Frost Durability of Roller-Compacted Concrete Pavements: Research Synopsis

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Introduction

Roller-Compacted Concrete (RCC) is a zero-slump concrete that has been used successfully for more than 30 years in all types of climates. Pavement applications vary from heavy-duty intermodal yards to streets and commercial parking areas. Despite the many advantages of RCC, there is a concern about its ability to resist frost attack and deicer salt-scaling. Because of the low volume of paste and the very stiff nature of these mixes, air entrainment is very difficult, thereby raising the question of the freeze-thaw durability of RCC pavements.

It is widely accepted that the presence of a large number of closely spaced air-voids throughout the cement paste represents the most effective way of protecting conventional concrete against frost damage. However, is air entrainment really necessary in RCC to provide adequate freeze-thaw resistance? Can air entrainment admixtures (AEA) be effectively incorporated into RCC? Are conventional concrete test methods for freeze-thaw and deicer salt-scaling appropriate for RCC? Are there benefits in using supplementary cementitious materials (SCM)?

In an attempt to answer the above questions, a major research project on frost durability of RCC pavements was conducted. The objectives of the project included:

- Assessing the frost durability of existing RCC pavements through laboratory testing of in-place field samples
- Determining whether air entrainment in RCC enhances frost durability
- Evaluating the effect of mixer type (twin-shaft mixer versus central drum mixer) on the ability to produce frost resistant RCC
- Evaluating various standard test procedures for frost resistance and deicer salt-scaling and determining their applicability to actual performance
- Comparing the benefits, if any, of supplementary cementitious materials.

The complete research report is available as *Frost Durability of Roller-Compacted Concrete Pavements*, by Service d'Expertise en Materiaux Inc, Portland Cement Association (PCA) publication RD135.

Past Research

Several studies have been conducted to evaluate the ability of RCC to resist damage due to freeze-thaw conditions and deicer salts. In addition to laboratory testing, condition surveys have been made of existing RCC pavement projects, many located in freeze-thaw climates, to evaluate the long-term performance of RCC. Results from one extensive survey indicated an overall good performance of the RCC pavements which varied in age from 3 to 20 years (Ref. 1).

On the basis of these past studies, it can be stated that the construction of a frost- and deicer salt-scaling–resistant RCC pavement is common, but the reasons for the good field performance are not yet clearly known. Good construction practices (including sufficient compaction and proper curing) are required. The use of supplementary cementitious materials also appears to provide benefit and there may need to be a requirement for a minimum cement content to ensure a certain degree of homogeneity of the microstructure. It is not clear, however, if air entrainment is required, and the conditions under which air entrainment in dry concretes can be successfully incorporated into the mixture.

The discrepancies between laboratory and field behaviors, as well as the unresolved question of the necessity of air entrainment, suggest the need for further research on the frost durability and scaling resistance of RCC mixtures. Although RCC mixes generally are proportioned to achieve an optimum density at the end of the consolidation operations, RCC mixtures are characterized by the numerous irregularly shaped voids formed during the compaction process. The role played by these "compaction voids" (or "entrapped air") in the protection against frost damage is uncertain.

Field Study

As part of this research project a testing program was initiated to evaluate the performance of existing RCC pavements. From 1987 to 1989 twenty-five test sections of roller-compacted concrete pavement were constructed

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near St. Constant, Quebec. From these sections, in 1999 and 2000 twenty-five 600x600x250 mm (24x24x10-in.) samples were sawn and then removed from the pavement sections and taken to the laboratory. The condition of the field samples were assessed using the following test procedures: Compressive Strength (ASTM C 39), Flexural Strength (ASTM C 78), Pulse Velocity (ASTM C 597), Chloride Profiles (ASTM C 1152 modified), and internal microcrack measurements.

Micro air-void analyses using a scanning electron microscope were also carried out on five concrete specimens. For these samples, the characteristics of the air-void system were determined in accordance with a modified version of ASTM C 457, *Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*. Finally, the frost resistance of selected samples was tested in accordance with ASTM C 1262, *Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units.* The ASTM C 1262 procedure is commonly used to investigate the frost durability of masonry products.

The compressive strength values ranged from 30.8 to 86.8 MPa (4,470 to 12,600 psi), and the flexural strength from 5.4 to 9.4 MPa (780 to 1,360 psi). The exposure to severe winter conditions apparently had no detrimental influence on the mechanical properties of the test sections.

Pulse velocity measurements were excellent, and indicated that none of the RCC sections had suffered from any frost-related damage over the years. The determination of total chloride content clearly indicated that the samples had been exposed to deicing salts, since no chloride-based admixtures had been used in the preparation of the mixtures. Internal microcrack measurements were in good agreement with strength and pulse velocity measurements and confirmed that

"… the RCC samples had not suffered from any significant degradation despite their long exposure to severe winter conditions."

The characteristics of the air-void system were studied in five of the samples, three which had used air-entraining agents, and two which had not. Overall, test results indicate that air is difficult to entrain in RCC mixtures. In all cases, the spherical air-voids content was lower than 0.6%, and the air-entrained mixtures did not contain more spherical voids than non-air-entrained mixtures. Despite the low spherical air-void contents, test results showed that the total air was relatively high (4.1 – 7.8%). This indicates that most air-voids probably result from consolidation operations.

The frost durability of selected sections was determined in accordance with ASTM C 1262. The ASTM C 1262 test is believed to be less severe than ASTM C 666, *Resistance of Concrete to Rapid Freezing and Thawing* and ASTM C 672 *Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals*. For concrete masonry products, a mass loss of 1% after 40 freezing and thawing cycles in a saline solution is usually considered the maximum limit for performance. All results from the field sections were under the 1% limit, with the maximum mass loss being 0.67%. Clearly the ASTM C 1262 procedure appears to be more reliable than any other standard test method for correctly predicting the ability of dry concrete products to be durable when exposed to freeze-thaw conditions.

The various measurements made on the samples extracted from the RCC experimental pavements (mechanical properties, pulse velocity, and microcrack density) indicate that none of the mixtures had suffered any significant degradation by surface scaling or frost-induced microcracking after more than ten winters of severe exposure. Even though the air-void content, excluding compaction voids, of all RCC samples was quite low (less than 1%), all had a relatively good air-void spacing factor (close to or lower than 230 μm), due to the high content of irregularly shaped compaction voids.

Laboratory Study: Air-Entraining Agents

To investigate the mechanisms of air entrainment on laboratory-made RCC mixtures, two series of mixtures were produced and tested: one series with total binder content of 250 kg/m^3 (420 lbs/yd^3), and one series with total binder content of 300 kg/m^3 (500 lbs/yd^3). For each series of RCC mixtures, three different air-entraining agents were evaluated: a conventional air-entraining agent, a powdered air-entraining agent, and a tension-active agent. Each agent was tested at two different dosages. For each cement content, one reference mixture was produced using no air-entraining admixture. All air-entraining mixtures were designed with a theoretical air content of 6%.

All RCC mixtures developed good mechanical properties. The average 28-day compressive strength of the higher cement content ranged from 43 MPa (6,200 psi) to 54 MPa (7,800 psi). For the lower cement content, compressive strengths were from 29 MPa (4,200 psi) to 46 MPa (6,700 psi). For both series, the air-entrained RCC mixes developed lower mechanical properties.

Overall, test results show that air bubbles were entrained in the RCC mixtures made in the laboratory. The spherical air-void content of both non-air-entrained mixes was 0.6%, while that of the air-entrained lower cement content was 2.3% to 3.9%, and 1.2% to 2.9% for the air-entrained higher cement content. The air-entrained mixtures had good spacing factors. Results from ASTM C 666 and ASTM C 672 tests showed that the incorporation of an air-entraining admixture in the RCC mixtures had a beneficial influence on their frost resistance. Results from ASTM C 672 tests are shown in Figure 1.

"Data also showed that very little air is needed to protect RCC against frost-induced microcracking."

Frost durability tests were also carried out in accordance with ASTM C 1262. Test results after 50 freezing and thawing cycles are given in Figure 2. As shown, the reference (non-air-entrained) mixture prepared with the lower cement content was the only one that failed the test. All the others had a mass of residues of less than 1% after 50 daily cycles. With the higher cement content, none of the mixtures failed the test.

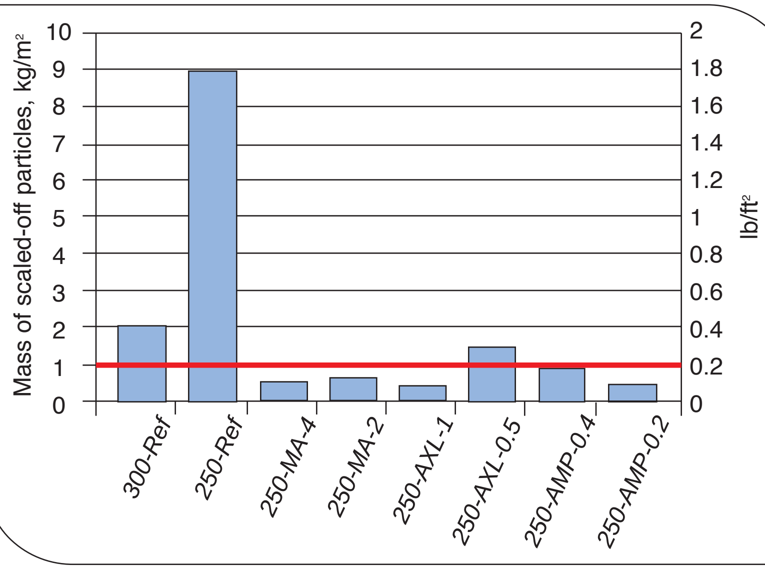

Figure 1. ASTM C 672 test results after 50 cycles, comparing different AEA.

Table 1. Description of mixes included in Figures 1 and 2.

Mix	Cement Content	Air Entraining Agent
300-Ref	300 kg/m^3 (500 lbs/yd^3)	none
250 – Ref	250 kg/m^3 (420 lbs/yd^3)	none
250-MA-4	250 kg/m^3 (420 lbs/yd^3)	Micro air: 400 ml/100 kg (6 oz/100 lb) of cement
250-MA-2	250 kg/m^3 (420 lbs/yd^3)	Micro air: 200 ml/100 kg (3 oz/100 lb) of cement
250-AXL-1	250 kg/m^3 (420 lbs/yd^3)	AireX-L: 100 ml/100kg (1.5 oz/100lb) of cement
250-AXL-0.5	250 kg/m^3 (420 lbs/yd^3)	AireX-L: 50 ml/100kg (0.75 oz/100lb) of cement
250-AMP-0.4	250 kg/m^3 (420 lbs/yd^3)	Airmix 200-P: 0.4% of the weight of cement
250-AMP-0.2	250 kg/m^3 (420 lbs/yd^3)	Airmix 200-P: 0.2% of the weight of cement

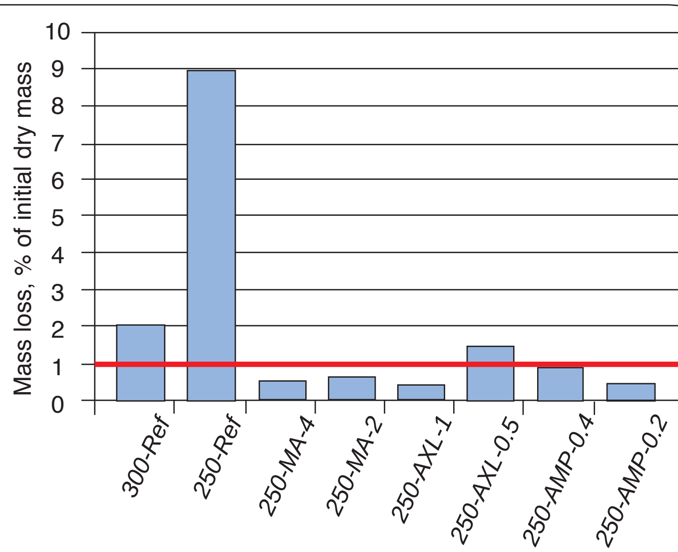

Figure 2. ASTM C 1262 test results after 50 cycles, comparing different AEA.

Laboratory Study: Influence of Silica Fume and Fly Ash

To study the influence of supplementary cementitious materials on the frost durability of RCC, two series of mixtures were produced: one series of RCC mixtures with a total cementitious content of 250 kg/m^3 (420 lbs/yd^3), and one series with total cementitious content of 300 kg/m^3 (500 lbs/yd^3). For each series, one RCC mixture was made using a Class C fly ash, a second mixture was produced with a Class F fly ash, and a third mixture was made with a blended 7% silica fume cement. Both fly ashes were used as partial cement replacement at 25% of the total binder.

Most of the RCC mixtures were found to be susceptible to frost-induced microcracking. These results were to be expected considering the relative severity of the ASTM C 666 procedure. However, the addition of silica fume was sufficient to reduce the mass of scaled-off particles below the 1 kg/m^2 (0.2 lb/ft^2) limit. The use of fly ash had very little influence on the scaling resistance of RCC. The beneficial influence of silica fume and the limited effect of fly ash were confirmed by both the ASTM C 672 and ASTM C 1262 test results (see Figures 3 & 4). The legend on the horizontal axis of these figures indicates either no supplementary material added (Ref), or adding blended silica fume cement (T10SF), Class C fly ash (FA-C), or Class F fly ash (FA-F).

Evaluation of Mixer Type

In this part of the study, eight additional RCC mixtures were produced in the field and tested: one series of four mixes was prepared in a twin shaft continuous flow pugmill mixer, and a second series of four mixes was produced in a central concrete batch plant. For each series, one reference mixture (without air-entraining admixture) was prepared and the different air-entraining agents were tested at a single dosage. All RCC mixtures were made with the 7% silica fume blended cement.

Good compressive strengths were obtained for both series of RCC mixtures, with most values greater than 50 MPa (7,200 psi). With only one exception, no significant differences were seen between strengths obtained from mixtures prepared with a continuous flow pugmill and those produced in the central batch plant.

Evaluation of the air-void system produced in the mixes confirmed that it is possible to entrain a little (but significant) volume of air under normal plant conditions for both mixer types. The spherical air-void contents of the non-air-entrained RCC mixtures are relatively low (0.2% for the mixture produced in a pugmill mixer, and 0.7% for the one prepared in a concrete batch plant) while those of the air-entrained mixtures ranged from 1.0% to 2.1%. The type of air-entraining admixture had no significant influence on the results.

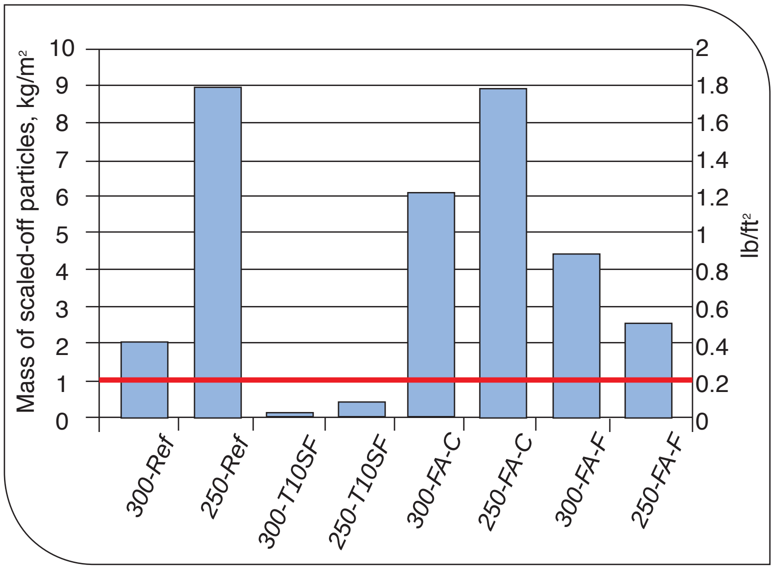

Figure 3. ASTM C 672 test results after 50 cycles, comparing different SCM.

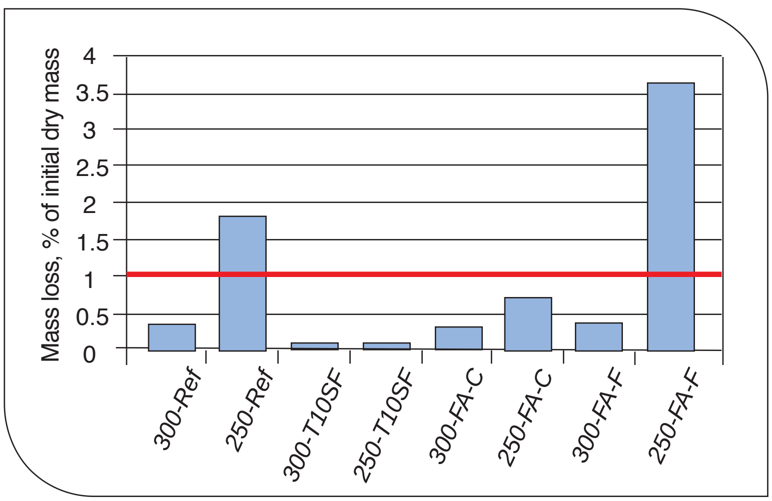

Figure 4. ASTM C 1262 test results after 50 cycles, comparing different SCM.

Although the best results were obtained with the central concrete batch plant, the addition of an air-entraining agent was found to reduce the spacing factor in all of the mixes. All of the RCC mixtures were found to be resistant to rapid freezing and thawing cycles in water, even the non-air-entrained mixtures. The durability factors obtained from ASTM 666 test results were 100% for all mixtures. These results tend to confirm the beneficial influence of the partial replacement of cement by silica fume.

Summary and Conclusions

Normal good quality concrete can be quite resistant to frost and deicer salt-scaling if it is properly air-entrained. On the other hand, Roller-Compacted Concrete has a very low water content and paste content, making it difficult to entrain air uniformly throughout the mixture. However, both laboratory and field studies have shown acceptable performance of non-air entrained RCC when exposed to freezing-thawing and deicer salts.. Where air entrainment has been attempted, results showed some success with entraining a small amount of air in the RCC mixtures in the laboratory, using a high energy pan mixer and a substantial dosage of air-entraining admixture.

Measurements made on the samples extracted from the RCC field sections indicated that none of the mixtures had suffered any degradation after more than 10 years of exposure to severe winter conditions. The good field performance of the test sections tends to indicate that unsaturated compaction air-voids offer some protection against frost action. The good frost resistance of non-air-entrained RCC was in good agreement with results from previous field investigations.

"Test results in the report strongly suggest that the ASTM C 1262 should be seriously considered as a reliable method to assess the frost durability of RCC."

Already used to test masonry products, the method is relatively simple and could be applied directly to RCC pavements.

References

1. Piggott, R.W., *Roller Compacted Concrete Pavements – A Study of Long Term Performance*, PCA Publication PR366, Portland Cement Association, Skokie, Illinois, USA, 1999, 62 pages

More Information

PCA offers a broad range of resources on RCC applications for pavements. Visit our Web site at **www.cement.org/pavements** for design and construction guidelines, technical support, and research on RCC, cement-modified soils, cement-treated base, and full-depth reclamation.

For local support, tap into the cement industry's network of regional groups covering the United States. Contact information is available at **www.cement.org/local**.

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