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Study on frost resistance durability and bubble parameters of high air content concrete under different freezing rate

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Abstract. The frost resistance durability and bubble parameters of high air content concrete under different freezing rate were studied from the perspective of macroscopic and microscopic properties. The frost resistance durability and air void parameters of concrete were analysed at multiple scales by electronic balance, non-metal ultrasonic tester and linear traverse method, respectively. The results indicated that the mass and dynamic elastic modulus of concrete decrease with the increase of freezing rate. As the freezing rate increases, the bubble spacing of concrete increases, and the average diameter of the bubbles becomes larger. Therefore, in addition to the low temperature during freezing, freezing rate is another important factor affecting the durability of concrete.

1. Introduction

Frost resistance is an important indicator of concrete durability. The anti-freezing test method for the temperature of the concrete specimen of -17 degrees is the commonly used test method in China. The evaluation of the frost resistance durability of concrete is basically based on the test method[1]. Air entraining is a common use method to improve the frost resistance of concrete[2]. Air entraining agent is a common method to improve the frost resistance of concrete. It can bring tiny bubbles into the concrete [3]. Most studies showed that in a certain air content, the frost resistance of concrete depends mainly on the bubble spacing and number of bubbles[4,5]. According to Powers' theory[6], the frost damage of concrete was mainly caused by pore water expansion in concrete. The volume expansion of water into ice causes concrete damage. As we all know, the speed of cooling can affect the process of water formation into ice. Therefore, This paper refers to the antifreeze test method in the Chinese standard, setting a low temperature of -40℃, and four different cooling rates. The frost durability performance of concrete with 6% air content at different cooling rates was studied. The frost durability of concrete was characterized by mass change, dynamic elastic modulus loss and bubble parameters.

2. Experimental method

2.1. Raw Material

P·O 42.5 ordinary Portland cement with 3.02 g/cm^3 specific gravity produced by a Chinese cement plant, grade Ⅰ fly ash, a concrete water reducer agent(20% solids content and 20.8% water-reducing ratio), and air-entraining agent named Air-202 (with 2% solids content) were used in this experiment. The sand used was natural medium with the following parameters: a fineness modulus 2.71 and water absorption of 1.26%. The limestone coarse aggregate with particle size of 5mm~20mm and 20mm~40 mm was used, a clay content of less than 1.0%, water absorption (saturated surface dry) of 1.53%.

2.2. *Mix proportions*

Referring to the standard specifications, a high air content concrete was prepared and tested (as shown in Table 1). In the table, the mix was marked as C30F300: C30 is a strength grade, F300 is a frost resistance grade. The amounts of admixtures, including water-reducing agent and air-entraining agent, were based on the total amount of cement and fly ash. The slump of concrete was controlled at 50mm~90mm, and the air content was controlled above 6.0%.

Table 1. Mix proportions of test concrete.

Sample	W/B ratio	Cement	Fly ash	Sand	Aggregate	Water-reducing Agent(1/100)	Air-entraining agent(1/10000)
C30F300	0.38	1	0.25	2.45	4.55	0.9	5.0

2.3. *Test methods*

All concrete samples with size of 100mm × 100mm × 400mm for experiment were prepared according to SL 352-2006 *Test code for hydraulic concrete* The entire concrete samples were cured 28 days in the 20℃ temperature and 90% relative humidity condition. The air content of the concrete sample was tested in accordance with SL 352-2006 *Test code for hydraulic concrete* by using the direct-reading air content meter. The dynamic elastic modulus of hydraulic concrete was tested according to SL 352-2006 *Test code for hydraulic concrete* by using a non-metal ultrasonic tester. The air void parameters were tested by using bubble parameter measuring instrument in accordance with ASTM C457/C457M-16. The freezing rate used in the freeze-thaw test as shown in Figure 1. Four freezing rates of 10℃/h, 20℃/h, 30℃/h and 60℃/h were adopted during the test. The thawing temperature was 8℃, and the thawing process lasts about two hours.

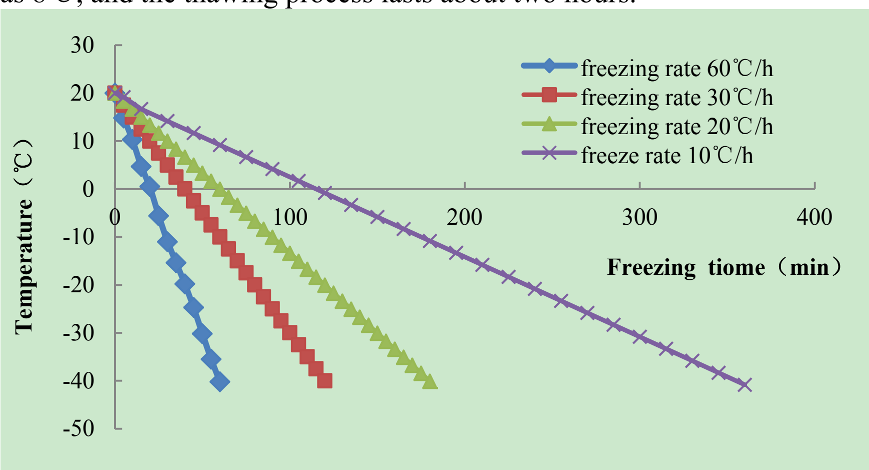

Figure 1. Four different freezing rate during freeze-thaw cycles test.

3. Results and discussion

3.1. *Frost resistance durability*

Three concrete samples were used for frost resistance test during freezing-thawing experiment. Before freezing and thawing experiment, the initial mass and initial dynamic elastic modulus of each samples were tested. After each fifty numbers of freeze-thaw, the frost resistance of the concrete samples were tested again. The frost resistance test results at four different freezing rate as shown in Figure 2.

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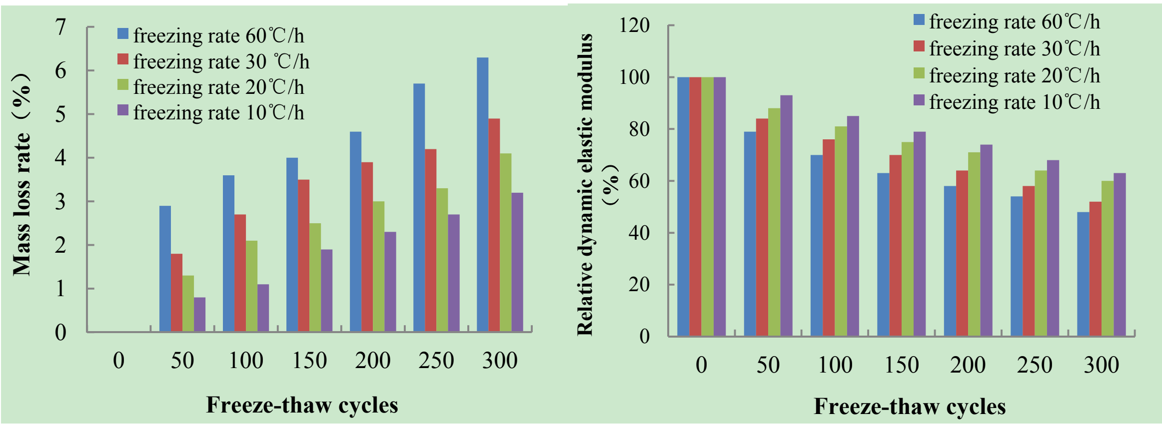

Figure 2. Frost resistance test results.

Although the freezing temperature and the thawing temperature during freeze-thaw cycle test were set at -40℃ and 8 ℃, respectively, the freeze resistance of concrete showed significant differences after 300 freezing and thawing due to different freeze rate. As shown in Fig.2, at a certain temperature freezing rate condition, the frost resistance decline degree of concrete increase with the freeze-thaw cycles. At certain number of freezing and thawing condition, the mass loss and dynamic elastic modulus loss of concrete increase with the increase of freezing rate. Rapid cooling of the freezing process causes more serious damage to concrete samples. Take the freezing rate 60℃/h and 10℃/h as an example, after three hundreds of freezing and thawing, the mass loss of concrete at 60℃/h cooling rate is almost twice the 10℃/h freezing rate.

3.2. Air void parameters

The air void parameters had important effect on the frost durability of concrete[7,8]. Part of the cut plane samples used for concrete bubble parameter test listed in Figure 3. For every 100 freezing and thawing cycles, a plane of 1cm thickness was cut from the concrete specimens that have been finished dynamic modulus test for bubble parameters experiment. Table 2 showed the bubble parameter test results.

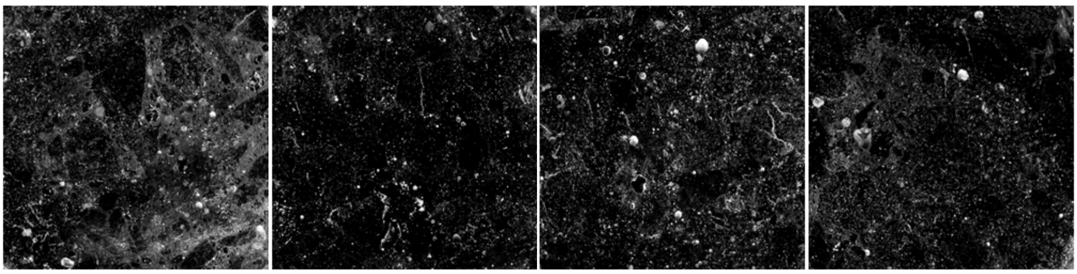

Figure 3. Cut plane concrete sample.

Table 2. Bubble parameters test results.

Freezing rate	Average diameter (μm)				Spacing factor (μm)			
(℃/h)	0	100	200	300	0	100	200	300
60	151	181	192	215	182	203	222	241
30		172	183	192		191	211	225
20		169	173	186		186	198	211
10		160	164	177		183	192	205

Before the freezing and thawing cycle test, the average bubble diameter of the concrete 151μm, the bubble spacing was 182μm. The variation of bubble parameters at different cooling rates was shown in Figure 4.

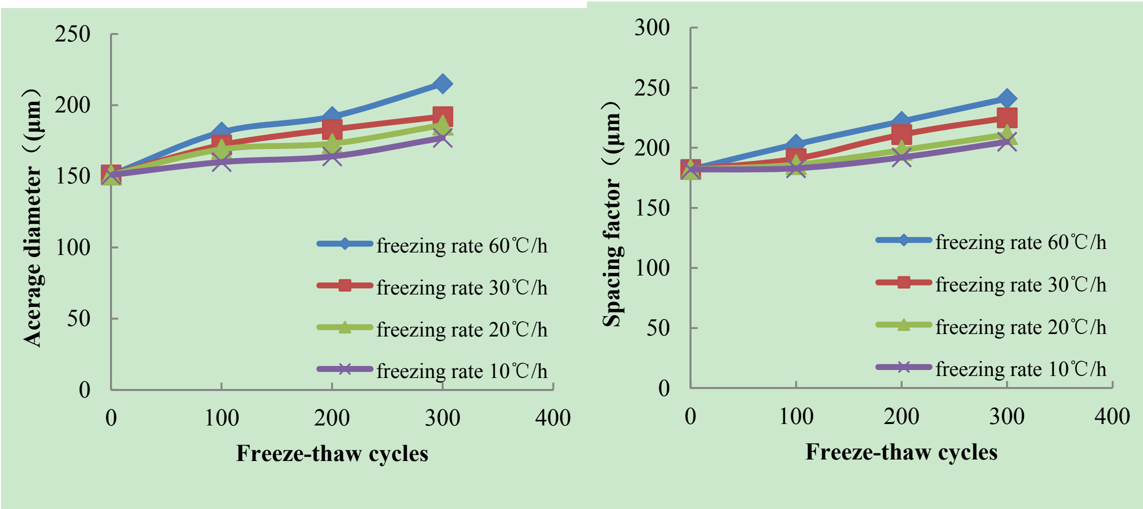

Figure 4. Air void parameters at different freezing rate.

Comparing the concrete samples at 10℃/h, 20℃/h, 30℃/h and 60℃/h freezing rate, with increasing freezing rate, the change of average diameter at the 300th freeze-thaw cycle as follows: 177μm, 186μm, 192μm and 215μm, the average diameter changed from the smallest to the largest. Rapid cooling causes an increase in the average diameter of bubbles in concrete. Moreover, the change of spacing factor at the 300th freeze-thaw cycle as follows: 205μm, 211μm and 241μm, 225 and 195μm, the spacing factor between the bubbles in the concrete also increases with rapid cooling.

4. Conclusion

The authors studied the relationship between cooling rate and frost durability of high air content concrete. The main conclusions were shown as follows.

Freeze temperature has an important effect on frost resistance durability of concrete during freeze-thaw cycle. Although the low temperature conditions at the end of the freezing and thawing process are the same, the frost resistance of concrete with high air content is significantly different after 300 freeze-thaw due to the different cooling speeds during the freezing process.

Rapid cooling will cause more deterioration of freeze durability of concrete with high air content. In addition, rapid cooling causes the average bubble diameter increase, and also the spacing between the bubbles increases. Larger bubble diameter and bubble spacing gradually make the frost durability of hardened concrete worse.

Acknowledgments

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