A NEW METHOD TO ANALYSE THE SCALING TEST RESULT

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Abstract
Hardened concrete exposed to freeze-thaw cycles may be damaged under the form of internal frost and/or scaling. The last one is a complex phenomenon, which leads to superficial damage particularly in the presence of de-icing salt.

The French scaling standard test requires 56 freeze-thaw cycles with a 3% sodium chloride solution laid on the exposed surface of the concrete. The result is expressed as the scaled mass related to the exposed surface. A quantitative statistical-based analysis with 3 different concrete mix compositions allows us to establish that these results follow lognormal distributions. This distribution law correctly translates the asymmetry and the observed dispersion. But it also shows that the standard test can discriminate high from weak resistant concrete.

A new method to analyse these results is to evaluate the number of freeze-thaw cycles necessary to reach a fixed scaled mass. These last results are distributed according to a normal distribution. This distribution is centered around an identifiable number of freeze-thaw cycles which is one of the major parameters of the deterioration. Furthermore, this new method to analyse the scaling test shows that it is possible to decrease the coefficient of variation for a higher number of cycles.
1. INTRODUCTION

Evaluating the frost resistance of cement-based materials is a major challenge for sustainable concrete manufacturing in building or bridge construction. Traditionally based on a prescriptive approach, it offers new possibilities in the EN 206-1 standard with performance-based specifications. For prescriptive or performance-based approaches and concrete durability in winter conditions, the frost effect indicators on hardened concrete are the accelerated laboratory tests with thresholds of acceptance [1]. The performance-based specification purpose is to preserve the life construction for 100 years. In spite of comparative studies [2][3][4], it remains difficult to correlate the accelerated laboratory test results and the speed of material deterioration exposed to real climatic conditions. Furthermore, the laboratory test of concrete frost durability, in particular scaling presents weak repeatable and reproducible results. In spite of its weak reproducibility, this test remains discriminating to qualify the scaling resistance of a hardened concrete.

2. THE LABORATORY TESTS TO EVALUATE THE FROST RESISTANCE

2.1 The French standard tests for hardened concrete manufactured according to the NF EN 206-1 standard

Frost resistance of cement-based material is a large and complex problem. There is not a universal way to deal with this topic to our current. Frost effect on concrete is commonly separated in two main appearance of deterioration: the internal frost and the scaling [5][6].

The first one, the internal frost, leads to micro-cracking of the cement paste in the concrete heart. It induces an inflation and decrease of the Young modulus. Identified by T.C.Powers [7][8], between 1946 and 1949, this deterioration is still the object of experimental research and modelling. The scientific community agrees on the main mechanisms of internal frost and the means to improve the resistance of a concrete by adding a network of air bubbles in the cement paste [9][10]. The internal frost evaluation follows, during the freeze-thaw cycles, the evolution of the relative elongation of the body and the modulus of elasticity through frequency of echo or ultra-sound measurements. The NF P18-424, “severe frost” and the NF P18-425, “moderated frost” French standard tests, correspond to the characterization of the internal frost for a concrete in saturated and no saturated condition. The elaboration of these standards is inspired by the North Americans experiments and standards [12][13].

The second one, the scaling, is the deterioration of a concrete saturated surface [14][15]. This deterioration is influenced by the presence of salts: a pessimum of salts concentration in the solution generates a maximal damage [16][17][18]. Mechanisms of deterioration including this pessimum effect have been recently proposed [19][20]. During the laboratory tests, the concrete surface is generally exposed to freeze-thaw cycles in the presence of a 3 % NaCl salt solution. The scaling test result is the amount of lost material related to the tested surface. The French standard test XP P18-421, is very similar to so known Swedish Standard SS 13 72 44 under the name of Boras test which is the reference method of the European prEN / CEN standard TS 12390-9.
2.2 The French scaling standard test: XP P18-420

The French scaling standard procedure is presented in the figure 1. The exposed surface is the bottom of mould face while the prEN / CEN TS 12390-9 tests a sawn surface. In the first case, the test represents the surface confined by an on-site exposed concrete, in the second case, the purpose is to test the more homogeneous properties in the heart of the concrete. Indeed, the skin of a concrete presents a gradient of in-depth property and heterogeneity of surface.

The cement substitutes or additives generate different evolutions of the body according to the cure and preservation. A carbonation effect in the conditions of cure and of preservation should be noted [21]. Theses elements may modify the scaling concrete resistance. So, specifications are introduced to limit scattering due to manufacturing, cure, preservation and preparation of the bodies.

3. STATISTICAL ANALYSIS OF SCALING INDIVIDUAL RESULT

Three concretes mixes (A, B and C) consisted of Ordinary Portland Concrete containing an air entraining agent allowed to estimate the repeatability of the individual scaling result. A significant number of bodies was manufactured from the same bath for each concrete mix: 16 samples for the concrete A, 16 for B and 24 for C. They were subjected at the same time to strictly identical cure, preservation and preparation up to the freeze-thaw cycle exposure. Characterizations led on fresh concrete during the manufacturing and on hardened concrete (28 days compression resistance, porosity, spacing factor) indicate a very good homogeneity.
of the bodies from the same batch. Then, the bodies were exposed to the same freeze-thaw cycles in a single climatic chamber.

These three experimental campaigns present a wide range of results (table 1). The median scaling mass result up to 56 freeze-thaw cycles is 75 g/m² for concrete A, 153 g/m² for concrete B, and 3006 g/m² for concrete C. Concrete A and B are scaling resistant in contrary to concrete C.

<table>
<thead>
<tr>
<th>Concrete</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ g/m²</td>
<td>76</td>
<td>172</td>
<td>3090</td>
</tr>
<tr>
<td>σ g/m²</td>
<td>46</td>
<td>46</td>
<td>1387</td>
</tr>
<tr>
<td>σ/μ</td>
<td>60%</td>
<td>60%</td>
<td>45%</td>
</tr>
<tr>
<td>median g/m²</td>
<td>75</td>
<td>153</td>
<td>3006</td>
</tr>
<tr>
<td>max. g/m²</td>
<td>185</td>
<td>305</td>
<td>5481</td>
</tr>
<tr>
<td>min. g/m²</td>
<td>13</td>
<td>55</td>
<td>927</td>
</tr>
<tr>
<td>R² (Henry)</td>
<td>91%</td>
<td>96%</td>
<td>95%</td>
</tr>
<tr>
<td>5% sup. fractile g/m²</td>
<td>208</td>
<td>377</td>
<td>5765</td>
</tr>
<tr>
<td>5% inf. fractile g/m²</td>
<td>15</td>
<td>49</td>
<td>888</td>
</tr>
</tbody>
</table>

3.1 Statistical analysis of individual results at 56 cycles

A statistical analysis allowed us to establish that the results are distributed according to a log-normal distribution. This type of distribution is confirmed by the three concretes and thus for the range of results, from 75 to 3000 g/m². The obtained results can be commented as follows:

- The scaling test allows to qualify the resistance against the scaling of a concrete: a lower fractile of 5% equal to 208 for concrete A and 377 g/m² for concrete B. Theses concretes are very resistant in the scaling compared to the French threshold of 600 g/m² [1]. On the contrary, the concrete C presents a higher fractile of 5 % equal to 888 g/m² which is upper than 600 g/m².
- The amplitude and the standard deviation are high. The coefficient of variation around 60% indicates scattering.
- The standard deviation and the coefficient of variation calculated with the raw values obtained from the test are false because these calculations assume a normal distribution of the results. They are systematically lower than the statistical estimation values.
- The distribution is asymmetrical: 38 and 62% with regard to the mean value. It presents a high number of low values and a low number of high values. The mode of the log-normal law is lower than the average or than the median. The peak of density quickly decreases with the increase of the scaled mass to become very low: 3 for 10000 for the concrete C.
The log-normal distribution of the scaled mass result at 56 cycles consolidates the hypothesis that the result of this test is a convolution of several phenomena combining mechanics, physics, and chemistry of porous media.

3.2 Analysis of the individual results corresponding to the determination of a number of cycles to reach a fixed scaled mass value

Another method to analyze the test was established in this study. It consists in estimating the necessary number of cycles to reach a fixed scaled mass value. The result is the number of cycles and the statistical analysis shows that this result is distributed according to a normal distribution. Furthermore, the estimated normal laws are defined by a similar average and a standard deviation.
Table 2 – Scaling individual results analysis (New method)

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Fixed scaled mass (g/m²)</th>
<th>Normal law</th>
<th>μ (number of cycles)</th>
<th>σ (number of cycles)</th>
<th>σ/μ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13</td>
<td>Not calculated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50[1]</td>
<td>37,6</td>
<td>11,2</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>54</td>
<td>36,0</td>
<td>11,6</td>
<td>32%</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>927</td>
<td>37,6</td>
<td>11,2</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>30,9</td>
<td>10,4</td>
<td>34%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>23,2</td>
<td>8,3</td>
<td>36%</td>
<td></td>
</tr>
</tbody>
</table>


The results of this method of analysis are commented as follows:

- If the fixed scaled mass value is too small, it is not possible to realize the statistical analysis. For the concrete A, the analysis with a fixed scaled mass value equal to 13 g/m² leads to a line of Henry with R² equal to 75%. A value of 50 g/m² allows obtaining a representative result.
- Holding the lowest value at 56 cycles as the fixed scaled mass (if it is superior to 50 g/m²) the necessary number of freeze-thaw cycles to reach this value is about 37 and the coefficient of variation is about 30%.
- For the concrete C, the adequacy to a normal distribution exists even by holding a value lower than all the masses scaled in 56 cycles for the fixed scaled mass. The coefficient of variation decreases if the fixed scaled mass value is increased for the analysis. This trend could allow decreasing the coefficient of variation by increasing the fixed scaled mass value and the number of cycles.
- The peak of density of the estimated normal law is of the same order for the 3 concretes and thus for the range of scaling result.

The coefficient of variation of the order of 30% shows some scattering although it decreases with this method of analysis. This scattering seems connected to a single parameter or mechanism because it follows a distribution centered around a recognizable number of freeze-thaw cycles.

If it is about a parameter, this last one maybe connected to:

- The heterogeneous intrinsic properties of the cement paste before the freeze-thaw cycles exposition: the mechanical resistance of the cement paste, the porosity, the permeability, the coefficients of transport, etc.
- A freeze-thaw cycle parameter which could engender different mechanisms. For example, the lower temperature (-20±2) °C authorizes the crossing of the eutectic temperature of -21.6 °C for the binary mixture (water/NaCl).

If it is about a mechanism, it can be a direct one as the over saturation of the porous medium connected to the presence of NaCl during the cycles or an indirect one and connected to the more or less fast evolution of an intrinsic property of the bodies.
4. CONCLUSIONS

An experimental program with 3 different concretes allowed studying the repeatability of individual scaling result according to the XP P18-420 French standard. Conclusions are confirmed for the three concretes and thus for the range of the obtained scaling values included between 50 and 3000 g/m² at 56 cycles.

When the result is expressed as the scaled mass at 56 cycles, it is distributed according to a log-normal law. This distribution presents an asymmetry with a significant number of weak values and a low number of high values. It is necessary to stress the impossibility to apply statistical analyses assuming a normal distribution. The coefficient of variation is higher than 60 %. This weak repeatability generates discrimination in favour of high resistant concrete. Indeed, to obtain a 5% inferior fractile regarding the French threshold of 600 g/m² implies a mean value three times lower.

On the other hand, the scaling result expressed as a number of cycles allowing reaching a fixed scaled mass is in accordance with a normal distribution. The average and the standard deviation, defining the normal law, are almost identical for the 3 concretes when the fixed scaled mass is equal to the lowest individual result at 56 cycles. In this case, the coefficient of variation is about 30%.

This normal distribution is centred around a recognizable number of freeze-thaw cycles. Thus, the mechanism of deterioration is correlated to the number of cycles. This link can be direct and concerns the parameters of exposure or indirect through the heterogeneousness of a property of the body as the porosity, the coefficients of transport of material, etc. and the evolution of which would be very sensitive to the freeze-thaw cycles.

This new method of analysis of the scaling test shows that it is possible to decrease the coefficient of variation for a higher number of cycles. The result expressed by the number of cycles is in that case concerning a quantity of scaled mass. It allows maintaining a criterion of acceptance by threshold of scaled mass for which we can obtain additional information about the "average speed" of samples degradation.

REFERENCES


[12] GCI 714 - Durabilité et réparations du béton, Chapitre 2, Cours département Génie Civil, Université de Sherbrooke, URL : http://www.civil.usherbrooke.ca/cours/gci714/


