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## Influence of crumb rubber on frost resistance of concrete and effect mechanism

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### Abstract

To provide the relationship between the freeze-thaw resistance of concrete and addition of crumb rubber, the effect of particles size, volume of crumb rubber on the freeze-thaw resistance of concrete was experimentally studied. The results show that the effect of particles size and the volume of crumb rubber on the freeze-thaw resistance of concrete are significant, apart from the air content of concrete. Excessively thick or excessively fine crumb rubber is not favorable for the freeze-thaw resistance of concrete. In addition, the excessive dosage of crumb rubber is also bad for the freeze-thaw resistance of concrete. Water swelling is one of the reasons for freezing and thawing failure of crumb rubber concrete in comparison to normal concrete.

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*Keywords:* crumb rubber concrete; freeze-thaw resistance; water swelling; durability

### 1. Introduction

Crumb rubber concrete (CRC) is a material produced by introducing a certain amount of crumb rubber into normal concrete, which provides superior crack resistance, high ductility and strong energy dissipation capacity, etc. And roads or bridge road engineering is one of more promising purposes<sup>[1-6]</sup>.

The mechanic properties of CRC have been extensively researched, and the system research achievements have achieved already. However, the durability, especially the freeze-thaw resistance of CRC has been relatively insufficient researched.

Savas<sup>[7]</sup>, Benazouk & Queneudec<sup>[8]</sup>, and Paine, who studied the freeze-thaw resistance of CRC, believe

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that appropriate dosage of crumb rubber can improve the freeze-thaw resistance of concrete. What's more, they consider that specific size of crumb rubber could be used as air entraining agent. But above studies on the mechanism of freeze-thaw resistance of CRC are all based on the classical theory of pressure of water of crystallization, which cannot explain the differences existing in CRC and normal concrete with same air content. The researches about CRC were focused on the mechanical performances before in China, while the freeze-thaw resistance research achievement seemed relatively less abundant. The requirements of freeze-thaw resistance capability of the road material seem particularly outstanding in the harsh freezing-thawing environment such as northern China. Therefore, it is necessary to study the freeze-thaw resistance of CRC, which can be both used to provide reliable experiment basis for the structure and durability design and widely use in the future. And it also has a positive effect on promoting the application of rubber concrete pavement.

## 2. Experiment

### 2.1. Materials and mixture ratio

C40 normal concrete is used as reference sample, which mix proportion is given in Table 1. Jinning sheep P · II 52.5 cement is used, and the water reducing agent is naphthalene series superplasticizer for type JM-B.

The CRC is produced by introducing a certain amount of crumb rubber into normal concrete, and the introduced crumb rubber replace isopyknic coarse aggregate and fine aggregate. The proportion of replaced coarse aggregate and fine aggregate complies with the sand ratio in normal concrete.

The crumb rubber used in this experiment involves 6 sizes, which are 6 mesh, 20 mesh, 40 mesh, 60 mesh, 80 mesh and 200 mesh. They are all produced by Beijing functional quantum technologies Co., LTD.

In addition, the air-entraining agent for type GYQ and antifoaming agents for type SP202 used in this experiment are produced by Jiangsu Academy of Building Science Co., Ltd and Tianjin Lingyunzhi technology Co., LTD respectively.

Table 1. Mixture ratio of referenced concrete

W/C	Volume (kg/m <sup>3</sup> )				
	Water	Cement	Fine aggregate	Coarse aggregate	Superplasticizer
0.44	164	374	670	1244	2.06

### 2.2. Experimental program

The influence of freeze-thaw resistance of CRC was studied separately from crumb rubber size and volume.

(1)The air-entraining agent or defoaming agent is used to control the air content of concrete to roughly similar level (6%~7%), and the effect of size of crumb rubber on the freeze-thaw resistance of concrete is studied under a fixed crumb rubber volume (30kg/m<sup>3</sup>).

(2)The effects of six different sizes of crumb rubber(6 mesh, 20 mesh, 40 mesh, 80 mesh and 200 mesh) on the freeze-thaw resistance of CRC is studied by introducing air-entraining agent or defoaming agent to control the air content of concrete and fixing the size of crumb rubber.

### 2.3. Test method

Type TDR-1 automatic fast freeze/thaw concrete testing machine is used to test the freeze-thaw resistance of crumb rubber concrete according to GBJ82-85 (Accelerated freezing thawing method).

### 3. Results

#### 3.1. Influence of size of crumb rubber

The influence of 5 different sizes of crumb rubber (20 mesh, 40 mesh, 60 mesh, 80 mesh and 200 mesh) on the freeze-thaw resistance of concrete was studied on condition that the air content of concrete was maintained to 6.0%~7.0%, and the crumb rubber volume was fixed to  $30\text{kg/m}^3$ . The results are shown in Fig.1.

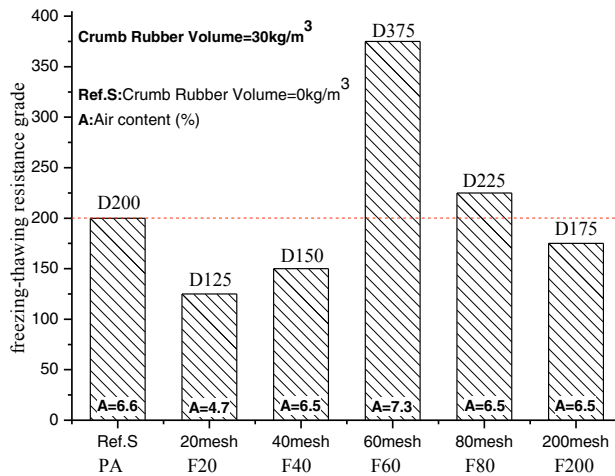


Fig. 1. The freeze-thaw resistance of concrete introduced with different size of crumb rubber

The results in Fig.1 indicate that the size of crumb rubber has obvious influence on the freeze-thaw resistance on condition that the crumb rubber volume stay the same and the air content of concrete tend to close. The freeze-thaw resistance of concrete increases with increasing the fineness of crumb rubber, when the size of crumb rubber does not exceed 60 mesh. In contrast, the freeze-thaw resistance of concrete reduces with increasing the fineness of crumb rubber when the size of crumb rubber exceeds 60mesh.

#### 3.2. Influence of volume of crumb rubber

The influence of 5 different sizes of crumb rubber (6 mesh, 20 mesh, 60 mesh, 80 mesh and 200 mesh) on the freeze-thaw resistance of concrete with different crumb rubber volume was studied. The results and analysis are shown below.

##### a) 6 mesh

The freeze-thaw resistance of 4 specimens of CRC with different volume crumb rubber ( $0, 60\text{kg/m}^3, 210\text{kg/m}^3$ ) was tested. A controlled specimen (PA) was set up to compare the effect of freeze-thaw resistance of concrete. The air content of controlled specimen increases by introducing air-entraining agent, and the other specimens including P, F6R60 and F6R210 maintain the natural state of air content.

The results are given in Fig.2.

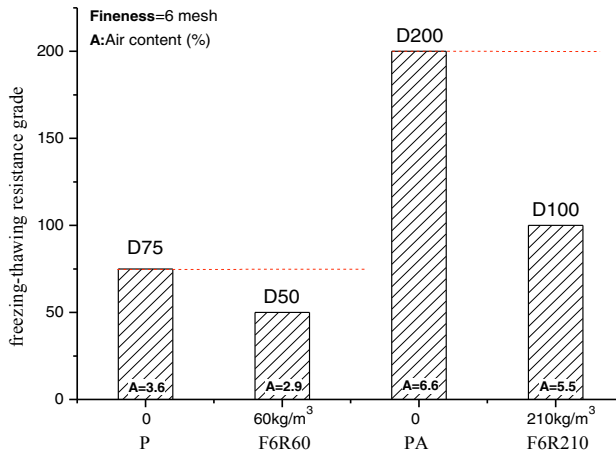


Fig. 2. The freeze-thaw resistance of concrete introduced with 6 mesh crumb rubber

The results indicate that the air content of F6R60 is slightly less than P, and the freezing-thawing cycles of the former is also slightly less than the latter. The air content of F6R210 is slightly less PA, but the freezing-thawing cycles of the former is only half of the latter. It shows that the crumb rubber of 6 mesh is not conducive to improving the freeze-thaw resistance of concrete when the volume of crumb rubber exceeds 60kg/m³.

**b) 20 mesh**

The freeze-thaw resistance of 7 CRC specimens with 20 mesh crumb rubber volume of 0kg/m³, 10kg/m³, 30kg/m³, 60kg/m³, 90kg/m³ and 150kg/m³ were tested. The results are shown in Fig.3.

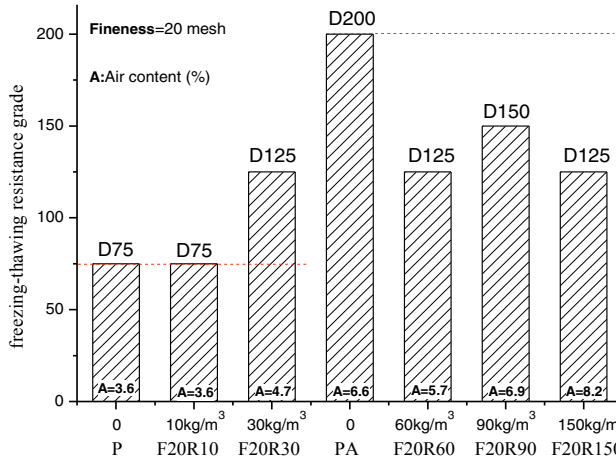


Fig. 3. The freeze-thaw resistance of concrete introduced with 20 mesh crumb rubber

The results show that the air content and freeze-thaw resistance of P and F20R10 are both the same,

which indicates that the freeze-thaw resistance is not influenced obviously when the volume of 20 mesh crumb rubber is  $10\text{kg/m}^3$ . The air content of F20R60 is one percentage point higher than F20R30 when the crumb rubber volume is increased from  $30\text{kg/m}^3$  to  $60\text{kg/m}^3$ , but the freeze-thaw resistance is not improved. It indicates that the negative effect on the freeze-thaw resistance is produced by increasing the volume of crumb rubber. The air content of F20R90 is slightly higher than the PA when the crumb rubber volume is  $90\text{kg/m}^3$ , while the freeze-thaw resistance of the former is 75% of the latter only. The air content of F20R150 is 1.3 percentages higher than F20R90 when the crumb rubber volume is increased from  $90\text{kg/m}^3$  to  $150\text{kg/m}^3$ , while the freeze-thaw resistance is decreased by 16.7%. The results above show that the freeze-thaw resistance is influenced by crumb rubber volume obviously. The influence of crumb rubber on the freeze-thaw resistance of CRC is not significantly affected when the volume of 20 mesh crumb rubber does not exceed  $30\text{kg/m}^3$ ; The 20 mesh crumb rubber has negative effects on the freeze-thaw resistance of CRC when the volume of crumb rubber exceeds  $30\text{kg/m}^3$ , and the freeze-thaw resistance of CRC gets worse with the increasing of volume of 20 mesh crumb rubber.

**c) 60 mesh**

The freeze-thaw resistance of 7 CRC specimens with crumb rubber(60 mesh) volume of  $0\text{kg/m}^3$ ,  $5\text{kg/m}^3$ ,  $10\text{kg/m}^3$  and  $30\text{kg/m}^3$  were tested, in which the air content controlled specimens with volume of  $0\text{kg/m}^3$ ,  $10\text{kg/m}^3$  and  $30\text{kg/m}^3$  (PA, F60R10D and F60R30D) were set up. The results are shown in Fig.4.

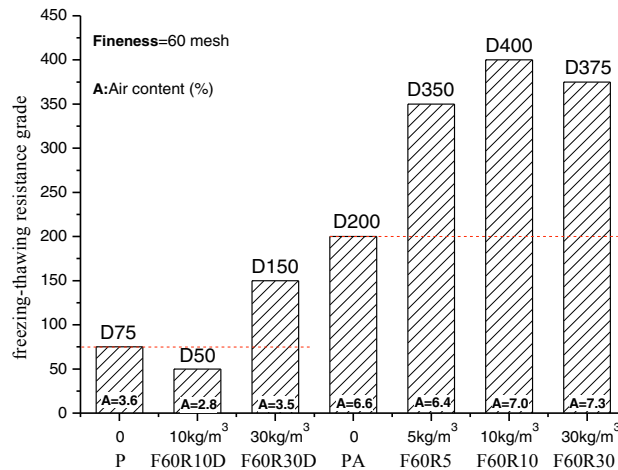


Fig. 4. The freeze-thaw resistance of concrete introduced with 60 mesh crumb rubber

The results show that the air content of F60R30D and P are similar, but the freezing-thawing cycles of the former is two times the latter. In addition, the air content of F60R5, F60R10 and PA are similar too, the freezing-thawing cycles of the first three are 1.75, 2.0 and 1.88 times PA respectively. The results above indicate that the freeze-thaw resistance of CRC is obviously improved by introducing 60 mesh crumb rubber when the volume does not exceed  $30\text{kg/m}^3$ .

**d) 80 mesh**

The freeze-thaw resistance of 3 CRC specimens with crumb rubber (80 mesh) volume of  $30\text{kg/m}^3$ ,  $60\text{kg/m}^3$  and  $90\text{kg/m}^3$  are tested. The results are shown in Fig.5.

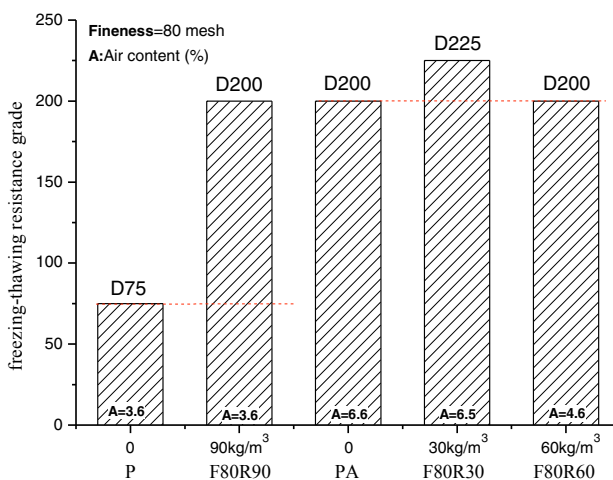


Fig. 5. The freeze-thaw resistance of concrete introduced with 80 mesh crumb rubber

The results show that the air content of F80R90 and P are the same, while the freeze-thaw cycles of the former is 2.67 times higher than the latter. In addition, the air content of F80R30 is similar to PA, but the freeze-thaw circles of the former increases 25 than the latter. It indicates that the freeze-thaw resistance of CRC is obviously improved by introducing 80 mesh crumb rubber when the volume does not exceed 90kg/m<sup>3</sup>. And the higher the volume is, the greater the improvement gets. Although the air content of F80R90 is one percentage point lower than F80R60, the freeze-thaw circles are the same. It indicates that the 80 mesh crumb rubber can improve the freeze-thaw resistance of concrete, and the increasing of the crumb rubber volume further improves the freeze-thaw resistance of CRC, which makes up for the negative effects brought by lower air content.

#### e) 200 mesh

The influence of 200 mesh crumb rubber on the freeze-thaw resistance of CRC with the volume of 30kg/m<sup>3</sup> is tested and the results are given in Table 2.

The results show that the air content of the specimen of F200R30 is close to PA, but the freezing-thawing cycles of the former accounts for 87.5% of the latter only. It indicates that the 200 mesh crumb rubber adversely affects the freeze-thaw resistance of CRC when the volume exceeds 30kg/m<sup>3</sup>.

Table 2. The freeze-thaw resistance of concrete introduced with 200 mesh crumb rubber

No.	Size of crumb rubber (mesh)	Volume of crumb rubber (kg/m <sup>3</sup> )	Air content (%)	Freezing-thawing resistance grade
PA	0	0	6.6	D200
F200R30	200	30	6.5	D175

### 3.3. Analysis and discussion

The above analysis shows that the effect of particles size and the volume of crumb rubber on the freeze-thaw resistance of concrete are very obvious, except for the air content of concrete. Excessively thick or excessively fine crumb rubber is not conducive to the freeze-thaw resistance of concrete. In addition, the excessive dosage of crumb rubber is also bad for the freeze-thaw resistance of concrete.

The influences of crumb rubber on the freeze-thaw resistance of CRC are focused on the following four aspects.

- The crumb rubber itself has certain flexibility, and the separation distance between the crumb rubber becomes larger with the increasing of its size on condition that the volume of crumb rubber is fixed, then the freeze-thaw resistance of CRC gets weaker, on the contrary, the more strong.
- The crumb rubber has certain effect of air-entraining, and it is beneficial to the freeze-thaw resistance of CRC. The effect of air-entraining gets stronger with the decreasing of the crumb rubber size. Therefore, the smaller the crumb rubber size is, the stronger the freeze-thaw resistance of concrete gets.
- The interfacial bonding area between cement mortar matrix and crumb rubber is the weak link of concrete, and it is bad for its freeze-thaw resistance. The interfacial bonding area gets larger with the increasing of the volume and the decreasing of the size of the crumb rubber. Therefore the thaw-freeze resistance of CRC gets worse.
- The crumb rubber has a strong character of water absorption, which swells after soaking up water in freeze-thaw environment. And the freeze-thaw failure of concrete is accelerated. The influence of crumb rubber on the freeze-thaw resistance of CRC is the result of comprehensive effect of these four factors above.

Hydrostatic pressure and osmotic pressure are the main freeze-thaw failure reasons for normal concrete. For CRC, the water absorption of crumb rubber accelerates the freeze-thaw failure. And the freeze-thaw damage provides more bibulous channels for the crumb rubber in CRC, which accelerates the water swelling of crumb rubber. Therefore, the CRC is vulnerable to damage by the interaction of freeze-thaw damage and crumb rubber. In addition, the higher the volume is, the more serious of the water swelling phenomenon gets. And it is disadvantage to the freeze-thaw resistance of CRC. In conclusion, water swelling is one of the reasons of freezing and thawing failure of crumb rubber concrete in comparison to normal concrete.

#### 4. Conclusions

1. The size of crumb rubber has obvious influence on the freeze-thaw resistance of CRC. The freeze-thaw resistance of CRC increases with increasing the fineness of crumb rubber, when the size of crumb rubber is less than 60 mesh. In contrast, the freeze-thaw resistance of CRC reduces with increasing the fineness of crumb rubber when the size of crumb rubber exceeds 60 mesh.
2. It is detrimental to improve the freeze-thaw resistance of CRC when the volume of 6 mesh crumb rubber exceeds  $60\text{kg/m}^3$ .
3. The influence of crumb rubber on the freeze-thaw resistance of CRC is not significantly affected when the volume of 20 mesh crumb rubber does not exceed  $30\text{kg/m}^3$ ; The 20 mesh crumb rubber has negative effects on the freeze-thaw resistance of CRC when the volume of crumb rubber exceeds  $30\text{kg/m}^3$ , and the freeze-thaw resistance of CRC gets worse with the increasing of volume of 20 mesh crumb rubber.
4. The freeze-thaw resistance of CRC is obviously improved by introducing 60 mesh crumb rubber when the volume does not exceed  $30\text{kg/m}^3$ .
5. The freeze-thaw resistance of CRC is obviously improved by introducing 80 mesh crumb rubber, and it would be beneficial to raising by increasing the volume.
6. The 200 mesh crumb rubber adversely affects the freeze-thaw resistance of CRC when the volume exceeds  $30\text{kg/m}^3$ .

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