NDT FOR CONCRETE UNDER ACCELERATED FREEZE/THAW TESTS AND SURFACE SCALING

Héctor L. Romero

Maria J. Casati

Jaime C. Gálvez

Abstract

Freezing of water or salt solution in concrete pores is a main cause for severe damage and significant reduction of the service life. Most of the freeze-thaw (F-T) accelerated tests measure the scaling of concrete by weighting. This paper presents complementary procedures based on the use of strain gages and ultrasonic pulse velocity (UPV) for measuring the deterioration of concrete due to freezing and thawing. These non-destructive testing (NDT) procedures are applied to two types of concretes, one susceptible to F-T damage and the other does not. The results show a good correlation between scaling and the measurements obtained with NDT. Showing NDT the advantage to detect before the damage and to perform continuous measurement.

Keywords: Concrete, Freezing and Thawing, NDT Methods, Scaling

1 Introduction

In countries with a continental climate the freezing of water in concrete pores may be the cause for severe damage of concrete. Most of the freeze-thaw (F-T) accelerated tests measure the scaling of concrete by weighting. This procedure is straightforward and easy to perform, but includes some drawbacks, the test must be stopped to perform the weight measurement and the deterioration is detected when there is an appreciate scaling. This paper proposes the use of NDTs to perform continuous monitoring of the damage, without stopping the test, and to detect before the material failure. The complementary procedures are: the use of strain gauges, placed on different areas of the specimen, and the evaluation of the ultrasonic pulse velocity (UPV). Both procedures were performed with specimens under F-T accelerated testing (CEN/TS 12390-9 [1]) with two types of concrete: one susceptible to F-T damage and the other does not.

2 Experimental programme

2.1 Materials

Two different concrete mixes were tested, combining two cement contents, two w/c ratios and the use or not of air-entrained admixture. **Tab. 1** shows the concrete mixes.

Tab. 1 Mix proportions (kg/m^3) and concrete properties

Mix Proportions	Air Entrained Admixture Concrete (AEAC)	Non Air Entrained Admixture Concrete (NAEAC)
Cement CEM I 42.5 R (kg/m^3)	450	360
Water (l/m^3)	180	162
w/c ratio	0.40	0.45
Fine Aggregate (kg/m^3)	640.9	710.2
Coarse Aggregate (kg/m^3)	1159.1	1129.8
Superplasticizer (kg/m^3)	1.80	1.08
Air-Entraining Admixture (kg/m^3)	0.45	-
Properties of Concrete		
Slump (cm)	8.0	7.5
Air Content (%)	7.5	2.6
Compressive Strength – 28d (MPa)	32.4	28.5

2.2 Test procedures and methods

The concrete specimens were half of a cube with a surface area of 150 x 150 mm^2 and thickness of 70 mm. Five specimens for each type of concrete were tested according to freeze-thaw standard CEN/TS 12390-9 [1]. They were inserted in a climatic chamber and subjected to 28 freeze-thaw cycles (FTCs) according to the temperature versus time diagram shown in **Fig. 1a.**

The test was performed with standard de-icing agent solution (97% of distilled water and 3% of NaCl). The surface deterioration was measured by weighting after 4, 6, 14 and 28 FTC.

2.3 Non-destructive test measurements

The superficial strain of the prism concrete samples was measured using two commercial strain gages by specimen, which were glued on the middle and upper part of the lateral surface of the specimens as shown in **Fig. 1b** (H_1= 30 mm and H_2= 55 mm).

A double zero crossing algorithm [2] was used to measure UPV. For each concrete specimen two longitudinal wave transducers (500 kHz) were glued directly to the surface of the concrete prisms. The position of the transducers is shown in **Fig. 1c**.

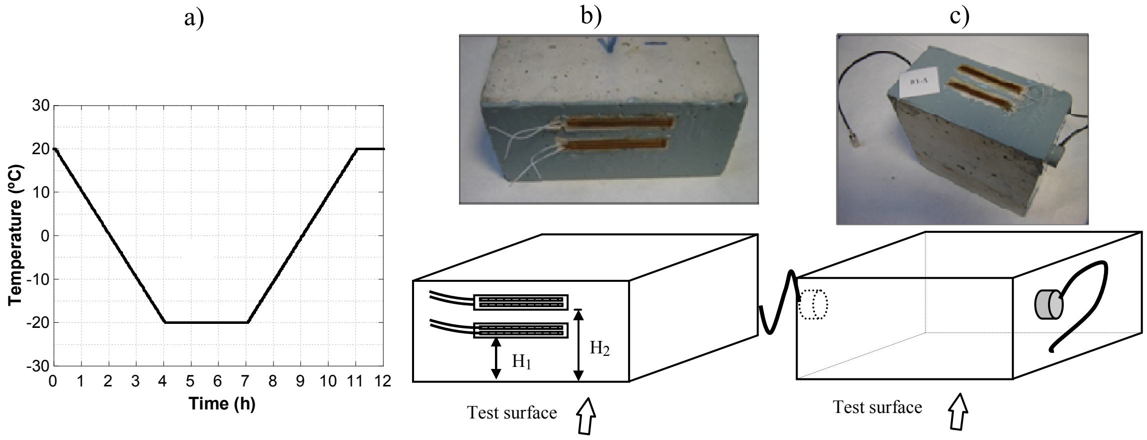

Fig. 1 a) Temperature for one FTC. Sensors used for NTD measurements in concrete prisms subjected to FTC: b) Strain gauges, c) Ultrasonic transducers

3 Experimental results and analysis

The results of scaling are shown in **Fig. 2a**. The NAEAC specimens failed before 28 FTC, with a cumulative scaling of 1.5 kg/m^2 on the 17th FTC, and 3.23 kg/m^{2}after 28 cycles. In contrast, the AEAC specimens reached only 0.10 kg/m^2 of cumulative scaling after 28 cycles. The concrete test surfaces in contact with the de-icing agent solution of some specimens of both concretes before testing, after 14 and 28 FTC, are shown in **Fig. 2b-d**. Salt scaling is often observed with the exposure of coarse aggregate.

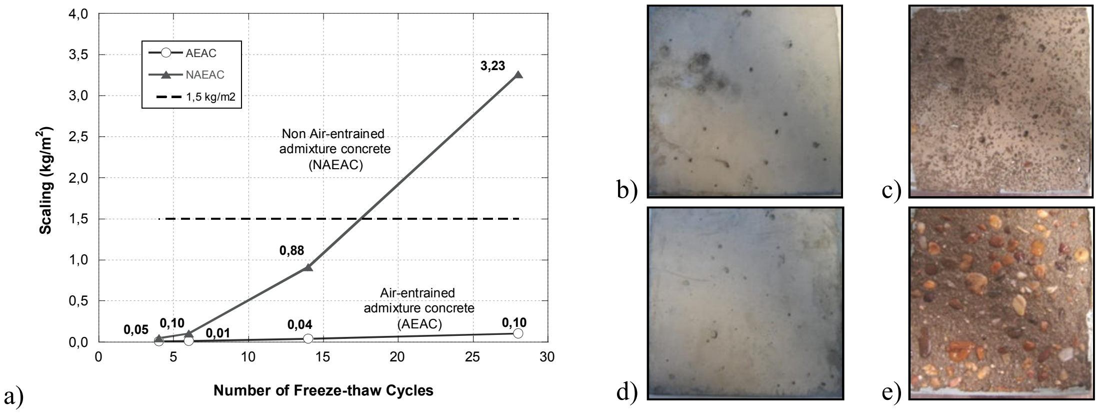

Fig. 2 Freeze-thaw test. a) Cumulative scaling. Photographs of test surface of concrete slabs during the FTC: b) AEAC before the test, c) AEAC after 28 FTC, d) NAEAC before the test, e) NAEAC after 28 FTC.

Fig. 3a shows the strain gages measures. NAEAC shows a residual strain of 1150 μm/m and AEAC a value of 65 μm/m, both after 28 FTC, measured with the strain gage at H_1. The growth of the residual strain in NAEAC specimens shows the progressive damage [3-4]. The strain gages placed at the upper part (H_2) showed lower deterioration, which indicates a gradient decreasing as it moves away from the immersed face.

The UPV was measured on each specimen under thawing (20ºC) and freezing (-20ºC) conditions. **Fig. 3b** shows the UPV measures during F-T testing. Under thawing conditions the progressive deterioration of concrete leads to a lower UPV, as figure shows. Under freezing conditions the ice in the micro-cracks increases the UPV, and the positive slope of the curve indicates a progressive deterioration of the concrete.

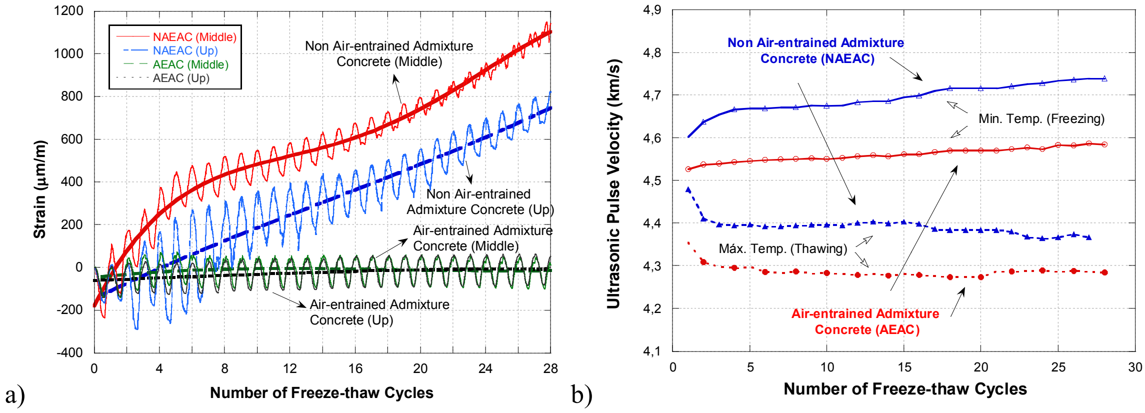

Fig. 3 Strains measurements a) Strains of concrete samples during 28 FTCs, b) UPV during FTCs. At the end of freezing (min. temp) and at the end of thawing (max. temp).

4 Conclusions

The damage caused by the freeze-thaw cycles in the AEAC prisms was negligible compared with the deterioration of the NAEAC specimens, as it was hoped. This result was confirmed by the scaling test and by the continuously measurement of strain and VPU.

Strain as a measurement of length changes is a good indicator of freeze-thaw concrete superficial deterioration. Commercial strain gages may replace the conventional scaling measures.

The measured differences of UPV of concretes specimens before and after 28 FTCs were very small. That means that 28 FTCs according to the CENT/TS 12390-9 test, do not lead to considerable internal damage of tested concretes as have been reported in studies that use a high number of rapid FTCs like the ASTM C666/C666M standard.

The authors gratefully acknowledge the financial support for the research provided by the Spanish Ministerio de Ciencia e Innovación under grants BIA-2008-03523 and MFOM-01/07. Héctor L. Romero also gratefully acknowledges the grant supplied by Fundación Agustín de Betancourt.

References

[1] CEN/TS 12390-9 EX. Testing Hardened Concrete. Part 9: Freeze-Thaw resistance. Scaling. CEN. Bruxelles. 2006.

[2] Hernández MG, Anaya JJ, Sanchez T, Segura I. Porosity estimation of aged mortar using a micromechanical model. Ultrasonics 2006 12/22;44 (Supplement 1):e1007-11.

[3] Bishnoi S, Uomoto T. Strain–temperature hysteresis in concrete under cyclic freeze–thaw conditions. Cement and Concrete Composites 2008 5;30(5):374-80.

[4] Penttala V. Freezing-induced strains and pressures in wet porous materials and especially in concrete mortar. Advanced Cement Based Materials 1998;7:8-19.

Hector L. Romero, C.Eng.
✉ Universidad Politécnica Madrid
E.T.S. de Ingenieros de Caminos
Dept. de Ingeniería Civil: Construcción
c/ Profesor Aranguren s/n
28040 Madrid, Spain
☎ +34 913 366 723
☺ hector.romero@caminos.upm.es

Dr. Maria J. Casati, Ph.D., C.Eng.
✉ Universidad Politécnica Madrid
E.U.I.T. Aeronáutica
Dept. Vehículos Aeroespaciales
Pl. Cardenal Cisneros s/n
28040 Madrid, Spain
☎ +34 913 367 503
☺ mariajesus.casati@upm.es

Prof. Jaime C. Gálvez, Ph.D., C.Eng.
✉ Universidad Politécnica Madrid
E.T.S. de Ingenieros de Caminos
Dept. de Ingeniería Civil: Construcción
c/ Profesor Aranguren s/n
28040 Madrid, Spain
☎ +34 913 365 350
☺ Jaime.galvez@upm.es