Effect of aircraft deicer on deicer-scaling resistance and frost resistance of airport pavement concrete

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Abstract. This paper studies the effect of aircraft deicer on deicer-scaling resistance and frost resistance of airport pavement concrete. The mass loss and surface profile of non-air-entrained and air-entrained concrete eroded by water and aircraft deicer are analysed. The surface profile, mass loss rate and relative dynamic elasticity modulus of air-entrained concrete eroded by water and 5% aircraft deicer are discussed during freeze-thaw cycles. It is shown that the low and medium concentration deicer has a negative effect on the deicer-scaling resistance of concrete, and 5% aircraft deicer has the greatest influence. Adding air-entraining agent can improve the deicer-scaling resistance of concrete. Compared with water, 5% aircraft deicer has a negative effect on the frost resistance of air-entrained concrete. The deicer-scaling resistance and frost resistance of air-entrained concrete meet requirements for airport pavement in the most severely cold regions in China.

1. Introduction

According to the safety operation requirements of civil aviation in China, the ice and snow on the aircraft must be removed in order to ensure the safety before aircraft taking off and landing in winter. At present, aircraft deicer is often used to remove ice and snow on aircraft. Finally, the diluted aircraft deicer flows to the airport cement concrete pavement. It causes serious frost damage and deicer-scaling damage to concrete, which affect the durability of concrete in cold regions [1]. In the past few decades, many researches have been conducted to solve these problems. These researches mainly focus on the influence of air-entraining agent [4], coarse aggregate [5, 6], binder [7], fiber [8] and nanosilica [9] on the frost resistance and salt frost resistance of concrete. There are few studies on the influence of aircraft deicer on deicer-scaling resistance and frost resistance of airport pavement concrete, and the raw materials and mix proportion of these studies are not consistent with the actual application of civil airports in China. Therefore, it is necessary to study the effect of deicer on deicer-scaling resistance and frost resistance of concrete.

2. Experiment

2.1. Raw materials

The cement is Ordinary Portland Cement 42.5. The fine aggregate is river sand with a fineness modulus of 2.88. The sand ratio is 0.32. The coarse aggregate is limestone gravel with two grades of gravel particle sizes. The sizes of coarse aggregate are 4.75–16 mm and 16–31.5 mm. The mixed water is tap water. The ratio of water to cement is 0.40. The air-entraining agent is sodium dodecyl benzene sulfonate.
The freeze-thaw solution is water and aircraft deicer, which contact with concrete as corrosive solution. The chemical components of aircraft deicer are composed of 85% industrial first-class glycol, 14% deionized water and 1% mixture assistant.

2.2. Mix proportions

The 28-day flexural strength of airport pavement concrete must be more than 5 MPa. We used two different mix proportions in the test. The mix proportions of concrete are given in Table 1. Non-air-entrained concrete consisted of cement, fine aggregate, coarse aggregate, water and water reducer. Air-entrained concrete consisted of cement, fine aggregate, coarse aggregate, water, water reducer and air-entraining agent, and the ratio of air-entraining agent to water reducer is 0.08%.

### Table 1. Mix proportions of concrete.

| Type of concrete | Cement (kg m⁻³) | Fine aggregate (kg m⁻³) | Coarse aggregate (kg m⁻³) | Water (kg m⁻³) | Water reducer (kg m⁻³) | Air-entraining agent (g m⁻³) |
|------------------|----------------|------------------------|--------------------------|---------------|------------------------|----------------------------|
| Non-air-entrained| 330            | 652.2                  | 554.3                    | 831.5         | 132                    | 6.6                        |
| Air-entrained    | 330            | 652.2                  | 554.3                    | 831.5         | 132                    | 6.6                        |

2.3. Specimen preparation and test method

In the paper, we prepared specimens based on the Chinese standard “Standard for test methods of long-term performance and durability of ordinary concrete” (GB/T 50082-2009) and “Specifications for construction of aerodrome cement concrete pavement” (MH 5006-2015). The specimens for frost resistance were prepared in the mold of 10 cm × 10 cm × 40 cm. The specimens for deicer-scaling resistance were prepared in the mold of 15 cm × 15 cm × 10 cm, and the size of the forming surface was 15 cm × 15 cm. The specimens were cured for 1 day at 20 ± 2℃ and 60% relative humidity, and then removed from the mold. The specimens were cured for 23 days at 20 ± 2℃ and above 95% relative humidity in the air. Finally, the concrete specimens were placed in the water for curing for 4 days. At the age of 28 days, the specimens for frost resistance were tested according to GB/T 50082-2009; the specimens for deicer-scaling resistance were tested according to MH 5006-2015. The 2%, 3%, 4%, 5%, 6%, 12%, 25%, 50% aircraft deicer and water were selected as the freeze-thaw solution and the forming surface of specimen was contacted with the solution. The salt freeze-thaw cycle apparatus was used, and the temperature range was set from -20℃ to 20℃ for every 12 hours. The mass loss is the accumulated scaling mass divided by the area of specimen that contact with the aircraft deicer or water, which is selected as the evaluation index to indicate the deicer-scaling resistance of concrete.

3. Results and discussion

In the test, the air content of non-air-entrained concrete is 1.6%. The air content of concrete increases because of the addition of air-entraining agent. The air content of air-entrained concrete is 3.0%. The slump of both non-air-entrained and air-entrained concrete is 1 cm. The deicer-scaling resistance and frost resistance of concrete are analysed.

3.1 Deicer-scaling resistance of concrete

Table 2 shows the freeze-thaw cycle test results of non-air-entrained concrete. Figure 1 shows the effect of aircraft deicer concentration on mass loss of non-air-entrained concrete after different freeze-thaw cycles. It can be clearly seen that the mass loss of non-air-entrained concrete increases when the aircraft deicer concentration is less than 5% at the same freeze-thaw cycles, and then quickly decreases after that. The mass loss of non-air-entrained concrete at 30 freeze-thaw cycles in the presence of 5% aircraft deicer is 0.676 kg/m², which is higher than the standard limit of 0.6 kg/m² and 16.5 times the mass loss...
of non-air-entrained concrete under water exposure. Figure 2 shows the effect of freeze-thaw cycles on mass loss of non-air-entrained concrete. It can be noticed that the mass loss of non-air-entrained concrete tend to increase linearly with freeze-thaw cycles. Compared with water freezing and thawing, the mass loss is greater when the non-air-entrained concrete is immersed in 2%–12% aircraft deicer, the mass loss is smaller when the non-air-entrained concrete is immersed in aircraft deicer that its concentration is more than 25%. For 2% and 3% aircraft deicer, the mass loss of non-air-entrained concrete is basically the same.

Table 2. Mass loss of non-air-entrained concrete.

| Aircraft deicer concentration | Mass loss (kg m⁻²) |
|------------------------------|--------------------|
|                              | 5 cycles | 10 cycles | 15 cycles | 20 cycles | 25 cycles | 30 cycles |
| 0 %                         | 0.005    | 0.010     | 0.017     | 0.023     | 0.033     | 0.041     |
| 2%                          | 0.021    | 0.069     | 0.145     | 0.207     | 0.263     | 0.298     |
| 3%                          | 0.031    | 0.076     | 0.148     | 0.209     | 0.265     | 0.309     |
| 4%                          | 0.052    | 0.154     | 0.265     | 0.362     | 0.448     | 0.516     |
| 5%                          | 0.071    | 0.222     | 0.380     | 0.494     | 0.595     | 0.676     |
| 6%                          | 0.014    | 0.031     | 0.060     | 0.088     | 0.127     | 0.162     |
| 12%                         | 0.013    | 0.025     | 0.041     | 0.052     | 0.066     | 0.078     |
| 25%                         | 0.007    | 0.010     | 0.011     | 0.013     | 0.017     | 0.022     |
| 50%                         | 0.004    | 0.007     | 0.008     | 0.009     | 0.012     | 0.015     |

Figure 3 shows the surface profile of non-air-entrained concrete under water exposure at 30 freeze-thaw cycles. The mass loss of non-air-entrained concrete is different under water and aircraft deicer exposure, which indicates that the different damage have taken place.

Figure 4 shows the surface profile of non-air-entrained concrete eroded by water after freeze-thaw cycles. The forming surface of concrete is smooth and flat before test. Mortar is obviously peeled off from the forming surface at 20 cycles. Figure 5 shows the surface profile of non-air-entrained concrete eroded by 5% aircraft deicer after freeze-thaw cycles. Only at 10 cycles, a large amount of mortar is peeled off from the forming surface. The microcracks appeared and air voids expanded, making the aircraft deicer easier to enter the inner structure of non-air-entrained concrete. Figure 6 shows the surface profile of air-entrained concrete eroded by 5% aircraft deicer after freeze-thaw cycles. Only the cement paste is peeled off from the forming surface.
Figure 3. Surface profile under water and aircraft deicer exposure at 30 cycles.

Figure 4. Surface profile of non-air-entrained concrete eroded by water.

Figure 5. Surface profile of non-air-entrained concrete eroded by 5% aircraft deicer.

Figure 6. Surface profile of air-entrained concrete eroded by 5% aircraft deicer.
Figure 7 shows the variation of mass loss with aircraft deicer concentration at 30 freeze-thaw cycles. It can be clearly seen that the deicer-scaling resistance of concrete is significantly improved by the addition of air-entraining agent, especially for concrete eroded by aircraft deicer with low and medium concentration. The mass loss of air-entrained and non-air-entrained concrete eroded by 5% aircraft deicer is the largest. The mass loss of non-air-entrained concrete eroded at 30 cycles. Figure 8 shows the variation of mass loss with freeze-thaw cycles. The mass loss of non-air-entrained concrete increases rapidly, while that of air-entrained concrete increases slowly.

3.2 Frost Resistance

Figure 9 and Figure 10 show the variation of mass loss rate and relative dynamic elasticity modulus with freeze-thaw cycles. At 300 freeze-thaw cycles, the mass loss rate of air-entrained concrete eroded by water and 5% aircraft deicer is 0.1% and 0.4%, respectively; the relative dynamic elasticity modulus of air-entrained concrete eroded by water and 5% aircraft deicer is 66.8% and 62.7%, respectively. The frost resistance of air-entrained concrete eroded by 5% aircraft deicer is worse than that of water.

Figure 9. Variation of mass loss rate with freeze-thaw cycles.

Figure 10. Variation of relative dynamic elasticity modulus with freeze-thaw cycles.
Figure 11 shows the surface profile of air-entrained concrete eroded by water and 5% aircraft deicer at 300 freeze-thaw cycles. It can be clearly seen that only cement paste is peeled off from air-entrained concrete eroded by water; while mortar is peeled off from air-entrained concrete eroded by 5% aircraft deicer, and a crack appears on the concrete surface. They meet the frost resistance requirements for airport pavement concrete in the most severely cold regions in China.

4. Summary
The mass loss of non-air-entrained concrete increases when the aircraft deicer concentration is less than 5% at the same freeze-thaw cycles, and decreases quickly when the aircraft deicer concentration is 5%~25%, and then tends to be stable after that. The mass loss of non-air-entrained concrete tends to increase linearly with freeze-thaw cycles for water and aircraft deicer with different concentrations. The mass loss of non-air-entrained and air-entrained concrete eroded by 5% aircraft deicer is the maximum, which is 0.676 kg/m² and 0.040 kg/m², respectively. Compared with water freezing and thawing, the deicer-scaling resistance of non-air-entrained concrete eroded by aircraft deicer with low and medium concentration is reduced, while that of high concentration is slightly improved. The deicer-scaling resistance of air-entrained concrete is significantly improved by the addition of air-entraining agent. Compared with water freezing and thawing, the 5% aircraft deicer has a great effect on the mass loss rate and relative dynamic elastic modulus of air-entrained concrete. Therefore, the 5% aircraft deicer has a negative effect on the frost resistance, but air-entrained concrete can meet the frost resistance of 300 freeze-thaw cycles and the deicer-scaling resistance of 0.6 kg/m² for airport pavement in the most severely cold regions in China.

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