EFFECT OF PREDRYING ON THE DEICER SALT SCALING RESISTANCE OF BLENDED CEMENT CONCRETES

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ABSTRACT

The effect of drying on the deicer salt scaling resistance of blended cement concrete has been investigated. Concrete mixtures were prepared at a water/binder ratio of 0.45. Specimens were dried in various ways, then resaturated with water. The deicer salt scaling resistance of concrete was assessed in accordance with ASTM C 672 standard. Results indicate that predrying at 40° C and 110° C and prolonged predrying at 20° C decreases the deicer salt scaling resistance of most concrete mixtures. Numerous wetting and drying cycles prior testing were found to have no significant effect on surface scaling. Results also demonstrate that the silica fume concrete pore structure and its resistance to surface scaling are much less sensitive to drying.

Keywords: Cement types, deicing salts, drying, fly ash, frost durability, surface scaling, silica fume.

1 INTRODUCTION

In a previous series of test /1/, it was found that the deicer salt scaling resistance of concrete could be significantly reduced when samples where subjected to a predrying treatment at 40°C and 0% relative humidity (R.H.) and then resaturated with water prior testing. Such an effect was associated with the pore structure coarsening resulting from the drying-resaturation treatment. The test results of this previous investigation also indicated that low water-to-binder ratio concretes and silica fume concretes were more stable with respect to drying and tended to preserve their deicer salt scaling resistance intact. These results were in good agreement with previous reports /2-4/.

In the present investigation, the effect of drying on the deicer salt scaling resistance of various blended cement concretes is reported. In addition to the ordinary Portland cement (OPC) and the blended silica fume cement used in the previous test series, another OPC and two other mineral additives (a class C and a class F fly ashes) were tested. Methanol diffusion measurements have indicated that the pore structure of hydrated cement pastes and concretes prepared with these two fly ashes are less sensitive to the effect of drying /1/.

In order to better understand how drying affects the deicer salt scaling resistance of concrete, several drying-resaturation treatments were studied. These included the drying temperature, the influence of wetting and drying cycles and the effect of prolonged drying were also investigated.

2 RESEARCH SIGNIFICANCE

Drying is known to alter the hydrated cement paste pore structure. Although under natural exposure conditions, concrete structures are often subjected to various forms of drying. However, such an effect is seldom taken into account in laboratory testing. Hopefully, results of the present investigation will help to better understand the field performance of concrete and evaluate the severity of existing test procedures and their ability in reliably predict the scaling durability.

3 MATERIALS AND EXPERIMENTAL PROCEDURES

3.1 Materials and mixture characteristics

Concrete mixtures were prepared with five different binders, two CSA[1] type 10 ordinary Portland cements (referred to as 10A and 10B), a blended silica fume cement (approximately 8% of silica fume by total mass of binder), cement 10A with an ASTM class C fly ash and cement 10A with an ASTM class F fly ash. The two fly ash blends were prepared in the laboratory and contained 20% fly ash by total mass of binder. The chemical analyses of the various binders are given in Table 1. For all concrete mixtures, a natural granitic sand, having a fineness modulus of 2.5 and a water absorption after 24 hours of 0.6% was used. The coarse aggregate consisted of a very dense crushed limestone with a maximum size of 20 mm. All aggregate were used saturated surface dry. Pertinent data for the aggregates are given in Table 2.

All concrete mixtures were prepared using a lignosulfonate based water-reducer and a synthetic detergent air-entraining admixture. Mixtures were all prepared at a water-binder ratio of 0.45 and at a paste volume of approximately 0.31 m^3/m^3. Batching was done using a counter-current pan mixer according to a standardized procedure. The water-reducer was first diluted in part of the mixing water. It was then mixed with the binder to obtain a uniform paste. The air-entraining agent and the remaining water were then added. After a period of one minute, the coarse and fine aggregates were placed in the mixer and the concrete was mixed for an additional three-minute period.

Fifteen 75 x 225 x 300 mm specimens for the scaling test were cast for each batch. Concrete was consolidated in the molds by vibration. The surface to be tested was lightly leveled with a wooden trowel. After casting, the specimens were covered with a wet burlap and left as such for 24 hours. At the end of this period, specimens were demolded and immersed in a saturated lime solution for 360 days prior to the testing. Concrete mixture characteristics are given in Table 3.

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[1] CSA = Canadian standard association

Table 1 — Chemical composition of the binders

Constituent	Binder				
	OPC A (%)	OPC B (%)	Blended silica fume cement (%)	Class C fly ash (%)	Class F fly ash (%)
Silicon dioxide	20.9	21.2	26.5	33.7	45.9
Aluminium oxide	4.1	4.8	4.2	21.2	26.9
Ferric oxide	3.2	3.6	3.3	5.7	14.4
Calcium oxide	61.9	62.7	59.0	20.7	3.5
Free lime	0.6	1.2	0.7	—	—
Sulfur trioxide	3.5	2.8	2.9	4.4	0.7
Magnesium oxide	2.4	2.9	2.3	4.1	0.7
Alkalies (eq. Na_2O)	0.9	1.1	0.8	7.2	2.4
Loss on ignition	1.4	0.8	2.5	1.7	4.6
Insoluble residue	0.6	0.5	0.7	—	—
Mineralogical composition (Bogue's equations)					
C_3S	50.9	48.6	—	—	—
C_2S	21.6	23.9	—	—	—
C_3A	5.5	6.6	—	—	—
C_4AF	9.6	11.0	—	—	—

Table 2 — Physical properties of the aggregates

Physical * properties	Fine aggregate	Coarse aggregate
Density	2.64	2.77
Absorption (%)	0.56	0.67
$MgSO_4$ (%)	4.2	3.8
Fineness modulus	2.45	—
Petrographic number	—	120

* According to CSA/CAN3-A23.2

Table 3 — Mixture characteristics

Mixture	Cement (kg/m3)	Fly ash (kg/m3)	Water (kg/m3)	Fine agg. (kg/m3)	Coarse agg. (kg/m3)
C-10A	400	—	180	826	1000
C-10B	400	—	180	826	1000
C-SF	368+32	—	180	815	1000
C-CC	320	80	180	813	1000
C-CF	320	80	180	805	1000

AEA = 60 ml/m^3 WRA = 400 ml/m^3 for all mixtures

3.2 Specimen conditioning

At the end of the curing period, a first series of specimens was placed in a room kept at 20°C and 50% relative humidity for 14 days. A second and a third series were oven-dried at 40°C and 110°C for 14 days. Typical weight loss curves are shown in Figure 1.

Specimens of a fourth series were subjected to 15 wetting and drying cycles. Each cycle included 4 days at 20°C and 50% R.H. and a resaturation with water for 3 days. Finally, a fifth series of specimens were left at 20°C and 50% relative humidity for a 120 day period. Weight loss data are given in Tables 4 and 5.

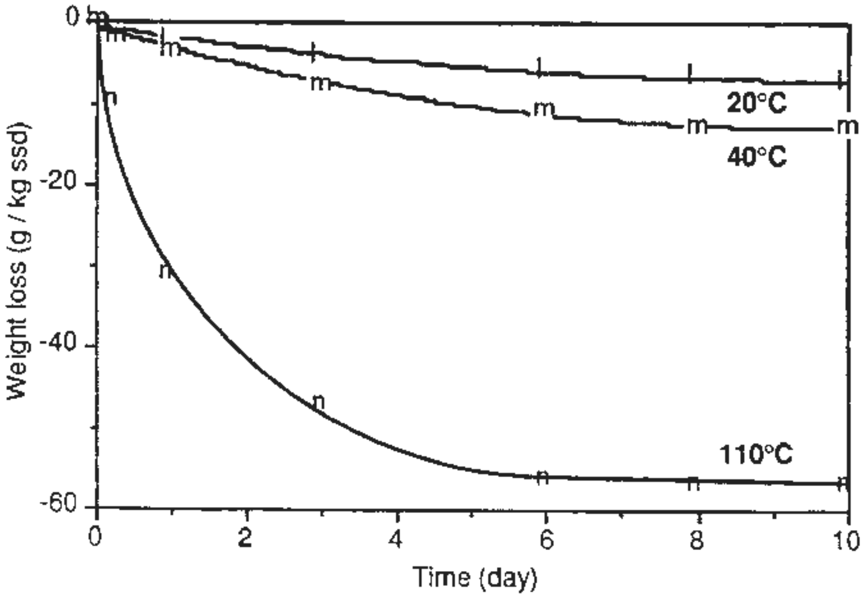

Figure 1 — Typical weight loss curves / Mixture 10A

Table 4 — Weight loss characteristics for the specimens dried at various temperatures

Mixture	Weight loss during drying			Weight gain during resaturation		
	20°C (g/kg ssd)	40°C (g/kg ssd)	110°C (g/kg ssd)	20°C (g/kg ssd)	40°C (g/kg ssd)	110°C (g/kg ssd)
C-10A	10.0	13.6	57.4	2.6	4.3	47.8
C-10B	8.7	12.9	55.0	1.7	3.7	41.7
C-SF	7.5	13.0	59.1	1.6	3.1	45.5
C-CC	8.5	12.6	58.8	2.2	3.9	49.9
C-CF	9.2	14.2	60.0	2.2	4.7	49.5

Note: All results = mean value of three specimens

Table 5 — Weight loss characteristics for the specimens dried at 20°C

Mixture	Weight loss during drying			Weight gain during resaturation		
	21 days (g/kg ssd)	120 days (g/kg ssd)	* Drying / wetting (g/kg ssd)	21 days (g/kg ssd)	120 days (g/kg ssd)	Drying / wetting (g/kg ssd)
C-10A	10.0	10.8	8.2	2.6	5.5	1.6
C-10B	8.7	9.9	8.4	1.7	4.6	1.4
C-SF	7.5	7.9	6.7	1.6	3.2	1.0
C-CC	8.5	9.3	7.1	2.2	4.2	0.9
C-CF	9.2	8.5	8.5	2.2	5.1	1.5

Note: All results = mean value of three specimens

* Maximum weight loss measured during the 14-day drying period prior the wetting and drying cycles

3.3 Testing procedures

The compressive strength of all mixtures was measured after 7, 28 and 90 days. In each case, three 100 x 200 mm cylinders were capped and tested in accordance with ASTM standards C 617 and C 39. The air-void characteristics of all concretes were determined in accordance with ASTM C 457 using the Modified Point-Count Method.

All deicer salt scaling tests were performed in accordance with ASTM C672. Three 75 x 225 x 300 mm specimens were tested for each testing condition. At the end of the drying treatment, the test surface of each specimen was covered with fresh water for 14 days. Weight gains measured at the end of the resaturation period are also given in Tables 4 and 5. At the end of the resaturation period, water on top of each specimen was flushed and the test surface was covered with a 3% NaCl solution (28 g/l). All specimens were subjected to 50 daily cycles of freezing and thawing. A typical freezing and thawing cycle, as measured at the solution-concrete interface, is given in Figure 2. In order to prevent any evaporation of the NaCl solution during testing, all specimens were covered with a plexiglass plate. After every 5 cycles, the salt solution was changed, and the specimens were weighed and rated as prescribed by the standard. Scaled off particles were also collected, dried and weighed.

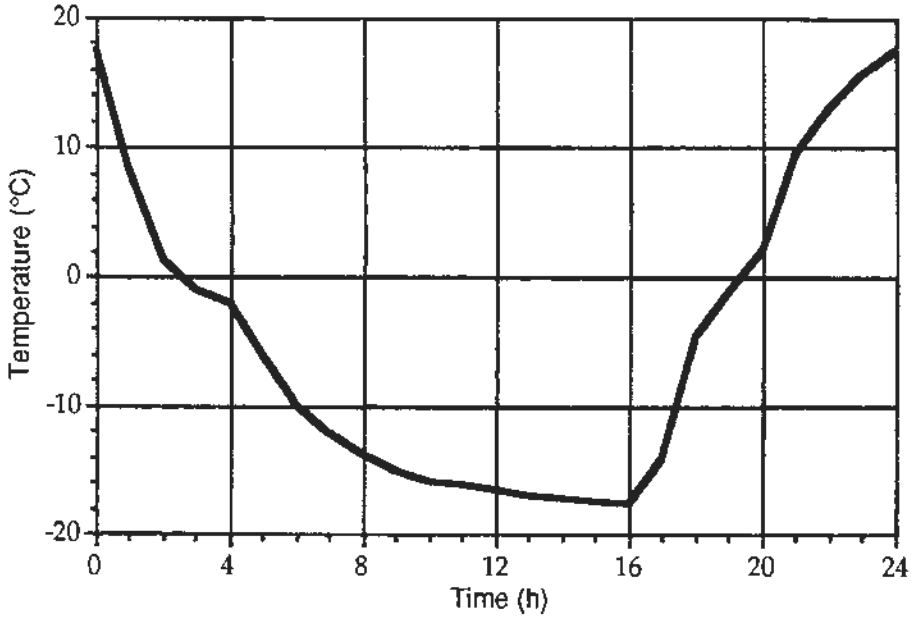

Figure 2 — Typical freezing and thawing cycle

4 TEST RESULTS

4.1 Properties of the fresh concrete

The properties of the fresh concrete are given in Table 6 for all mixtures. Except mixture C-CF, the air content of all concretes is in the 5 to 6% range. It can also be seen that good workabilities were obtained for all concretes.

Table 6 — Properties of the fresh concrete

Mixture	Air content (%)	Slump (mm)	Density
C-10A	5.8	92	2.203
C-10B	5.0	110	2.232
C-SF	6.0	135	2.189
C-CC	6.0	190	2.189
C-CF	2.5	180	2.232

4.2 Air-void characteristics

The air-void characteristics of all concrete mixtures are summarized in Table 7. As can be seen, good spacing factors (≈ 250 µm) were obtained for all concretes except mixture C-CF. This mixture was produced with the class F which has a high carbon particle content. These particles are known to reduce substantially the efficiency of air-entraining agents /5, 6/. Thus, it is highly probable that the dosage of this admixture was insufficient to achieve a correct air-bubble system.

4.3 Compressive strength results

Compressive test results are given in Table 7. After a 7-day curing period, the compressive strength of the silica fume concrete is slightly lower than that of the two OPC concretes. At later times, values measured for silica fume concrete are significantly higher. The slower strength development, at early ages, of the silica fume concrete has already been observed in a previous test series /1/, and is in good agreement with data reported by SELLEVOLD and RADJY /7/. Results of Table 7 also indicate that the strength developments of the two fly ash concretes are much slower than that of the other mixtures. After 90 days of curing, the addition of the class C fly ash appears to be beneficial.

The low values measured for the class F fly ash concrete are a little surprising considering the low air content of that mixture. Previous test results have, however, indicated that the class F fly ash concrete tends to develop substantial strength between 90 and 360 days /1/.

4.4 Sample conditioning before the scaling test

As could be expected, weight loss tended to increase significantly with an increase of the drying temperature. It is however surprinsing to note that, for the samples kept at 20° C, an increase of the drying period from 14 days to 120 days did not contribute to makedly affect the weight loss (see Table 5). Although the drying of concrete is a non-linear phenomenon with a very slow kinetics, the weight losses after 120 should be higher than the measured values. It is probable that carbonation of the concrete surperficial layers has contributed to significantly alter the drying process.

Data of Tables 4 et 5 also indicate that a 14-day resaturation period was clearly not sufficient to fully resaturate the concrete samples. It should however be emphasized that the concrete

Table 7 — Air-void characteristics and compressive strength results

Mixture	Air-void characteristics			Compressive strength		
	Air content (%)	Specific surface (mm^{-1})	Spacing factor (µm)	7 days (MPa)	28 days (MPa)	90 days (MPa)
C-10A	7.0	20.4	252	32	38	43
C-10B	5.1	21.6	261	33	41	45
C-SF	7.9	20.0	201	30	48	51
C-CC	5.5	22.4	221	28	37	48
C-CF	1.8	24.8	355	28	33	38

samples were allowed to dry from all sides while only the top surface of the concrete was covered with water during the resaturation period. It is thus reasonable to believe that the surface layer of concrete subjected to the test was probably back to its initial state of saturation before the freezing and thawing cycles.

It is also possible that the disrepency between the weight loss and the weight gain measurements could be attributed, at least in part, to the entrained air voids. The initial 360 days curing period has certainly led to the filling of a substantial portion of the air pores. These voids dried out during the drying period but probably did not refill on the 14-day suction.

It should finally be emphasized that the reduced degree of saturation of the concrete samples prior the test should theoretically increase their resistance to deicer scaling,at least for the first cycles.

4.5 Deicer salt scaling results - General considerations

As previously mentioned, three specimens were tested for each testing condition. Hereafter, results are reported as mean values. Overall, the three replicates represent a larger test surface than that required by the standard (approximately 110 cm^2 vs 90 cm^2). The increased number of specimens was motivated by the relatively large scatter in the test results observed earlier. From a statistical analysis, the variability of the ASTM C 672 procedure was recently evaluated to be in the 20 to 30% range /1/. In the present test series, the scatter was found to be slightly less important. However, marginal differences between two values can not be considered as very significant.

The ASTM C 672 standard does not include any limit to evaluate the deicer scaling resistance of concrete. According to the Swedish standard /9/, a mass of scaled off particles of 1 kg/m^2 after 56 cycles of freezing and thawing is considered to be acceptable. The Swedish test procedure is a modified (improved) version of ASTM C 672.

4.6 Deicer salt scaling results - Influence of the predrying temperature

The mass of scaled-off particles and the ASTM ratings after 50 cycles are given in Table 8 for all the specimens predried at 20°C, 40°C and 110°C for 14 days. Except for the class F fly ash mixture, all concretes tested according to the standard procedure, i.e. predried at 20°C, are found to have, at least, an acceptable scaling resistance. Best performances are obtained for two OPC concretes while the class C fly ash concrete is found to be very close to the 1 kg/m^2 limit. When compared to the OPC mixtures, the lower durability of the silica fume concrete is a little surprising taking into account the good spacing factor as well as the high compressive strength. This tendency has been observed in some previous test series /3, 10, 11/, but not in others /4/. The poor deicer salt scaling resistance of the class F fly ash concrete is most probably due to its high spacing factor.

Table 8 — Scaling test results - Influence of the predrying temperature

Mixture	Drying = 20 °C		Drying = 40 °C		Drying = 110 °C	
	Visual rating	Scaled off particles (kg/m^2)	Visual rating	Scaled off particles (kg/m^2)	Visual rating	Scaled off particles (kg/m^2)
C-10A	2	0.28	3	1.11	5	5.03
C-10B	1	0.24	4	2.11	5	5.22
C-SF	3	0.71	2	0.51	5	4.33
C-CC	3	1.06	3	1.28	5	8.75
C-CF	5	6.85	5	10.50	Dis.	Dis.

Note: Dis. = both specimens totally disrupted

As can be seen in Table 8, predrying at 40° C has considerably increased the scaling of the two OPC concretes. In both cases, the drying treatment has more than triple the mass of scaled-off particles after 50 cycles. The effect of the drying temperature on the durability of mixture C-10A can be better visualized in Figure 3. On the other hand, predrying at 40°C does not appear to have significantly affected the silica fume and the class C fly ash concretes. The higher stability of the silica fume concrete with respect to drying is illustrated in Figure 4. Given the very high scaling values, the effect of predrying at 40°C on the class F fly ash can hardly determined.

Results of Table 8 also underline the extreme severity of predrying at 110°C. For all concretes, such a treatment results in a considerable reduction of the deicer salt scaling resistance. No significant effect of the type of binder can be observed. These results are in good agreement with the data reported earlier /1/.

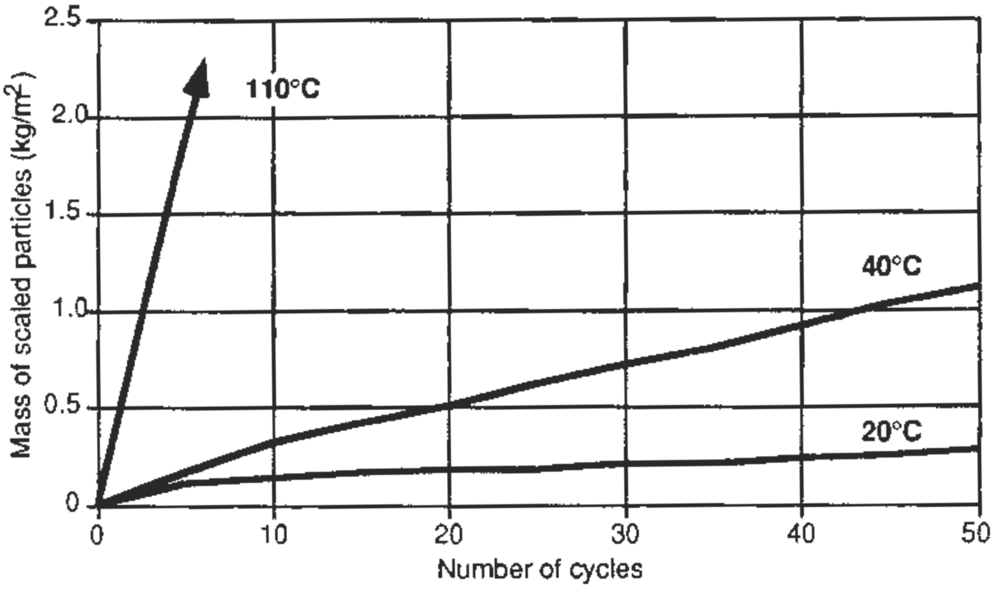

Figure 3 - Influence of the predrying temperature on the scaling resistance of concrete C-10A

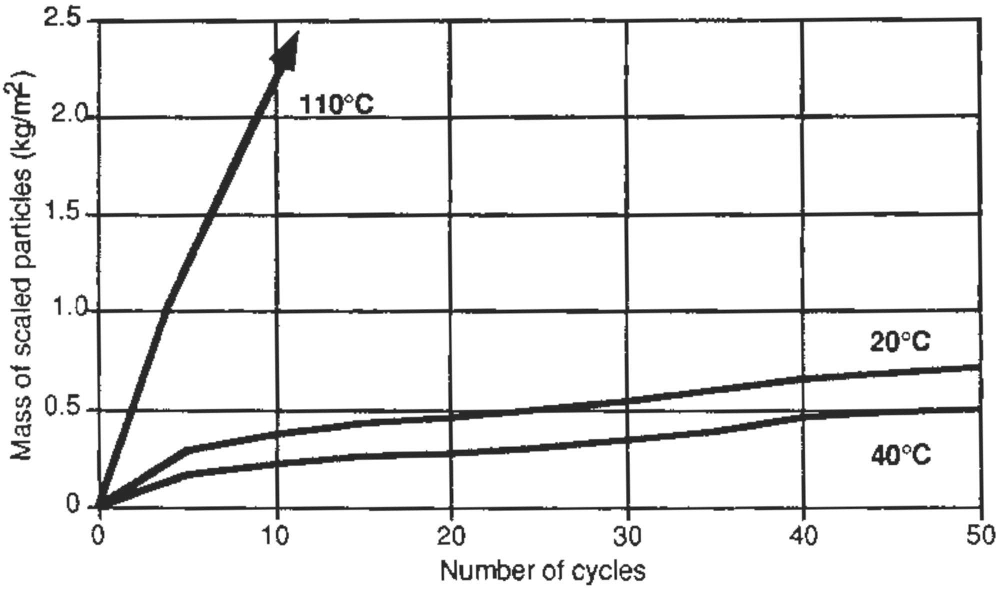

Figure 4 - Effect of the drying temperature on the scaling resistance of the silica fume concrete

4.7 Deicer salt scaling results - Drying at 20°C

The mass of scaled-off particles and the ASTM ratings after 50 cycles are given in Table 9 for all the specimens predried at 20° C. In all cases, prolonged drying at 20° C increases the mass of scaled-off particles. Although, this effect is less important for some concretes, mixture C-SF for instance, the detrimental influence of the prolonged predrying results in a significant reduction of the scaling resistance for all mixtures. As can be seen in Figure 5, specimens predried for 120 days usually exhibit a higher scaling for the first cycles, after which their curves stabilize to become very similar to that of the specimens predried for 14 days.

Results of Table 9 indicate that wetting and drying cycles slightly increase the deicer salt scaling resistance of most concretes. In all these cases, the reduction of the mass of scaled off particles can be considered to be significant. The only exception is mixture C-10B for which the wetting and drying cycles double the mass of scaled-off particles after 50 cycles.

5 DISCUSSION

5.1 Standard procedure (predrying at 20°C for 21 days)

The good scaling resistance of the two OPC concretes can certainly be explained by the length of the curing period (i.e. 360 days) and the quality of the air-void system. These results indicate, however, that, even when very good concreting practices are followed, ordinary concretes always show some scaling. This seems to be especially the case when wood-troweled surfaces are tested.

The lower scaling resistance of the silica fume concrete can hardly be explained, and is in conflict with data reported in a previous study /4/. Silica fume is known to reduce the hydrated cement paste permeability. Lower permeability is expected to increase the deicer salt scaling resistance of concrete. It has been earlier suggested that the lower scaling resistance of silica fume concrete could be attributed to the higher brittleness of the cement paste matrix /11/. Silica fume pastes contain less $Ca(OH)_2$ crystals and are usually found to have a denser and more uniform microstructure /12, 13/. Frost-induced microcrack propagation is thus more likely to occur in these pastes. This can probably account, at least partially, for the lower scaling resistance of the silica fume concrete.

5.2 Effect of the predrying temperature

The detrimental effect of predrying at 40° C on the scaling resistance of OPC concretes is in good agreement with earlier test series. It has been found that scaling is, at least qualitatively, related to the amount of ice formed between 0° C and -20° C /2, 3/. In a previous study /1/, it has been shown that drying tends to coarsen the pore structure of OPC pastes, and increases the amount of freezable water. The same investigations have also indicated that the pore structure of blended cement concretes are less affected by drying. Instead of being coarsened, the pore structure of these concretes appears to be more compact. This seems to particularly true for the silica fume concretes.

The marked effect of predrying at 40° C on the deicer salt scaling deterioration of the OPC concretes can not be solely explained on the basis of previous test results /1/. Neither the methanol diffusion measurement nor the ice formation data showed any significant difference between predrying at 20° C and predrying at 40° C. In both cases, the level of pore structure alterations appeared to be similar.

It is probable that the significant increase of scaling associated with predrying at 40° C can simply be explained by the fact that a higher volume of concrete near the surface is affected at

Table 9 — Scaling test results for the concretes dried at 20° C

Mixture	Drying = 14 days		Drying = 120 days		Drying / wetting	
	Visual rating	Scaled off particles (kg/m^2)	Visual rating	Scaled off particles (kg/m^2)	Visual rating	Scaled off particles (kg/m^2)
C-10A	2	0.28	3	0.65	1	0.19
C-10B	1	0.24	2	0.41	2	0.46
C-SF	3	0.71	3	0.97	2	0.23
C-CC	3	1.06	4	1.84	3	0.30
C-CF	5	6.85	5	4.40	5	4.25

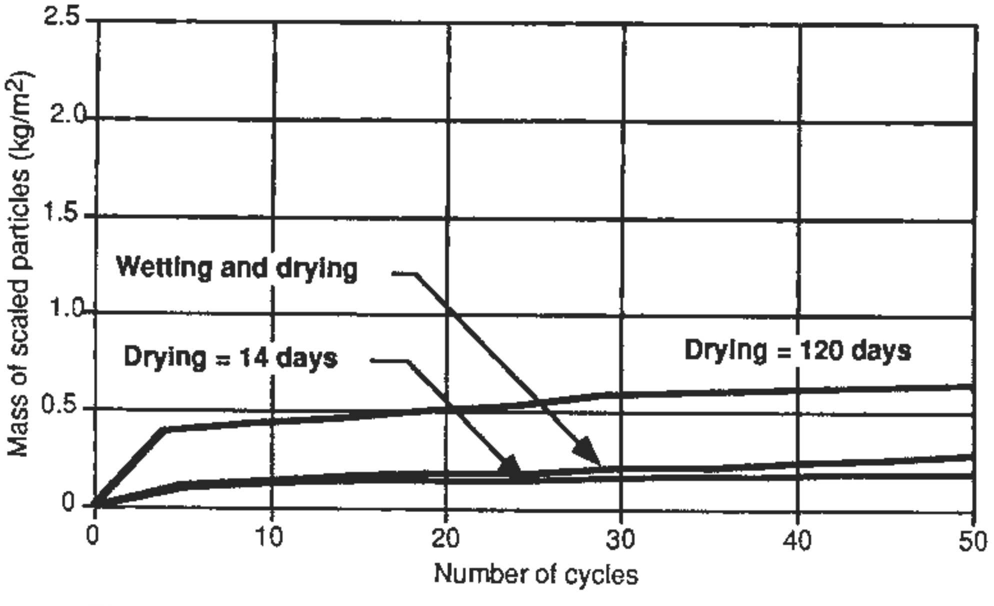

Figure 5 - Typical effect of the various predrying treatments at 20°C on the scaling resistance of concrete (Mixture C-10A)

this temperature. As explained by BAZANT and NAJJAR /13/, the diffusion of water during drying is a nonlinear phenomenon. According to these authors, after several days at 20° C and 50% R.H., only the first millimeters under the surface are affected by drying. An increase of the predrying temperature probably increases the thickness of the layer of concrete affected by drying.

As previously mentioned, the bad performance of all the concretes predried at 110° C is in good agreement with previous test results. At this temperature, not only the pore structure of the hydrated cement paste is coarsened, but concrete also is severely microcracked and significant phase transitions can occur. Ettringite, for one, has been found to be stable up to 75°C after which its dehydration starts /14, 15/.

5.3 Effect of pretreatments at 20° C

The effect of the various pretreatments at 20° C can also be analyzed by considering the thickness of the concrete layer affected by each procedure. It is probable that the wetting and drying cycles only contributed to increase microcracking in the first millimeters near the surface, and that the thickness of the concrete layer affected by drying was not significantly increased. In a previous study, microcracking was not found to have a detrimental influence on surface scaling /1/. Although microcracking contributes to increase (at least locally) the amount of freezable water, it also probably increases the permeability of the matrix. The global effect is probably a slight increase of the scaling resistance.

The slight improvement of the deicer salt scaling resistance of concrete by the wetting and drying cycles is of particular interest with regard to testing. Under field exposure conditions, concrete surfaces are more likely to be subjected to several wetting and drying cycles. In this respect, most laboratory test procedures are not well designed to account for such an improvement.

It is most likely that prolonged predrying increases the thickness of the concrete layer affected. Such a treatment also increases the period during which the hydrated cement paste is subjected to the action of capillary forces. This is believed by many authors to increase the pore structure coarsening /16, 17/.

6 CONCLUSION

Test results clearly indicate that the deicer salt scaling resistance of concrete is affected by the temperature of drying. Predrying at 40° C was found to reduce significantly the deicer salt scaling resistance of OPC concretes. Blended cement concretes did not appear to be significantly affected by such a pretreatment. Test results also indicate that predrying at 110° C considerably reduces the deicer salt scaling resistance of all concretes, whatever the type of binder used. Given the detrimental effects of drying at 40° C and 110° C on the deicer salt scaling resistance of OPC concrete, both treatments should be avoided.

Numerous wetting and drying cycles prior to testing appeared to slightly increase the deicer salt scaling resistance of all concretes. On the other hand, prolonged predrying at 20° C was found to increase the scaling of concrete. Silica fume concrete appeared to be less affected by this pretreatment.

According to these test results, a predrying period of 14 days at 20° C followed by a resaturation period appears to be the best procedure to assess the deicer salt scaling behavior of concrete in laboratory.

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