FROST RESISTANCE OF CONCRETE AFTER IMPREGNATION WITH A WATER REPELLENT AGENT

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ABSTRACT

Although major mechanisms of frost damage are known and the technology for preparing frost resistant concrete have been developed in practical applications serious frost damage still occurs. Surface treatment with water repellent agents has been applied with variable success. In this contribution, experimental results are presented on frost resistance of untreated and impregnated concrete. If less than 30 frost cycles are applied, a water repellent agent significantly increases frost resistance. In case the concrete surface is in contact with a salt solution for several months, however, the situation becomes more complex. Two opposing processes, i.e. salt migration and drying have to be taken into consideration. The impregnated cover can be locally damaged and then frost action destroys the underlying untreated concrete quickly.

1 INTRODUCTION

Frost damage has been observed very early and as a consequence, the relevant mechanisms have been studied with enormous efforts numerous. By now, the major effects are known and resistant concrete can be produced for severe climates. the expansion of freezing water and the crystallization of salts from the pore solution are next to thermal gradients and the thereby provoked eigenstresses the most important causes for frost damage. For this reason, among other test methods, the critical saturation has been suggested as a reliable measure to determine frost resistance of porous materials.

Under normal conditions, concrete binds chemically enough water as to provide space for the expansion of freezing capillary water. By capillary suction, however, concrete can be resaturated if in contact with liquid water. Liquid water films can be formed by different processes, such as driving rain or condensation. With the water aggressive dissolved salts can be transported into the porous concrete.

Surface treatment with a water repellent agent drastically reduces capillary suction. As a consequence, an impregnated concrete element should be more frost resistant than an untreated companion specimen. In case a liquid film is in contact with an impregnated concrete surface for a longer period, however, moisture movement in form of water vapour into the concrete or from the concrete is still possible. It is the aim of this contribution to study the consequences of these complex interactions for frost resistance experimentally.

2 INFLUENCE OF A WATER REPELLENT IMPREGNATION ON FROST RESISTANCE

In order to study the freeze-thaw and deicing salt resistance concrete slabs with a surface of 400 x 400 mm and a thickness of 70 mm have been cast. Two different types of concrete, with two minor variations each, have been prepared, i.e. a normal and a pumped conrete. The composition of the two mixes is given in Table I. In all concretes, the maximum aggregate size was chosen to be 32 mm. The size distribution in the normal concrete followed approximately the Fuller curve and in the pumped concrete the content of finer fractions was increased.

On the surface of these slabs a 3% Na Cl solution has been placed and then frost cycles between +20 C and -12 C have been carried out. After 10, 20 and 30 cycles the material loss by surface scaling has been determined gravimetrically [1-4].

Results of a first test series are shown in Fig. 1.
The material loss has been determined on three elements in each case. Results are shown as a mean cumulative function. The normal concrete in the untreated state has a moderate frost resistance while the pumped concrete must be classified as being not frost resistant. As can be seen from Fig. 1, both concretes are extremely frost resistant once treated with a water repellent agent. In this case, a siloxane dissoved in an organic liquid has been applied.

It has always been questioned if 30 cycles are really enough to characterize frost resistance of concrete in real applications realistically. Therefore, a second series with a higher number of frost cycles, up to one hundred, was carried out. Results are shown in Fig. 2.
The normal concrete and the pumped concrete both had a slightly lower water/cement ratio in this second series (see Table I).

TABLE I Mix composition of normal and pumped concrete

Type of concrete	PC kg/m^3	Water l/m^3	W/C
normal (A)	300	150	0.50
normal (B)	300	159	0.53
pumped (A)	325	189	0.58
pumped (B)	325	192	0.59

FIG. 1 Loss of material from the exposed surface of treatment and impregnated concrete as function of the number of frost cycles.

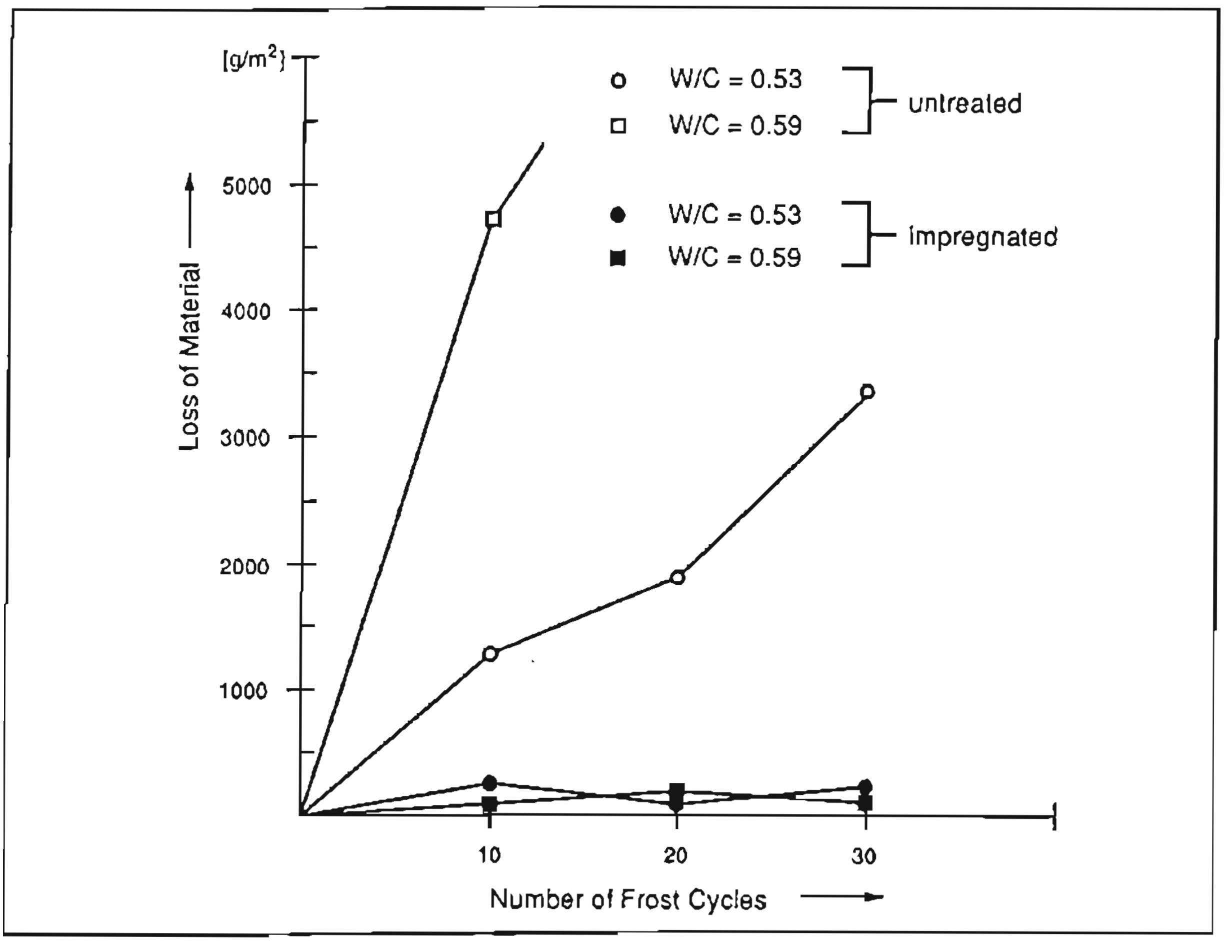
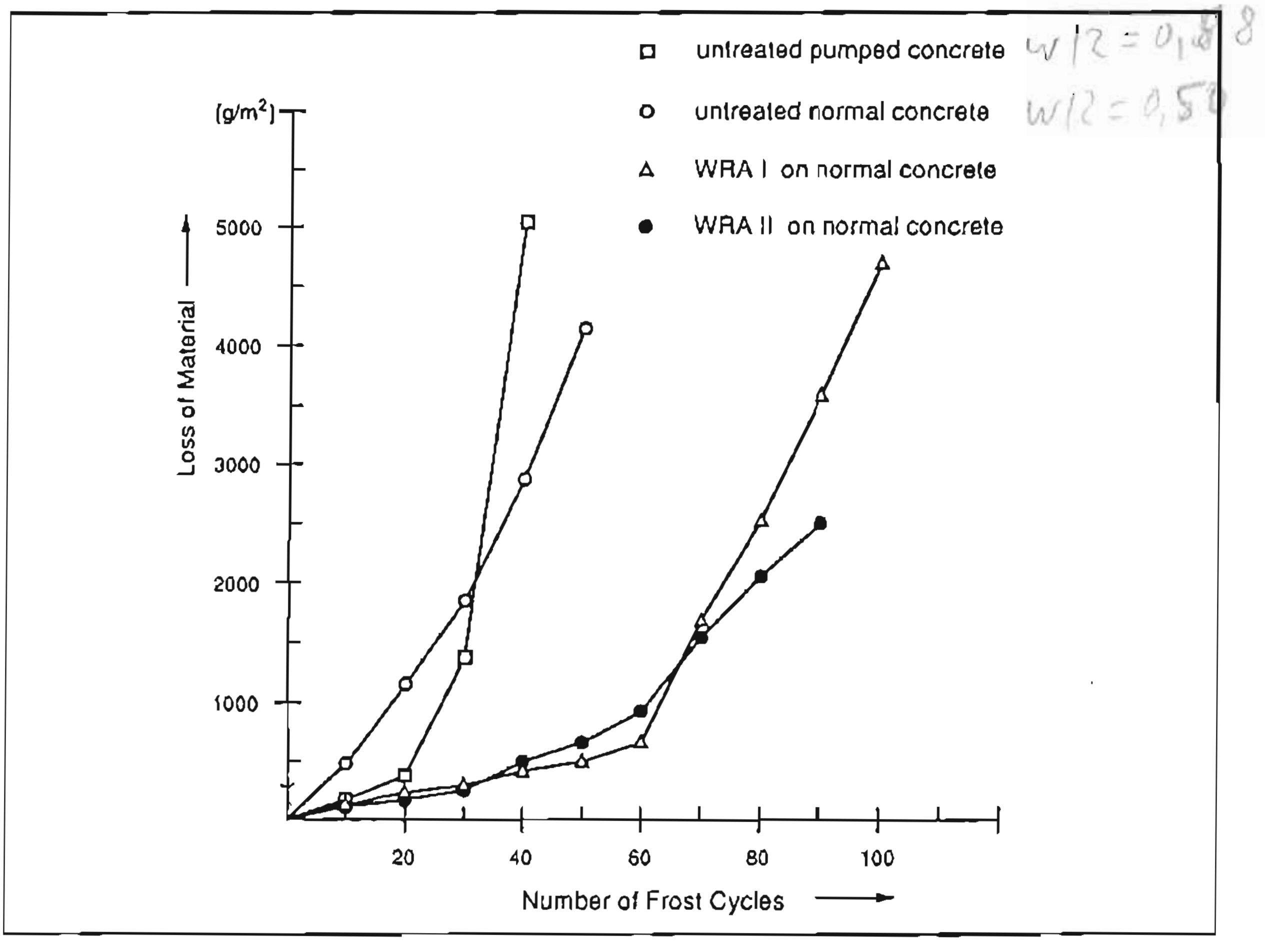


Fig 2 Loss of material from the exposed surface of untreated and impregnated normal concrete (W/C = 0.50) and pumped concrete (W/C = 0.58).



The behaviour of the normal concrete of the second series is similar to the one in the first test series. The pumped concrete, however, behaves satisfactorily until 30 frost cycles in this case. This may be due to the slightly decreased water / cement ratio. Only few cycles more than 30 are needed to destroy the pumped conrete slab nearly completely. This result is clear evidence that 30 cycles cannot be considered as a reliable basis for the prdiction of concrete structures under variable frost action.

If these two types of concrete are surface treated with a water repellent agent the frost resistance remains good until 60 frost cycles. Then, both curves bend suddenly upwards. Frost damage has been delayed by the impregnation but not prevented.

3 INFLUENCE OF THE DURATION OF CONTACT OF THE SALT SOLUTION WITH THE CONCRETE SURFACE ON FROST RESISTANCE

Many different tests have been suggested in order to investigate frost resistance of concrete and other porous materials. Tests have become more sophisticated and recently good reproducibility has been found with the recently developed CDF-method [5]. Often it is claimed that no good correlation between laboratory test results and performance in practice can be established. One reason for this discrepancy is certainly the influence of different and variable curing conditions in practical cases.

In most test procedures the concrete surface is brought into contact with a salt solution and then the first frost cycle is started immediately. In practical cases, however, the surface of concrete can be in contact with the salt solution for rather long periods before numerous frost cycles occur.

Concrete slabs with the dimensions of 400 x 400 x 70 mm have been prepared again. Half of the slabs have been impregnated with a dissolved siloxane [3]. The frost resistance as determined in a standard testing procedure, i.e. immediate start of frost cycles, is shown in Figs. 3 and 4.

FIG. 3 Loss of material from the exposed surface of untreated normal concrete (W/C = 0.5) as function of the number of frost cycles.

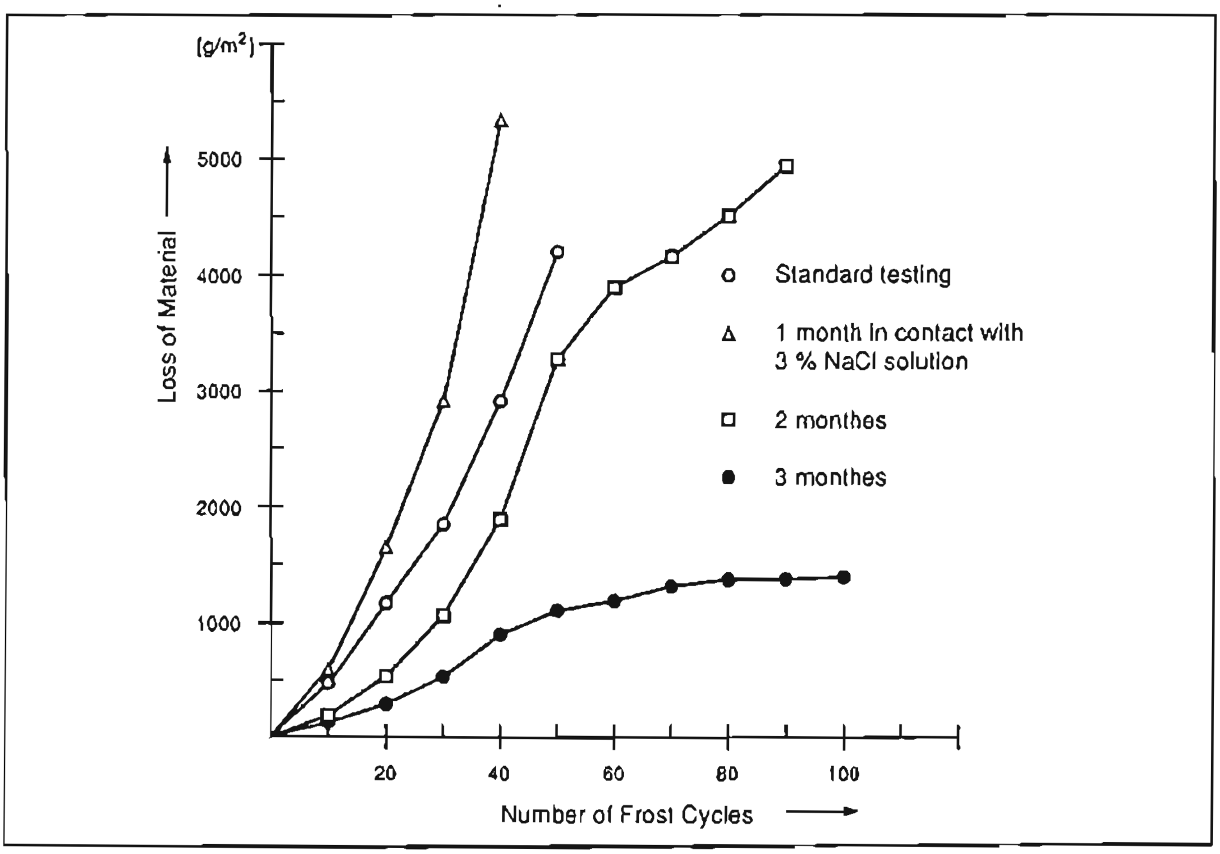
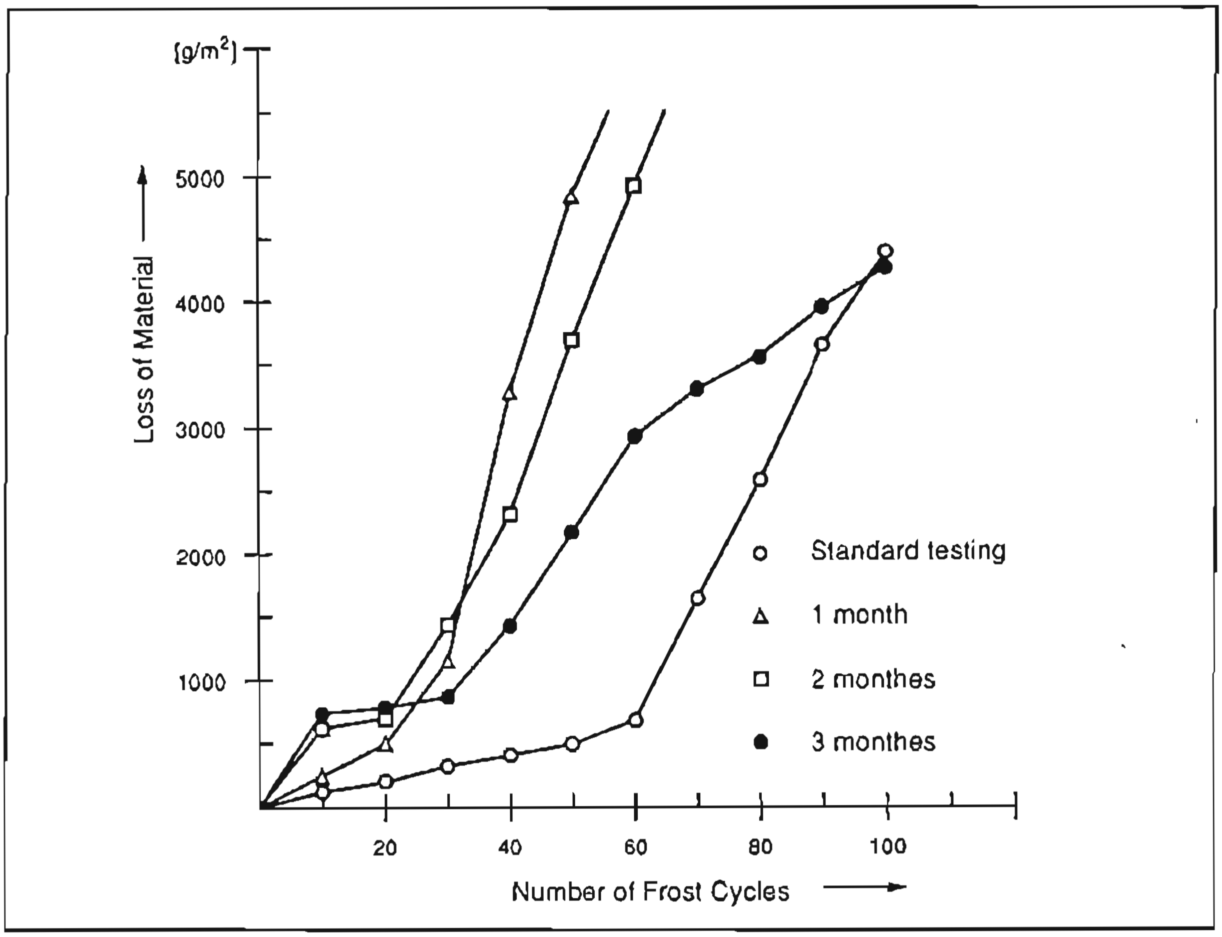


FIG. 4 Loss of material from the exposed surface of impregnated concrete as function of the number of frost cycles



Here, results obtained on normal concrete are shown exclusively. Similar tests have been made on pumped concrete elements [3]. It can be seen that the untreated concrete deteriorates rather quickly after having reached 30 cycles while the impregnated concrete remains nearly intact until 60 cycles. The impregnated concrete, however, deteriorates rather quickly under higher numbers of cycles.

Then, identical specimens have been prepared. But now, the surface was kept in contact with a 3% NaCl solution for one, two and three months. Results are also shown in Figures 3 and 4 as well. It is interesting to see that a one month contact period leads to a substantially accelerated frost attack for both untreated and impregnated concrete slabs. If the contact period before the start of the frost cycles is further increased the influence on frost resistance is reversed. The concrete elements become more durable. This effect is most pronounced in the case of untreated normal concrete. After a three month period, the frost resistance is very good up to 100 frost cycles. In the case of impregnated concrete elements, the frost resistance of slabs with a contact period of 3 months after 100 cycles is practically the same as compared to the standard testing procedure.

At this point, a tentative explanation of these observations can be given only. If the salt solution is in contact with the concrete surface for one month a small amount of chloride ions can transgress the impregnated surface layer. This has been verified experimentally. At longer periods of contact, however, the drying process which is provoked by the salt solution dominates. A 3% NaCl solution is in equilibrium with about 87% RH. It cannot be excluded that during contact period the salt solution reached a higher concentration and hence was in equilibrium with an even lower humidity. In this case, the salt solution on the surface partially dried the surface near zones of the concrete elements and provided a higher frost resistance. In other words, there are two opposing effects to be distinguished. First, some chloride ions can penetrate into the porous structure. This leads to a lower frost resistance. Later, the drying process dominates and increases the frost resistance.

The same concrete if exposed for a short period to a salt solution may be seriously damaged by frost scaling and if exposed for a long enough period may survive a high number of frost cycles without noticeable damage. This is further evidence that none of the existing test mehtods can be expected to reflect the risk of frost damage under all possible curing conditions in a realistic way.

4 CONCLUSIONS

Frost resistance of concrete elements depends on the material properties but also on the curing conditions before the first cycles.

An impregnation with a water repellent agent drastically improves frost resistance. At high enough frost cycles local damage of the concrete surface may occur.

Extended exposure of the concrete surface to a salt solution leads to drying and hence to increased frost resistance.

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