1999. Three-point flexural test was conducted and averages of three specimens for each batch were reported as tested results. Six broken samples after flexural test were used to measure compressive strength and the average of six samples was reported as the tested compressive strength. Typical specimens were selected for determining air bubble and pore structure in hardened UHPC. The air bubble or void distribution was carried out by using a microscope with super depth of field (as shown in Fig. 1). Pore size distribution test was carried out by using a IV 9510 mercury intrusion porosimeter (MIP) with a pressure range from 0 to 60000 psi (414 MPa), capable of measuring pore size diameter down to 3.0 nm.

Fig. 1 - DSX-HRSU microscope with super depth of field.

3. Results and discussion

3.1. Flowability and air content

Figure 2 exhibits the effects of three kinds of anti-foaming admixture on the air content and flowability of fresh UHPC mixtures when the water-binder ratio is 0.17. The air content of the control UHPC mixtures is 9.6%, which was remarkably higher than that of normal concrete (1%-2%) and it was decreased obviously with the introduction of anti-foaming admixture. Similar effect was reported for fresh self-compacting concrete (SCC) [19,20]. At the same level of dosage, XP1 has the best effect of decreasing air content and XP3 behaves the worst. For every anti-foaming admixture, the air content decreased firstly and then increased with the more addition. The optimal dosage of XP1, XP2 and XP3 are 0.25%, 0.30% and 0.25% respectively. Compared with the air content of control mixture, the minimum air content at these dosage levels decreased by 64.58%, 59.38% and 46.88% respectively. With the introduction of anti-foaming admixtures, the flowability of fresh mixture fluctuated more or less with the air content. Generally, the highest fluidity occurs around the lowest air content [20], possibly due to less water and paste needed for coating bubble surface.

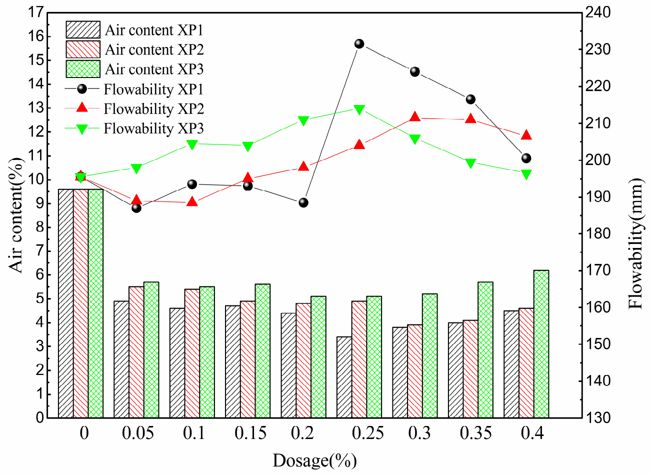


Fig. 2 - Effects of anti-foaming admixture on air content and fluidity of fresh UHPC mixture (w/b=0.17)

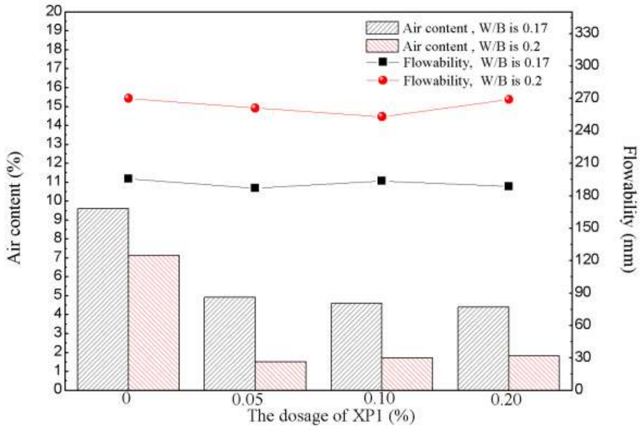


Fig. 3 - Fluidity and air content of fresh UHPC mixtures with different water-binder ratio.

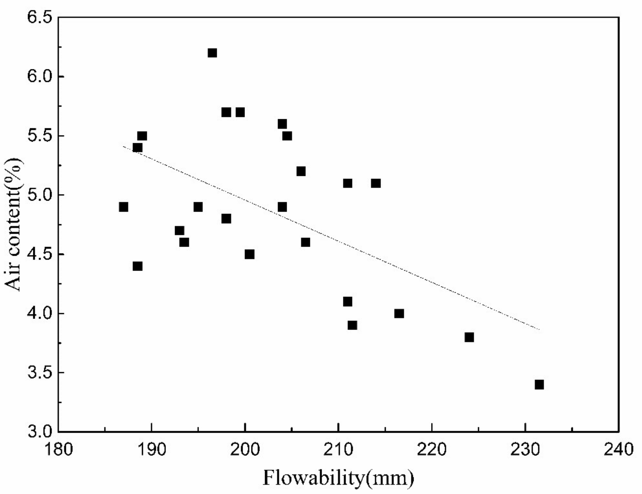


Fig. 4 - The relationship between the flowability and air content.

Figure 3 presents the flowability and air content of UHPC mixtures with two different water-binder ratios. The flowability of mixture with water-binder ratio of 0.2 is obviously higher than that of mixture with water-binder ratio of 0.17 as expected. When the dosage of XP1 increased from 0 to 0.2%, the flowability of fresh mixture fluctuated in a limited range for these two water-binder ratios. Therefore, the addition of anti-foaming admixture has little influence on the flowability. The entrapped air content in fresh UHPC was remarkably reduced by the addition of 0.05% anti-foaming admixture XP1 from 9.6% to 4.9% for water-binder ratio of 0.17 and from 7.1% to 1.5% for water-binder ratio of 0.20. Therefore, the lower water-binder ratio results in the more entrapped air content in UHPC mixture and weakens the reducing air bubble effect of anti-foaming admixture, being possibly related to the increased viscosity. The increasing dosage of XP1 from 0.05% to 0.20% has little influence on the air content for these two water-binder ratios.

The relationship between flowability and air content of UHPC is plotted in Fig. 4. It can be found that there was nearly a linear relationship between flowability and air content, the increase of flowability caused the decrease of air content. It was reported that rheological parameters determined the nature of changes in air content for non-air-entrained concrete mixtures [21]. Previous investigates revealed that the decrease of plastic viscosity and yield stress can cause the increase of slump flow diameter and decrease of slump flow time, furthermore the air content in the SCC mixture also decrease [22]. This can be used to explain the tendency of change in air content with flowability for the UHPC in this study.

3.2. Compressive strength

Figure 5 presents the effects of three kinds of anti-foaming admixture on the compressive strength of UHPC at 7 and 28 days when the water-binder ratio is 0.17. Generally, the compressive strength of UHPC increased with the introduction of anti-foaming admixture due to the decreased air bubbles [18-20]. Being similar to air content tendency, the compressive strength of UHPC raised firstly and then declined with the increasing addition of anti-foaming admixture. The maximum compressive strength of UPHC at 28 days reaches 111.6 MPa, 115.4 MPa and 109.1 MPa, being compared with 94.5 MPa for the blank sample, when 0.25% of XP1, 0.3% of XP2 and 0.25% of XP3 was added respectively. Therefore, the addition of anti-foaming admixture has a significant increasing effect on strength of UHPC.

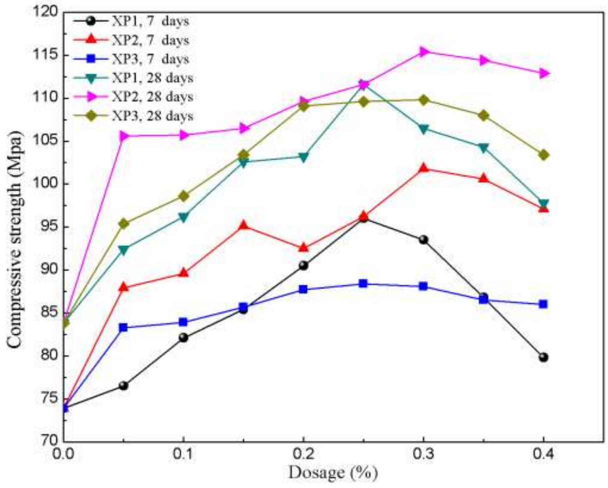


Fig. 5 - Compressive strength of UHPC added with different kinds of anti-foaming admixture (w/b=0.17).

Figure 6 exhibits the compressive strength of UHPC containing XP1 when the water-binder ratios are 0.17 and 0.2 respectively. The compressive strength of UHPC at 7 days and 28 days substantially increased with the increasing of water-binder ratio from 0.17 to 0.20. This is related to less air bubbles entrapped in the higher water-binder ratio mixture and insufficient mixing water for cement hydration when the water-binder ratio is very low. The optimal dosage of XP1 decreased from 0.25% for the water-binder ratio of 0.17 to 0.05% for the water-binder ratio of 0.20. This is possibly due to the better dispersion and higher efficiency of anti-foaming agent in mixture with higher fluidity, and other reasons should be further researched.

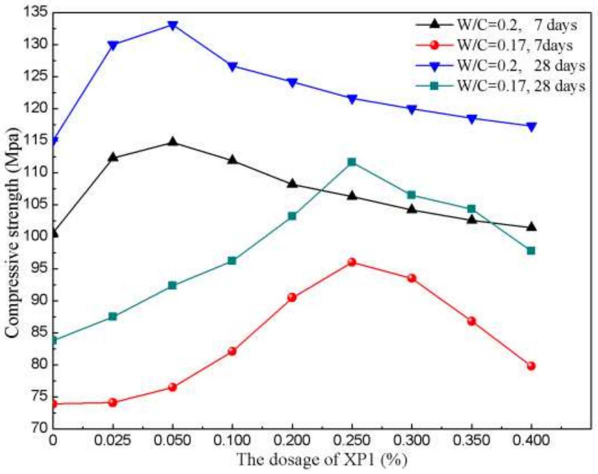


Fig. 6 - Compressive strength of UHPC with different water-binder ratio.

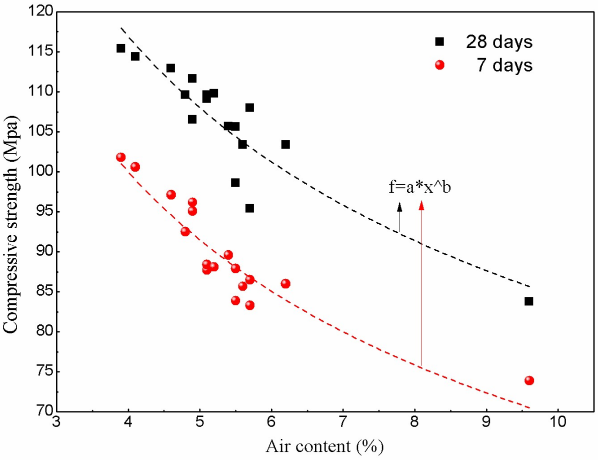


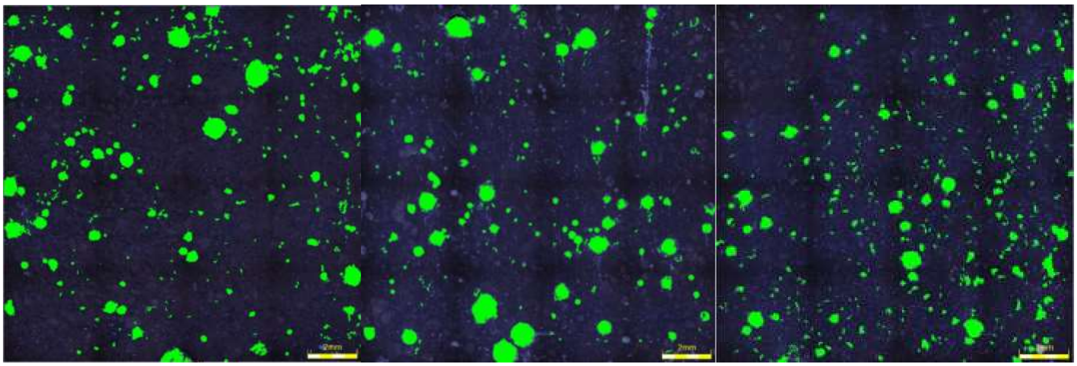
Fig. 7 - Relationship between air content and compressive strength.

3.3. Relationship between air content and compressive strength

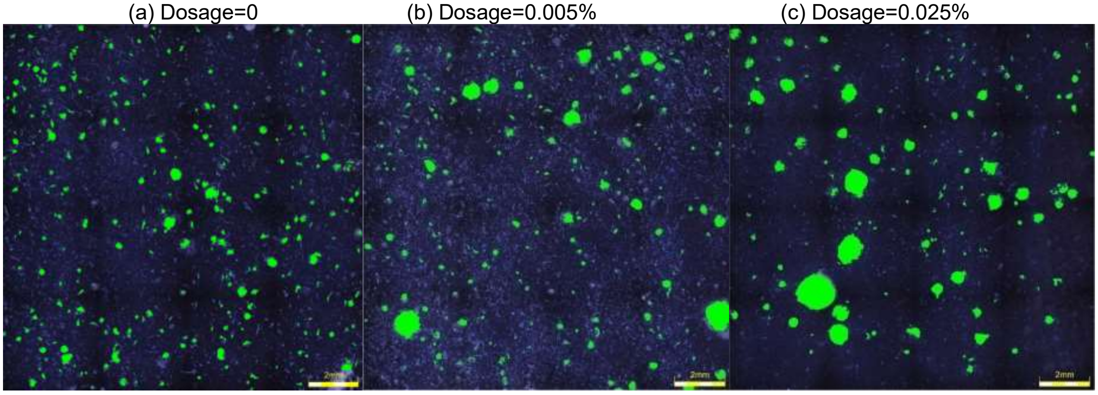
Figure 7 exhibits the relationship between air content and compressive strength of UHPC. The compressive strength of UHPC at 7 days and 28 days increased with the decrease of air content, being similar to ordinary concrete [17]. For ordinary concrete, every 1% decrease in air content increases compressive strength by 4%-6% [23], which is similar with that found in UHPC (about 4.6%) in this study. It was also indicated that the air-void characteristics consists of dispersion, size distribution and shape have substantial effects on the mechanical properties of concrete [24]. The relationship between air content and compressive strength can be expressed by equation

7d: $f=173.702*x^{(-0.39835)}$

28d: $f=191.27259*x^{(-0.3551)}$ [3-1]



(a) Dosage=0 (b) Dosage=0.005% (c) Dosage=0.025%



(d) Dosage=0.05% (e) Dosage=0.1% (f) Dosage=0.2%

Fig. 8 - Air bubbles in the cross section of hardened UHPC specimens containing XP1.

Table 3

Air bubble distribution of different UHPC.

Group	Total bubble content(%)	Bubble size distribution（%）		
		<100μm	100～200μm	>200μm
Control	8.43	80.88	12.65	6.47
XP1-0.005%	6.66	82.19	13.12	4.69
XP1-0.025%	5.3	83.56	13.69	2.75
XP1-0.05%	2.91	92.47	7.53	0
XP1-0.1%	3.42	86.06	10.58	3.36
XP1-0.2%	4.52	89.51	7.69	2.8

The correlation coefficients of the two equations are 0.9596, 0.90336 respectively. Based on this result, the air content reduction is an important method to improve mechanical strength of UHPC[25].

3.4 Air bubbles and pore structures

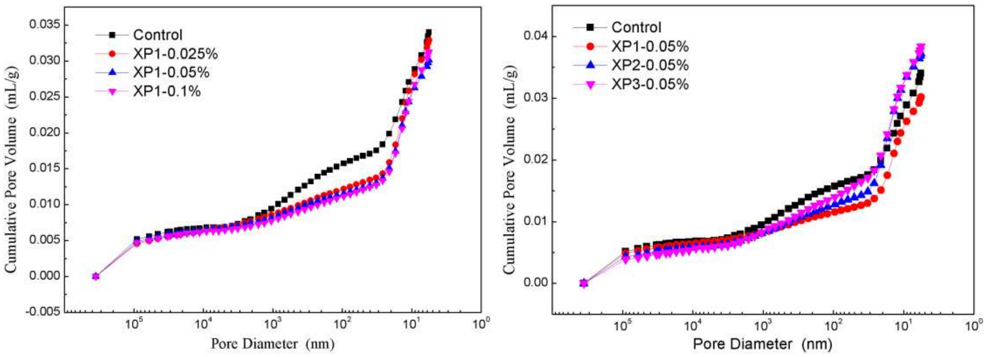
3.4.1. Air bubbles observed by Super Depth of Field Microscope

The air bubble distribution in cross section of UHPC samples with water-binder ratio of 0.20 is presented in Figure 8. For the control sample without anti-foaming agent, there are many air bubbles with different sizes in specimen and the average area content of air bubbles in the cross section is around 8.43%, a little higher than the volume content in fresh mixture. The increased content is probably attributed to small pores among particles initially occupied by mixing water. In terms of bubble size distribution, there are 80.88% bubbles with diameter of smaller than 100μm, 12.65% bubbles with diameter of 100μm~200μm and 6.47% bubbles bigger than 200μm.

With the more addition of XP1, the air bubbles decreased firstly and then increased, with a similar tendency of air content in fresh mixture. From Table 3, the total bubble content by area is 2.91%~6.66% with the introduction of XP1. The minimum point occurs at the dosage level of 0.05%, being in accordance with the strength and air content results mentioned above. In terms of bubble size distribution, there are 82.19%~92.47% bubbles with diameter of smaller than 100μm, 7.53%~13.69% bubbles with diameter of 100μm~200μm and 0%~4.69%bubbles bigger than 200μm. Therefore, the increasing effect on UHPC mechanical strength of anti-foaming agent is mainly attributed to the decreasing content of air bubbles with diameter bigger than 100μm.

3.4.2 Pore structure by MIP

The pore structures for selected samples were measured by MIP and the results are presented in Figure 9. Typical pore parameters are



(a) Different dosage of XP1 (b) Different kinds of anti-forming admixtures

Fig. 9 - The pore structure results of UHPC samples.

Table 4

Pore structure parameters of different UHPC.

Group	Porosity (%)	Most probable pore diameter（nm）	Pore size distribution（%）			
			<10nm	10～50nm	50～100nm	>100nm
Control	7.44	12.2526	20.45	30.22	4.41	44.92
XP1-0.025%	7.24	12.2471	21.38	38.87	3.79	35.96
XP1-0.05%	6.68	12.2485	19.31	39.79	3.54	37.36
XP1-0.1%	6.89	12.2487	22.11	39.28	3.92	34.69
XP2-0.05%	8.16	12.7378	15.77	46.90	4.00	33.33
XP3-0.05%	8.38	12.7327	17.44	41.22	6.24	35.10

included in Table 4. The porosity of UHPC samples added with 0.025%, 0.05%, 0.1% of XP1 are all less than the control sample without introducing anti-foaming admixture. Nevertheless, the porosity of UHPC samples added with 0.05% of XP2, XP3 were all slightly higher than the control sample. From the pore size distribution, all the UHPC samples containing anti-foaming admixture have less content of coarse pores with diameter bigger than 100 nm. This is another reason for the increasing effect on strength of UHPC. And the related mechanism of anti-foaming admixture to refine pore structure of UHPC will be further studied.

4. Conclusions

From the above experimental results, the following conclusions can be obtained:

1) The air content of UHPC decreases obviously with the introduction of anti-foaming admixture. XP1 behaves the best effect, decreasing 64.58% of air content by the optimum dosage of 0.25%. On the other hand, the fluidity of fresh UHPC mixtures is increased more or less by the addition of anti-foaming admixture.

2) Anti-foaming admixtures can improve the compressive strength of UHPC. XP2 presents the best effect with the optimum dosage 0.3%. Compared with the control mixture, the compressive strength of UHPC at 28 days is increased by 9.3%.

3) The decrease of water-binder ratio from 0.2 to 0.17 does not lead to an increase in compressive strength due to the more air bubbles entrapped in very low water-binder ratio mixture.

4) The compressive strength of UHPC decreases with the increase of air content. The relationship between these factors at 7 days and 28 days can be expressed by: f=173.702*x^(-0.39835), f=191.27259*x^(-0.3551).

5) The incorporation of anti-foaming admixture decreases the coarse pore content (＞100nm) and air bubbles with diameter bigger than 100μm in hardened specimen, playing a positive role in optimizing pore structure and improving strength.

REFERENCES

1. M. A. Mosaberpanah, O. Eren. Relationship between 28-days compressive strength and compression toughness factor of ultra high performance concrete using design of experiments. Procedia Engineering, 2016, **145,**1565.
2. A. Alsalman, C. N. Dang, W. M. Hale. Development of ultra-high per-formance concrete with locally available materials. Construction and Building Materials, 2017, **133**, 135.
3. A. Hu, Y. Fang, J. F. Young, et al. Humidity dependence of apparent dielectric constant for DSP cement materials at high frequencies. Journal of the American Ceramic Society, 2010, **82**(7),1741.
4. S. Donatello , M. Tyrer , C. R. Cheeseman. Recent developments in macro-defect-free (MDF) cements. Construction and Building Materials, 2009, **23**(5),1761.
5. P.Richard, M. Cheyrezy. Reactive powder concretes with high ductility and 200-800 mpa compressive strength. Aci Special Publication, 1994, **114**, 507.
6. P. Richard, M. Cheyrezy. Composition of reactive powder concretes. Cement and Concrete Research, 1995, **25**(7), 1501.
7. F. D. L.Sedran. Optimization of ultra-high-performance concrete by the use of a packing model. Cement and Concrete Research, 1994, **24**(6), 97.

8. H. Yiğiter, S. Aydın, H. Yazıcı, M. Y. Yardımcı. Mechanical performance of low cement reactive powder concrete (lcrpc). Composites Part B Engineering, 2012, **43**(8), 2907.
9. Y. N. Liang, B. C. Chen, J. I. Tao, Z. B. Huang, Y. Z. Zhuang. Effects of sand-binder ratio, water-binder ratio and volume percentage of steel fiber on the performance of rpc. Journal of Fuzhou University, 2011, **39**(5), 748.
10. H. Huang, C. Qian, F. Zhao, J. Qu, J. Guo, M. Danzinger. Improvement on microstructure of concrete by polycarboxylate superplasticizer (pce) and its influence on durability of concrete. Construction and Building Materials, 2016, **110**, 293.
11. X. Shu, Q. Ran, J. Liu, H. Zhao, Q. Zhang, et al. Tailoring the solution conformation of polycarboxylate superplasticizer toward the improvement of dispersing performance in cement paste. Construction and Building Materials, 2016, **116,** 289.
12. S. Janusz, L. P. Beata. Air-entrainment problem in self-compacting concrete. Journal of Civil Engineering Management, 2009, **15**(2),137.
13. Y. Li, C. Yang, Y. Zhang, J. Zheng, H. Guo, M. Lu. Study on dispersion, adsorption and flow retaining behaviors of cement mortars with tpeg-type polyether kind polycarboxylate superplasticizers. Construction and Building Materials, 2014, **64**(22), 324.
14. B. Ma, M. Ma, X. Shen, X. Li, X. Wu. Compatibility between a polycarboxylate superplasticizer and the belite-rich sulfoaluminate cement: setting time and the hydration properties. Construction and Building Materials, 2014, **51**(2), 47.
15. S. Das, L. D. Weerasiri, W. Yang. Influence of surface tension on bubble nucleation, formation and onset of sliding. Colloids & Surfaces A Physicochemical & Engineering Aspects, 2017, **516**, 23.
16. P. J. Andersen. The effect of superplasticizers and air-entraining agents on the Zeta potential of cement particles. Cement and Concrete Research, 1986, **16**(6), 931.
17. B. Łaźniewska-Piekarczyk. Analysis of the influence of type, amount and way of introduction of anti-foaming admixture (afa) on the properties of self-compacting concrete mix. Brittle Matrix Composites, 2010, **4**(1), 1.
18. B. Łaźniewska-Piekarczyk. The influence of chemical admixtures on cement hydration and mixture properties of very high performance self-compacting concrete. Construction and Building Materials, 2013, **49**(1), 643.
19. B. Łaźniewska-Piekarczyk. Influence of antifoaming admixture type on several properties of high-performance self-compacting concrete. Journal of Materials in Civil Engineering, 2015, **27**(9), 04014247.
20. B. ŁazniewskaPiekarczyk. Influence of anti-foaming admixture on frost resistance and porosity characteristic of self-compacting concrete. Archives of Civil Engineering, 2012, 57.
21. R. Wang , X. Gao. Relationship between flowability, entrapped air content and strength of UHPC mixtures containing different dosage of steel fiber. Applied Sciences, 2016, **6**(8), 216.
22. A. Kostrzanowska-Siedlarz, J. Gołaszewski. Rheological properties and the air content in fresh concrete for self compacting high performance concrete. Construction and Building Materials, 2015, **94,** 555.
23. R. Y. Bai, J. W. Cai, J. X. Wu, et al. Influence of air content on the compressive strength of concrete. Advanced Materials Research, 2012, **535-537,**1790.
24. P. Choi, J. H. Yeon, K. K. Yun. Air-void structure, strength, and permeability of wet-mix shotcrete before and after shotcreting operation: The influences of silica fumeand air-entraining agent. Cement and Concrete Composites. 2016, **70,**69.
25. J. Dils, V. Boel, G. D. Schutter. Vacuum mixing technology to improve the mechanical properties of ultra-high performance concrete. Materials and Structures, 2015, **48**(11), 3485.

* * *

MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS

Advanced Materials for Sustainable Infrastructure Development

Gordon Research Conference

Green and Low Carbon Cementitious Materials for Sustainability

August 5 - 10, 2018 , The Hong Kong University of Science and Technology , Clear Water Bay, Kowloon
Hong Kong, CN

The energy consumption of buildings is about 25 to 40% of the total energy consumption of the whole society. Hence, it is important to make buildings energy efficient to achieve the sustainability of the world. The energy efficiency of buildings depends largely on the material employed. With sustainable materials, the ability of future generations to meet their needs will not be compromised by the construction and operation of buildings.

Cement is the largest manufactured product on Earth by mass. Combined with water and mineral aggregates it forms cement-based materials. This conference will focus on the information exchange on these new developments in the sustainable cementitious material as well as the close collaboration among the conference participants in the future. The topics of the conference will cover both basic research and practical application of sustainable cementitious materials for sustainable energy effective buildings.

Contact: https://www.grc.org/advanced-materials-for-sustainable-infrastructure-development-conference/2018/