# COMPARISON OF ASTM AND CANADIAN FREEZE-THAW DURABILITY TESTS

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## Summary

The paper emphasizes the influence of various accelerated laboratory tests on freezing and thawing performance of concrete pavers. Paving blocks, manufactured using a single-pallet machine, was produced in batches using 7 different combinations of cements and aggregates. The freezing and thawing durability of paving units was assessed according to ASTM C 67, ASTM C 666, ASTM C 672 and CSA-A231.2. Companion samples were also laboratory tested to determine their physical and mechanical characteristics. The freezing and thawing evaluations were compared and then correlated with the mixture proportions and bulk properties of the test pavers.

The test results showed great differences between the minimum paver unit properties required to satisfy ASTM C 67 and the other tests. The findings suggest (a) that ASTM C 67 should be replaced (as a test method within ASTM C 936) with a more meaningful experiment capable of ensuring durability similar to that of the other tests, and (b) the need to specify minimum characteristics of a concrete paver required to assure durability in the field. These may include cement factor, absorption, and compressive and splitting-tensile strengths.

## Introduction

The American Society of Testing and Materials (ASTM) provides a standard for concrete paving blocks for use in the United States. The reference is C 936, Standard Specification for Solid Interlocking Concrete Paving Units [1]. Since its publication by ASTM in 1982, C 936 includes a freezing and thawing durability test. It is referenced as ASTM C 67, Section 8, Standard Test Methods of Sampling Brick and Structural Clay Tile [1].

The C 67 test method consists of placing the top of a brick (or concrete paver) unit in a tray with 13 mm deep water. The unit is subjected to 50 freezing and thawing cycles with one cycle consisting of 20 hours of freezing at -9° C and 4 hours of thawing at 24° ±5.5° C. No more than 1% loss of material is allowed after 50 cycles in order to satisfy the test according to ASTM C 936.

When C 936 was first introduced in 1982, there were no freezing and thawing durability tests developed specifically for concrete pavers. Since those writing the C 936 standard in 1982 were predominantly from the masonry industry, the accelerated laboratory freezing and thawing test developed for clay brick wall units, ASTM C 67, was selected. It was a familiar test method and concrete pavers could easily satisfy its requirement. The existing freezing and thawing durability tests for in-situ concrete were considered to be too severe at that time. These tests include C 666, Resistance of Concrete to Rapid Freezing and Thawing and C 672, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals [2].

In 1985, the Canadian Standards Association (CSA) developed CSA-A231.2-M85, Precast Concrete Pavers, as the standard for units made in Canada [3]. The standard was recently revised and issued in 1995 as CSA A231.2-95. The 1985 standard includes a rigorous freezing and thawing deicing salt test where units are completely immersed in a 3% saline solution and subjected to 50 cycles. Full immersion is used to simulate the typical presence of salts on all sides of the unit, i.e., resting on the surface, collecting in the bedding sand, and in the joints. In order to successfully complete the Canadian freezing and thawing conditions, units must not lose more than 1% of their original dry mass after 50 cycles.

The CSA durability test, considered as one of the most severe for concrete pavers, was borne out of a freeze-thaw failure in the City of Montreal, Quebec in the early 1980's. Pavers had been subjected to deicing salts which later accumulated in the bedding sand, eroding the bottom of pavers. The tops of the pavers were not damaged, but upon removal, the pavers revealed as much as half of their thickness eroded away from deicing salts. The City of Montreal suspended construction of interlocking concrete pavements for a year while the Canadian paver industry developed a test method and standards that would assure freezing and thawing durability under deicing salt use.

Since the CSA test was developed, pavers subject to freeze-thaw and deicing salts have performed substantially better in Canada. For example, 15,000 m$^2$ of concrete pavers in streets and sidewalks of the City of North Bay, Ontario experience about 300 tons of deicing salts each winter. Since their installation in 1983, the pavers have endured extremely well under these conditions [4]. The pavers were successfully evaluated for deicing salt durability using the CSA test after their installation. Based on performance in North Bay and several other pavements in Canada and the U.S., the CSA standard has provided assurance of freezing and thawing durability over the past 10 years.

Climate and deicing salt use are essentially the same in many parts of the U.S. and Canada, and there have been numerous failures of concrete pavers from their effects. Documentation of these failures is scarce, since manufacturers and contractors do not systematically report embarrassing events. In spite of these failures, the U.S. paver industry is beginning to compete with other pavements in municipal, commercial, industrial, port, and airport markets. Therefore, it is essential that the national standard for concrete pavers, ASTM C 936, provide the manufacturers and users with some assurance of durability under freezing and thawing deicing salt conditions.

## Mixing and Testing Program

The need to address this issue prompted members of the Interlocking Concrete Pavement Institute to commission Southern Illinois University-Carbondale in 1992 to evaluate the effects of four freezing and thawing durability tests on concrete pavers of various mixture designs. The four tests were ASTM C 67, ASTM C 666, ASTM C 672, and CSA-A231.2. Other unit properties; including splitting-tensile strength (ASTM C 1006), compressive strength (ASTM C 140), density (ASTM C 140), and absorption (ASTM C 67); were also evaluated. The mixture constituents consisted of Type I ordinary portland cement, siliceous fine aggregate (fineness modulus = 2.68 and SSD specific gravity = 2.60), crushed limestone coarse aggregate (maximum size of 3/8 of an inch and SSD specific gravity = 2.70), and tap water. The mass ratio of coarse to fine aggregate was kept uniform at 1:2. The 7 different aggregate-cement ratios used in this study are shown in Table 1. The range of water-cement ratios was fairly narrow (0.21-0.34), governed by the moldability characteristics of the materials in relation to the needs of the molding process.

60 mm concrete pavers were manufactured without admixtures on a single pallet machine by Balcon, Incorporated of Crofton, Maryland. They were air-cured indoors (21 ±1°C) for one day prior to shipment to Southern Illinois University at Carbondale. A typical photomicrograph of the polished surface from a paver containing 447 kg/m$^3$ portland cement (not shown here) revealed the entrapped air voids that could easily be counted. The shape of the air voids was irregular, suggesting they were possibly interconnected. Other parameters such as specific surface and spacing had little meaning for this type of air void structure.

## Discussion of Results

Table 1 summarizes the mean bulk characteristics of the test pavers which showed significant improvements as the cement content of the mixture was increased. The average cumulative mass loss of the paving block specimens subjected to a freezing and thawing regime of ASTM C 67 is shown in Table 2. The specimens of cement content groups A through D experienced deterioration in terms of scaling, whereas the surface of the remaining samples (cement groups E through G) appeared undisturbed. The exposure conditions of ASTM C 67; moderate cooling rate, extended freezing period, and above-zero freezing temperature; favored the osmotic failure mechanism. The rate of mass loss was uniform and the increase in cement content reduced the rate at which deterioration occurred (mass loss per cycle of 0.033%, 0.022%, 0.011% and 0.001 for the test specimens containing 200, 223, 252 and 295 kg/m$^3$ portland cement, respectively). Keeping concrete paver mass loss from exceeding the maximum 1% requirement was achieved with 223 kg/m$^3$ cement content, corresponding to a compressive strength of approximately 43.5 MPa and absorption of 5.7%.

Tables 3 and 4 present the mean cumulative mass loss and rate of deterioration (mass loss per cycle), respectively, of the test pavers at various numbers of rapid freezing and thawing cycles (ASTM C 666). Upon the completion of 300 cycles, only the specimens of cement groups F and

G were still being tested, whereas the rest of the mixtures had since been removed due to excessive deterioration. The failure of ASTM C 666 specimens was attributed to the formation and rapid propagation of cracks which were originated from localized micro-fractures that quickly grew with additional freezing and thawing cycles. Pavers usually failed within 50 cycles from the time when visible surface cracks were developed. The high cooling rate and zero freezing temperature associated with ASTM C 666 are believed to have caused excessive hydraulic pressures, leading to concrete spalling and crumbling. Using no greater loss than 1% as a test criteria, pavers required at least 395 kg/m$^3$ cement content to complete 300 rapid freezing and thawing cycles, an increase in cement content of 57% over that required under ASTM C 67. The exposure conditions of ASTM C 666 also required a minimum compressive strength of 67 MPa and an absorption capacity of no more than 4% to satisfactorily ensure the requirements of rapid freezing and thawing durability.

The mean cumulative mass loss and rate of deterioration of the pavers tested under conditions of CSA-A231.2-M85 are shown in Tables 5 and 6, respectively. The only mixture proportions to successfully complete the testing, with less than 1% loss of materials after 50 freezing and thawing cycles, were group F and G (A-C of 4.5:1 and 4:1, respectively). Deterioration rates for the pavers of cement content groups A through E were found to increase, non-uniformly, with additional freezing and thawing cycles; whereas the remaining mixture proportions experienced nearly constant rates of mass loss throughout the entire test. The mode of failure exhibited by the test pavers was in line with the damage usually caused by freezing and thawing with deicer salts. The pavers of groups A through E showed widespread and inward progression of scaling throughout the top and side surfaces. A lesser degree of scaling (and not as widespread) was experienced with the pavers of cement content groups F and G (395 kg/m$^3$ and 447 kg/m$^3$, respectively). Under the exposure conditions of CSA-A231.2-M85, a minimum cement content of 395 kg/m$^3$ offers adequate resistance to freezing and thawing with deicing salts. This level of cement content provides a compressive strength of 67 MPa and an absorption value of less than 4%.

Table 7 shows a summary of the test results, expressed in terms of mean cumulative mass of scaling residues (kg/m$^2$) and visual surface rating, induced by the freezing and thawing conditions of ASTM C 672. This freezing and thawing method was found to be inappropriate for the pavers with a cement content below 295 kg/m$^3$. These test pavers experienced difficulties in retaining the solution on the top surface due to high porosity and permeability. Consequently, they exhibited significant damage near their base and eventually failed due to surface heaving within the first 25 freezing and thawing cycles. Pavers with a minimum cement content of 356 kg/m$^3$ and 395 kg/m$^3$ did not display any sign of surface scaling after 50 and 200 cycles, respectively. In order to allow an appropriate evaluation under ASTM C 672 conditions and ensure minimal scaling, paving blocks should possess a minimum compressive strength of 61.3 MPa and a maximum absorption capacity of 4%.

In summary, the minimum average of 55 MPa compressive strength and maximum absorption of 5% required in ASTM C 936 are not adequate to satisfy the requirements of ASTM C 666, C 672, and CSA-A231.1 durability tests, except C 67. However, most manufacturers in freezing climates voluntarily make 60 mm thick concrete pavers that will exceed 55 MPa thereby rendering freezing and thawing durability in their pavers.

## Conclusions

There is a very substantial difference in the unit properties required to pass C 67 and the other three durability tests. These differences underscore the point that C 67 is for clay wall brick and the other three tests can be used to assure durability of concrete pavers. It appears as though the U.S. concrete paver industry does not yet have a test that will assure freezing and thawing durability in the field. For technical credibility and marketing purposes, a more severe (and more meaningful) freeze-thaw test should be considered for adoption into ASTM C 936. The test would require a higher cement content (a lower aggregate:cement ratio) in a paver needed to pass the compressive strength and absorption requirements of C 936.

It may be simpler and less expensive to adopt a well-known test such as ASTM C 666, CSA-A231.2, or some variation of either one. C 666 is used for ready-mix concrete and is understood by pavement engineers. The concrete paver industry could attain a higher degree of assurance of freezing and thawing durability by adopting ASTM C 666 or the CSA test into C 936. The use of C 666 would have marketing potential in competing against in-situ concrete because of its high level of recognition among engineers.

There may be resistance by some producers of pavers for fear of not being able to pass these tests, or that the tests are overly severe. It is human nature to not change unless pressured by circumstances. There is little impetus to change ASTM C 936 now. However, the reality of freezing and thawing related failures in the field (such as those experienced by the Canadian industry in the early 1980's), and the loss of sales, may be the greatest motivation to change the U.S. concrete paver standard.

## Acknowledgments

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## References

1. American Society for Testing and Materials, *1995 Annual Book of ASTM Standards*, Volume 4.05 (Philadelphia, Pennsylvania, 1995).

2. American Society for Testing and Materials, *1989 Annual Book of ASTM Standards*, Volume 4.02 (Philadelphia, Pennsylvania, 1989).

3. Canadian Standards Association, CSA A231.2-M85, "Precast Concrete Pavers," (Rexdale, Ontario, Canada, 1985).

4. Rada, G.R., Stephanos, P.J., and Smith, D.R., “Interlocking Concrete Pavements in North America: A Performance Evaluation Study,” in Proceedings of the Second International Workshop on Concrete Block Pavement, June 17-18, 1994, Oslo, Norway (Norwegian Concrete Industries Association), pp. 224-233.

Table 1. Bulk Characteristics of Concrete Pavers

| Spec. Code | Cement Cont. (kg/m$^3$)/(AC Ratio) | Density (kg/m$^3$) | Absorption (%) | Comp. Str. (MPa) | Sp. Ten. Str. (MPa) |
|---|---|---|---|---|---|
| A | 200 / 9:1 | 2101 | 5.86 | 40.32 | 3.365 |
| B | 223 / 8:1 | 2116 | 5.73 | 43.46 | 3.634 |
| C | 252 / 7:1 | 2184 | 4.72 | 51.00 | 4.254 |
| D | 295 / 6:1 | 2219 | 4.35 | 52.75 | 4.820 |
| E | 356 / 5:1 | 2255 | 4.09 | 61.23 | 5.667 |
| F | 395 / 4.5:1 | 2272 | 3.97 | 67.04 | 6.481 |
| G | 447 / 4:1 | 2317 | 3.76 | 75.00 | 6.688 |

A-C Ratio = Aggregate-cement ratio

Table 2. Mean Cumulative Mass Loss at Various Numbers of F-T Cycles (ASTM C 67)

| Spec. Code | Mean Cumulative ML (% of original dry mass) | | |
|---|---|---|---|
| | 20 cycles (%) | 35 cycles (%) | 50 cycles (%) |
| A | 0.44 | 0.92 | 1.42 |
| B | 0.32 | 0.66 | 0.97 |
| C | 0.16 | 0.35 | 0.50 |
| D | 0.04 | 0.06 | 0.08 |
| E | ND | ND | 0.03 |
| F | ND | ND | 0.03 |
| G | ND | ND | 0.02 |

ND = No mass loss detected
ML = Mass loss

Table 3. Mean Cumulative Mass Loss at Various Numbers of F-T Cycles (ASTM C 666)

| Spec. Code | Mean Cumulative Mass Loss (% of original dry mass) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 50 cycles | 100 cycles | 150 cycles | 200 cycles | 250 cycles | 275 cycles | 300 cycles | 350 cycles |
| A | 0.34 | 5.60 | TT100 | “ | “ | “ | “ | “ |
| B | 0.15 | 0.58 | 4.38 | TT150 | “ | “ | “ | “ |
| C | 0.03 | 0.19 | 0.96 | 6.11 | TT200 | “ | “ | “ |
| D | 0.00 | 0.15 | 0.36 | 0.87 | 4.09 | TT250 | “ | “ |
| E | 0.04 | 0.08 | 0.15 | 0.32 | 1.24 | 3.38 | TT275 | “ |
| F | 0.04 | 0.08 | 0.11 | 0.18 | 0.34 | ND | 0.88 | 3.88 |
| G* | 0.01 | 0.05 | 0.11 | 0.20 | 0.43 | ND | 0.64 | 1.01 |

* Mass loss of 2.99% at 450 cycles
TT = Testing terminated (number indicates after which cycle)
“ Not applicable

Table 4. Rate of Deterioration at Different Numbers of F-T Cycles (ASTM C 666)

| Spec. Code | Rate (ML (%) per cycle) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0-50 | 50-100 | 100-150 | 150-200 | 200-250 | 250-275 | 250-300 | 300-350 |
| A | 0.0068 | 0.105 | TT100 | " | " | " | " | " |
| B | 0.0030 | 0.0086 | 0.076 | TT150 | " | " | " | " |
| C | 0.0006 | 0.0032 | 0.015 | 0.103 | TT200 | " | " | " |
| D | 0.0016 | 0.0014 | 0.0042 | 0.010 | 0.064 | TT250 | " | " |
| E | 0.0008 | 0.0008 | 0.0014 | 0.0034 | 0.018 | 0.086 | TT275 | " |
| F | 0.0008 | 0.0008 | 0.0006 | 0.0014 | 0.0032 | ND | 0.011 | 0.060 |
| G | 0.0002 | 0.0008 | 0.0012 | 0.0018 | 0.0046 | ND | 0.0042 | 0.0074 |

ND = Mass loss not determined

TT = Testing terminated (number indicates after which cycle)

ML = Mass loss

" Not applicable

Table 5. Mass Loss at Various Numbers of F-T Cycles (CAN3-A231.2-M85)

| Spec. Code | Mean Cumulative Mass Loss (% of original dry mass)/ Surface Mass Loss ($kg/m^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 5 cycles | 10 cycles | 15 cycles | 25 cycles | 40 cycles | 50 cycles |
| A | 0.32/0.103 | 3.83/1.25 | 16.4/5.31 | TT15 | " | " |
| B | 0.46/0.151 | 1.60/0.527 | 6.88/2.28 | TT15 | " | " |
| C | 0.23/0.078 | 1.47/0.478 | 4.12/1.35 | TT15 | " | " |
| D | - | 0.29/0.098 | 0.72/0.244 | 2.23/0.566 | TT25 | " |
| E | - | 0.16/0.054 | - | 0.86/0.288 | 1.78/0.596 | 3.57/1.19 |
| F | - | 0.08/0.029 | - | 0.41/0.142 | 0.73/0.249 | 0.91/0.308 |
| G | - | 0.08/0.029 | - | 0.39/0.132 | 0.64/0.215 | 0.80/0.269 |

- Mass loss residues not collected

TT = Testing terminated (number indicates after which cycle)

" Not applicable

Table 6. Rate of Mass Loss at Various Numbers of F-T Cycles (CAN3-A231.2-M85)

<table>
<tr><th rowspan="2">Spec. Code</th><th colspan="5">Rate (mass loss (%) per cycle)</th></tr>
<tr><th>0-5 cycles</th><th>5-10 cycles</th><th>10-15 cycles</th><th>15-25 cycles</th><th>25-50 cycles</th></tr>
<tr><td>A</td><td>0.06</td><td>0.70</td><td>2.51</td><td>TT15</td><td>"</td></tr>
<tr><td>B</td><td>0.09</td><td>0.23</td><td>1.06</td><td>TT15</td><td>"</td></tr>
<tr><td>C</td><td>0.05</td><td>0.25</td><td>0.53</td><td>TT15</td><td>"</td></tr>
<tr><td>D</td><td colspan="2">0.03</td><td>0.09</td><td>0.15</td><td>TT25</td></tr>
<tr><td>E</td><td colspan="2">0.02</td><td colspan="2">0.05</td><td>0.11</td></tr>
<tr><td>F</td><td colspan="2">0.008</td><td colspan="2">0.022</td><td>0.020</td></tr>
<tr><td>G</td><td colspan="2">0.008</td><td colspan="2">0.021</td><td>0.016</td></tr>
</table>

TT = Testing terminated (number indicates after which cycle)

" Not applicable

Table 7. Surface ML and Visual Rating at Various Numbers of F-T Cycles (ASTM C 672)

| Number of F-T Cycles | Mass Loss (kg/m$^2$)/Rating of Different A-C Ratios | | | | |
|---|---|---|---|---|---|
| | B (8:1) | D (6:1) | E (5:1) | F (4.5:1) | G (4:1) |
| 50 | TT2 | TT25 | 0.009/0 | 0.009/0 | ND/0 |
| 60 | " | " | 0.014/0 | 0.019/0 | ND/0 |
| 70 | " | " | 0.019/0 | 0.028/0 | ND/0 |
| 80 | " | " | 0.024/0 | 0.033/0.25 | ND/0 |
| 90 | " | " | 0.026/0 | 0.043/0.25 | ND/0 |
| 100 | " | " | 0.031/0 | 0.047/0.25 | ND/0 |
| 110 | " | " | 0.035/0 | 0.052/0.25 | ND/0 |
| 120 | " | " | 0.037/0 | 0.064/0.25 | ND/0 |
| 130 | " | " | 0.041/0 | 0.076/0.25 | ND/0 |
| 140 | " | " | 0.047/0.25 | 0.085/0.25 | ND/0 |
| 150 | " | " | 0.052/0.25 | 0.095/0.50 | ND/0 |
| 160 | " | " | 0.060/0.25 | 0.107/0.50 | ND/0 |
| 170 | " | " | 0.068/0.25 | 0.117/0.50 | ND/0 |
| 180 | " | " | 0.076/0.25 | 0.122/0.50 | ND/0 |
| 190 | " | " | TT180 | 0.126/0.50 | ND/0 |
| 200 | " | " | " | 0.131/0.50 | ND/0 |

TT = Testing terminated (number indicates after which cycle)
ND = No surface mass loss detected
ML = Mass loss
A-C = Aggregate-cement
" Not applicable