

# Study on the Influence of Air-Entraining Agent on Concrete Pore Structure Based on Nuclear Magnetic Resonance Technology

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**Abstract:** In this study, the effects of air-entraining agent dosage and freeze-thaw on the microporous characteristics of concrete were systematically investigated. By testing the working performance of fresh concrete, the change of elastic modulus after freezing and thawing, combined with nuclear magnetic resonance technology, the mechanism of air-entraining agent on pore structure parameters was revealed. The test found that the appropriate amount of air-entraining agent could improve the workability of the mixture and enhance the frost durability of concrete. With the increase of the amount of air-entraining agent, the internal porosity of the material continued to increase, and the pore size distribution showed an evolution law of first optimization and then deterioration. When the dosage of air-entraining agent was 0.04%, after 250 freeze-thaw cycles, the proportion of beneficial pores in concrete reached a peak, which was higher than that of other dosage groups. However, when the dosage increased to 0.06%, not only the number of harmful pores increased significantly, but also the excessive porosity and complex pore morphology led to the deterioration of frost resistance. This study provides an important technical basis for the design of engineering concrete mix ratio in cold areas.

**Keywords:** Air-entraining agent, Working performance, Relative dynamic modulus of elasticity, Pore structure.

## 1. Introduction

In the extreme climate environment of the cold region of Northwest China, the concrete structure has been subjected to severe conditions such as freeze-thaw cycles and salt erosion for a long time, and its durability is facing severe challenges. As a key admixture to improve the frost resistance of concrete, the air-entraining agent can effectively alleviate the frost heave pressure and significantly improve the frost resistance durability of concrete by introducing evenly distributed microscopic bubbles[1]. Although scholars at home and abroad have carried out extensive research on the application of air-entraining agents in concrete, the research on the influence mechanism of air-entraining agents on concrete properties is still not perfect in view of the compound environmental factors such as dry-cold alternation and strong ultraviolet radiation unique to the cold region of Northwest China[2][3], especially in the quantitative relationship between air-entraining agent content and concrete mechanical properties and frost resistance. Yun et al. showed that air entrainment can reduce the viscosity and flow resistance of the slurry, thereby improving the pumpable performance, and the viscosity changes tend to stabilize when the gas content exceeds 5%. Mohamed[4]-[5]found that the frost durability of concrete is affected by multiple factors such as air content, critical bubble spacing, water-glue ratio, aggregate characteristics, critical water saturation and cooling rate. By analyzing the effects of freezing conditions on the frost

resistance and microstructure of concrete, Sahin Yusa [6]believes that repeated freeze-thaw cycles are the main causes of frost damage and early failure of concrete structures, and the degree of damage can be evaluated by the degree of internal crack propagation and surface erosion. By adjusting the amount of air-entraining agent, pore structure analysis and microscopic morphology observation, this study reveals the internal mechanism of air-entraining agent to improve the frost resistance of concrete, and provides scientific basis for improving the durability of concrete structures and optimizing material design in northwest cold region.

## 2. Raw Materials and Test Methods

### 2.1. Raw materials

In In this experiment, cement, water, fly ash and air-entraining agent were used as raw materials to prepare concrete. P·O 42.5 Portland cement grade II fly ash; The fine aggregate is natural river sand, the coarse aggregate is 5~31.6mm continuous granular gravel, the air-entraining agent is GYQ-III®. concrete high-efficiency air-entraining agent, and the superplasticizer is polycarboxylate superplasticizer.

### 2.2. Mix ratio

The air-entraining agent adopts the external doping method, and the air-entraining agent content is the mass fraction of the total cementitious material, and the dosage is 0%, 0.02%, 0.04% and 0.06% respectively, as shown in Table 1.

Table 1. Cementitious material mix

numbering	water (kg/m <sup>3</sup> )	cement (kg/m <sup>3</sup> )	Fly ash (kg/m <sup>3</sup> )	Bulking agent (kg/m <sup>3</sup> )	Water reducer (kg/m <sup>3</sup> )
J1	166	353	62	/	4.15
Y1	166	353	62	0.08	4.15
Y2	166	353	62	0.17	4.15
Y3	166	353	62	0.25	4.15

### 2.3. Test Method

In this study, a standard slump cylinder was used for the slump test, the rapid freeze-thaw method was used for the freeze-thaw test, and the concrete rapid freeze-thaw testing machine was used to freeze-thaw the drawing specimens for freeze-thaw cycle, and the core temperature thawing temperature was 5°C and the freezing temperature was -18°C. Pore structure characterization was carried out based on the Macro MR12-150H-I low-field NMR system, which has the dual functions of micro-imaging and relaxation analysis. The

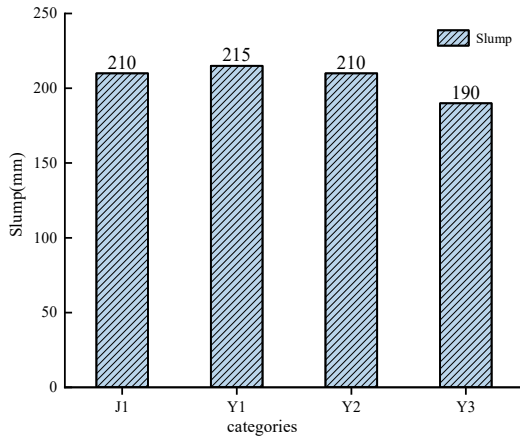


Figure 1. Concrete slump

system is equipped with 0.3T permanent magnet, working frequency 12.38MHz, and the magnet temperature is maintained at 32°C±0.02°C by high-precision temperature control module.

## 3. Analysis of Test Results

### 3.1. Changes in work performance

The test results of the effect of air-entraining agent content on the working performance of concrete are shown in Fig. 1 and Fig. 2.

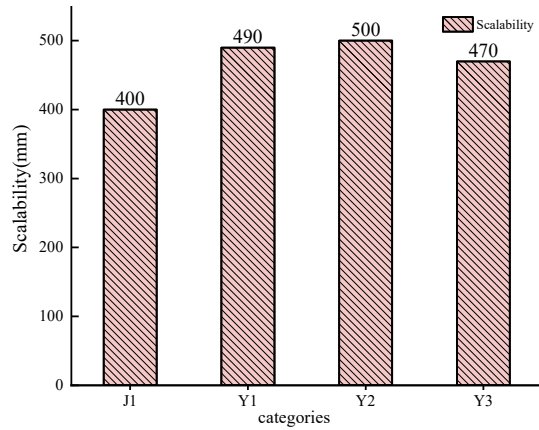


Figure 2. Concrete expansion

The amount of air-entraining agent has a great influence on the working performance of concrete. Compared with the J1 group, the concrete slump of the Y1, Y2 and Y3 groups decreased by 2.38%, 0% and 9.52%, respectively. The concrete slump first increased and then decreased with the increase of air-entraining agent, and the concrete slump under 0.06% air-entraining agent was the lowest in the air-entraining agent group, which was only 190mm. This is because the incorporation of excess air-entraining agent leads to an excessive number of air bubbles inside the concrete, an increase in porosity, and an increase in viscosity, thereby reducing the fluidity of the concrete. With the increase of air-entraining agent content, the expansion degree of concrete

first increased and then decreased, and the influence of air-entraining agent on concrete expansion was greater than that of slump. Compared with the J1 group, the expansion degree of Y1 group, Y2 group and Y3 group increased by 22.5%, 25% and 17.5%, respectively, and the concrete expansion under 0.04% content was the largest, and the concrete expansion under 0.06% content was the lowest, which was only 470mm.

### 3.2. Change in quality loss rate

The variation of mass loss of concrete with different amounts of air-entraining agent in freeze-thaw cycles is shown in Figure 3.

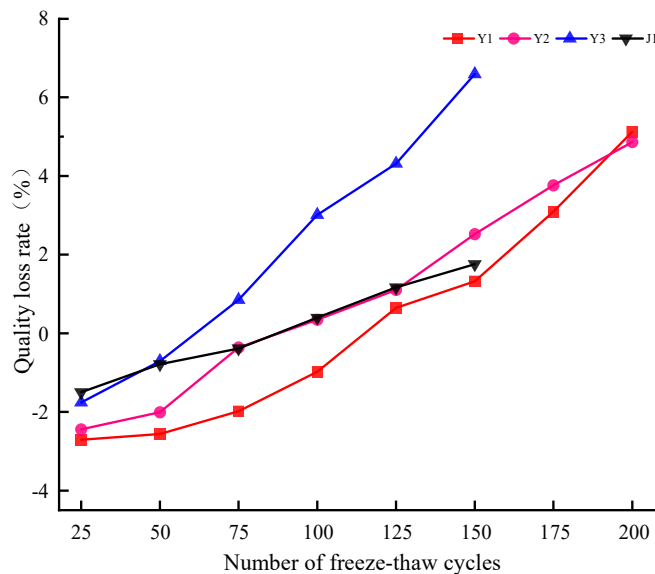


Figure 3. Diagram of the change law of concrete mass loss

It can be seen from the figure that Y2 has the best performance, and the mass loss rate only increases from -2.44 to -0.36 in the first 75 cycles, and it fails in 175 cycles. The loss rate of Y1 slowly increased from -2.71 to -0.98 in the first 100 cycles, and the loss rate increased from -1.50 to 1.76 in 150 cycles, and the loss rate increased sharply from -1.76 to 6.59 in the first 150 cycles due to the structural deterioration of JY3, and the loss rate increased sharply from -1.76 to 6.59 in 150 cycles. The results showed that 0.04% air-entraining agent was the best and could form a stable bubble structure, while too high dosage would reduce the durability due to

excessive porosity, and the frost resistance of the unmixed air-entraining agent specimens was significantly inferior to that of the doping group.

### 3.3. Change in relative dynamic modulus of elasticity

The relative dynamic modulus of elasticity of concrete changes with the increase in the number of freeze-thaw cycles, and the relative dynamic modulus of elasticity is shown in Figure 4 below:

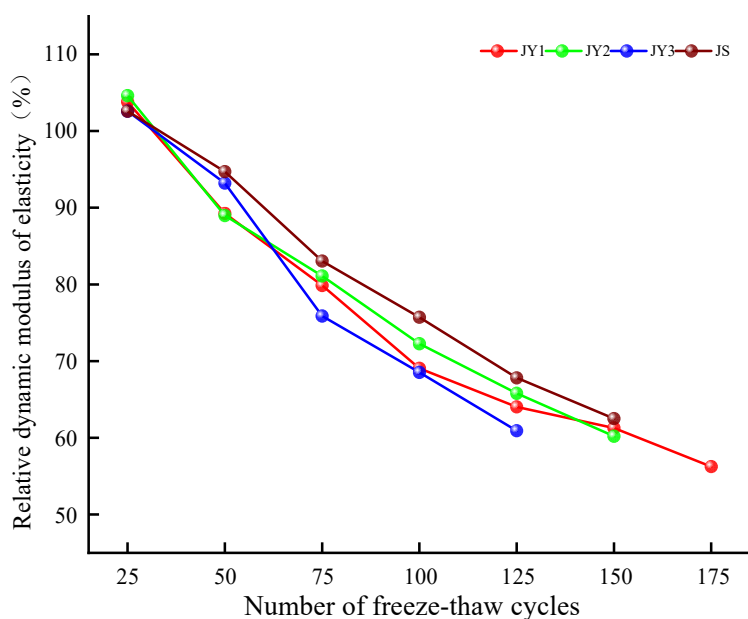


Figure 4. Diagram of the relative dynamic modulus of elasticity of concrete

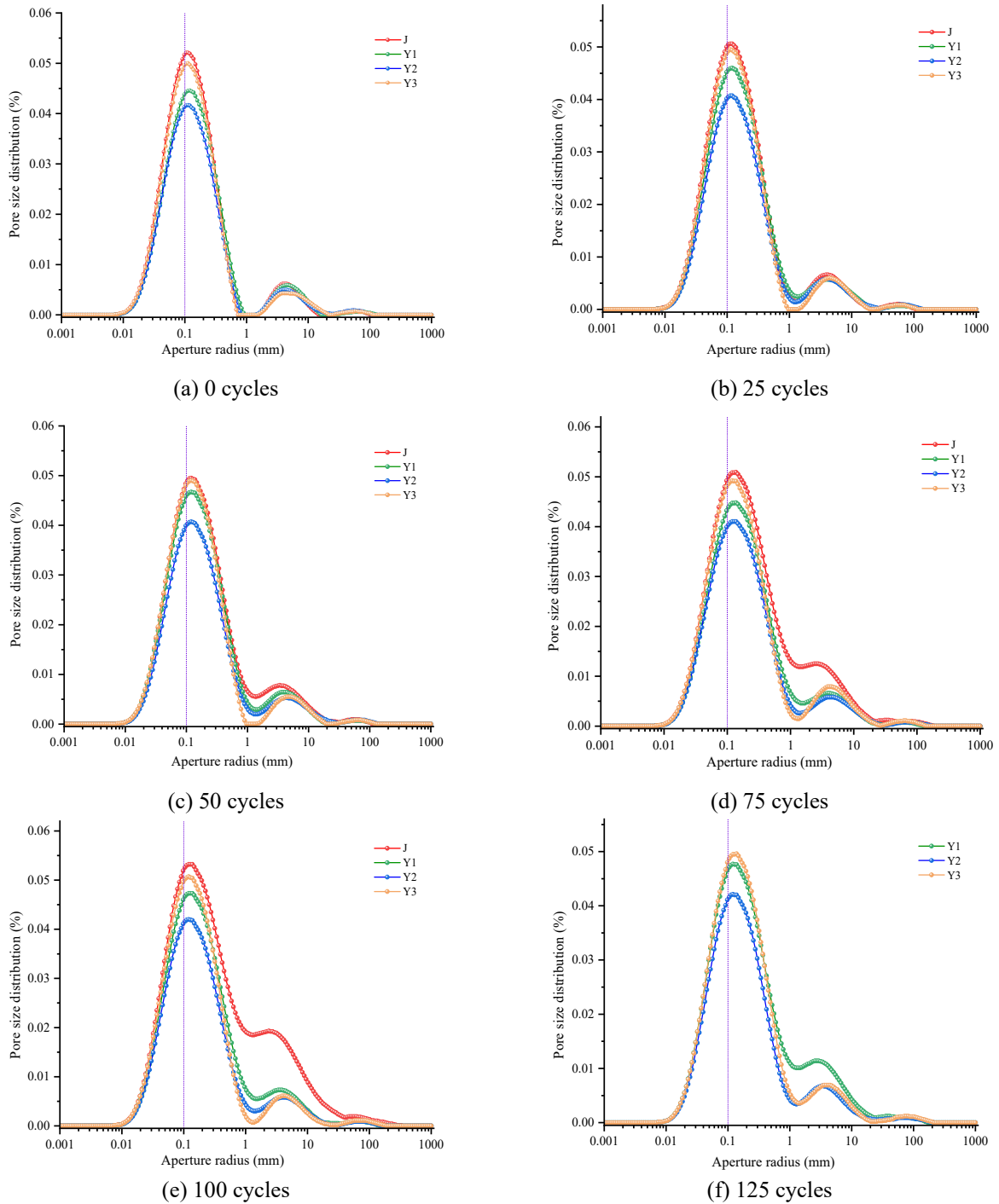
By comparing the relative dynamic elastic modulus of concrete specimens with different air-entraining agent dosages, it can be found that the JY2 specimens with 0.04% dosage exhibit the best frost resistance, and its initial relative dynamic elastic modulus reaches 104.62%, which can still maintain 71.63% after 150 freeze-thaw cycles. In contrast, the JY1 group with 0.02% content decreased from 103.81% to 61.28%, the JY3 group with 0.06% content decreased from 102.59% to 64.35%, and the JS control group without air-entraining agent decreased from 102.60% to 62.52%. The test data show that when the air-entraining agent content is 0.04%, the concrete can form the optimal pore structure distribution, so as to effectively maintain the stability of the dynamic elastic modulus. However, too high air-entraining agent content or no air-entraining agent at all will lead to significant deterioration of the performance of concrete under freeze-thaw cycles, which may be caused by the excessive air-entraining agent resulting in too high internal porosity of concrete.

### 3.4. Changes in pore structure

The concrete pore structure changes continuously with the

freeze-thaw cycle, and the pore size distribution changes as shown in Figure 5 below.

Fig. 5 reveals the synergistic effect of air-entraining agent dosage and freeze-thaw cycles on the pore structure of concrete. The initial structure of group J concrete without air-entraining agent is dense but brittle, and the pores expand rapidly and communicate during the freeze-thaw process, and the frost resistance is the worst. After the incorporation of air-entraining agent, the pore distribution tended to be uniform, and the Y2 group with 0.04% content and Y3 group with 0.06% content showed significant freeze-thaw resistance. With the progress of freeze-thaw cycles, the protection effect of the Y1 group with a low content of 0.02% was limited, and the pore structure deteriorated rapidly. The Y2 group still maintained good integrity in the middle and late freeze-thaw stages. The pore structure of the Y3 group was the most stable during the whole freeze-thaw process, but excessive air-entraining agent may lead to the increase of macropores in the later stage. The test results show that the dosage of 0.04% air-entraining agent can optimally balance the relationship between pore structure and frost resistance.



**Figure 5.** Effect of air-entraining agent on concrete pore size distribution under different freeze-thaw cycles

## 4. Conclusion

In this paper, the effects of different amounts of air-entraining agents on the working energy, frost resistance and microscopic pore size distribution of concrete were studied, and the following conclusions were obtained through relevant experiments and results analysis:

1. When the air-entraining agent content is 0.04%, the compressive strength reduction rate of concrete is 2.8%, and when the air-entraining agent content is 0.06%, the compressive strength reduction rate of concrete is 22.6%, so the air-entraining agent content is considered not to exceed 0.04%.

2. The 0.04% air-entraining agent has the lowest mass loss rate and stable frost resistance, while too high the dosage will

reduce the durability of concrete due to excessive porosity, and the frost resistance of the unmixed air-entraining agent specimen is inferior to that of the doping group.

3. The initial dynamic elastic modulus and final dynamic elastic modulus of concrete were increased by 1.5%, 4.2%, 3.7% and 16.0%, 28.2% and 19.5%, respectively, with 0.02%, 0.04% and 0.06% air-entraining agents, respectively. During the whole freeze-thaw cycle, the air-entraining agent content and the relative dynamic elastic modulus of concrete increased first and then decreased, and the frost durability of concrete was the best when the air-entraining agent content reached 0.04%.

4. After the incorporation of air-entraining agent, the pore distribution tended to be uniform, and the Y2 group with 0.04% content and Y3 group with 0.06% content showed significant freeze-thaw resistance. However, excessive air-entraining

agent may lead to an increase in the proportion of macropores in the later stage.

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