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NONDESTRUCTIVE TESTING OF CONCRETE AFFECTED BY SWELLING PATHOLOGIES: FROM THE LABORATORY TO ON SITE SCALE

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ABSTRACT

Early age detection of swelling pathologies in concrete by non-destructive testing (NDT) is a major concern for safety of concrete structures, especially in the case of nuclear power plants where core drilling is not allowed. This work is part of a program focusing on detection and 3D-quantification of swelling pathologies at early stages, for massive concrete structures.

To reach this goal, three scales of concrete pieces are currently studied in order to pass from laboratory experiments to on site testing. The present paper is related to first scale and deals with the detection and the characterization by ultrasonic NDTs of Delayed Ettringite Formation occurring at a low expansion level. Linear acoustics (Resonant Ultrasonic Spectroscopy), nonlinear acoustics (Nonlinear Resonant Ultrasonic Spectroscopy), as well as a passive technique (Acoustic Emission), were tested on DEF-affected specimens (7×7×28 cm³). Microscopy and destructive micro-cracking analyses were also conducted. All the results are consistent but unexpected: early DEF does not create significant damage to these stress free samples while expansion reaches 0.21%.

Keywords: Nondestructive Testing, Ultrasonic, Concrete, Swelling pathologies, Delayed Ettringite Formation

NOMENCLATURE

α Non classical nonlinear parameter

1. INTRODUCTION

In nuclear power plants, the reactor building is the third containment barrier, preventing the dispersion of radioactivity in the event of a severe accident in addition to its own structural function. Thus, concrete has to maintain low permeability and sufficient mechanical properties all along its service life. Regular monitoring must be carried out to ensure that the safety function of the containment building is not affected by a swelling pathology.

This work is a part of an international project named Observatoire de la Durabilité des Ouvrages en Béton Armé (ODOBA). The final objective is to detect and map the extent of swelling pathologies at early stages in massive concrete elements using ultrasonic nondestructive testing. The two pathologies considered are Alkali Silica Reaction (ASR) and Delayed Ettringite Formation (DEF). To reach this goal, it has been decided to consider three scales of concrete pieces in order to pass from laboratory experiments to on site testing:

- The first scale is based on laboratory samples measuring 7×7×28 cm³ and allows the sensitivity of NDT to pathologies to be tested under controlled conditions (Fig. 1).

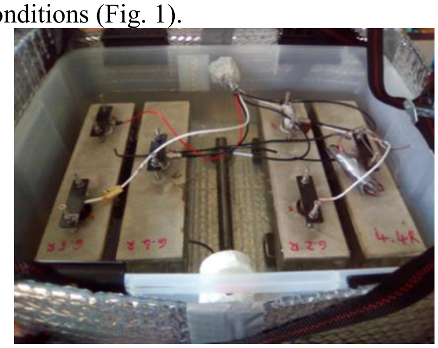

FIGURE 1: Samples (7×7×28 cm³) affected by DEF inside their aging chamber, with acoustic emission sensors on the upper face

- The intermediate scale deals with blocks with dimensions of 40×40×70 cm³. These blocks are a first step to develop NDT techniques in order to map the extent of pathologies in a large element (Fig. 2)

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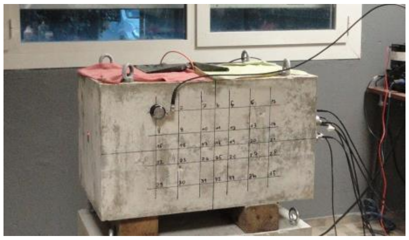

FIGURE 2: Concrete block 40×40×70 cm^3 during a NDT experiment in nonlinear acoustics in order to map the extent of the pathology

- The last scale refers to large concrete elements (100×200×400 cm^3) simulating a part of a containment building. This will confirm the reliability of the techniques developed at the previous scale in real conditions (Fig. 3)

FIGURE 3: In-situ sample (100×200×400 cm^3) affected by swelling pathologies

The general concept is to use a method capable of continuously monitoring the evolution of concrete over large areas in the event of swelling pathologies. The Acoustic Emission (AE) method can perform this function and will be studied as part of this work. Through this global method, areas of potential interest will be identified. A second phase can then be launched using more accurate NDT techniques to confirm detection and, if necessary, map the extent of the pathologies.

In this context, a bibliographic review that is synthetized in Fig. 4 shows that classical linear acoustics like velocity measurements or resonant methods are weakly sensitive to ASR or DEF at early stages. On the opposite, several studies show that nonlinear acoustics allow an early detection of ASR on small laboratory samples with a high variation of the non-classical nonlinear parameter. A similar study was conduct on mortar samples affected by DEF[1] but not on realistic concrete (concrete may behave differently from mortar). This must be done, that is why it is proposed to focus on this subject in the following work.

	Monitoring (long time)	Short time process	Sensitive to ASR	Sensitive to DEF	Enable on large concrete element	Spatial Localization
Acoustic Emission (AE)	Yes		Yes	To be studied	Yes	Yes
Ultrasonic Pulse Velocity		Yes	Low	Low	Yes	Yes
Resonant Ultrasonic Spectroscopy (RUS)		Yes	Low	Low		
NonLinear Resonant Ultrasonic Spectroscopy (NRUS)		Yes	High	To be studied		
New Nonlinear technique based on dynamic acousto elastic principle		Yes	High	To be studied	To be developed	To be developed

FIGURE 4: Bibliographical synthesis of NDTs in the case of concrete affecting by ASR or DEF

2. MATERIALS AND METHODS

The present work proposes quantitative linear and nonlinear evaluation [2] applied for the first time to concrete samples affected by DEF with a realistic grain size distribution and with a moderate kinetic expansion[3]. This makes it possible to extend a nonlinear quantitative database already formed by studies carried out on concrete samples affected by ASR [4], carbonation [5], freeze-thaw cycles [6], or thermal damage [2].

Samples were also monitored by Acoustic Emission (AE) which continuously records the acoustic signals emitted by the creation and opening of micro-cracks [7][8][9].

In order to go further in the understanding of the evolution of the pathology, microscopy and micro-cracking analyses were performed on the samples at the end of the experiments.

2.1 Sample preparation and aging process

Several Prismatic specimens (7×7×28 cm^3) were cast with a concrete formulation composed of six granular classes up to 12.5mm. Directly after pouring, half of the specimens were introduced in a climatic chamber to be exposed to heat treatment.

The ageing process makes it possible to accelerate the development of the pathology. One chamber contained two non-heat-treated control specimens and two heat-treated specimens. This aging chamber was filled with a 0.6 mol/L LiOH solution. Lithium is described in the literature as able to partially inhibit or delay the development of DEF [10]. By soaking the two heat-treated specimens in this solution, it was possible to better characterize the effects of lithium on the pathology. For the other two control samples, it was admitted here that this lithium-based preparation has no significant effect on the concrete. The second aging chamber (Fig. 1), filled with distilled water only, contained the remaining four heat-treated samples.

2.2 Nondestructive Testing in linear acoustics

In order to determine properties of the samples such as the dynamic elastic modulus and Poisson's ratio, Ultrasonic Pulse Velocity (P and S waves) and Resonant Ultrasonic Spectroscopy (RUS) were used.

Concerning Acoustic Emission, one transducer was affected to each sample in order to record the number of ultrasonic signals associated with an energy release due to the creation and the opening of micro-cracks. A filtering process was applied after the signals were recorded.

2.3 Nondestructive Testing in nonlinear acoustics

Nonlinear Resonant Ultrasonic Spectroscopy (NRUS) that is used in these experiments is considered as the reference method for evaluating the non-linearity on small specimens. More precisely, NRUS consists in measuring the frequency shift of a resonant mode induced by the nonlinear behavior as a function of the excitation amplitude (Eq. 1):

$$\frac{\Delta f}{f_0} = \frac{f - f_0}{f_0} = -\alpha . \Delta\epsilon \quad (1)$$

where α is the quantitative non classical nonlinear constant, f is the resonance frequency corresponding to a Δε strain amplitude and f_0 the resonant frequency for a strain amplitude tending towards zero.

3. RESULTS AND DISCUSSION

Experiments were stopped when expansion reached 0.21% for the reactive sample, after 150 days. It is admitted that the early stages of DEF development were largely exceeded. The expansion curve of this sample is practically linear, with an average rate of 0.0014% per day witnessing an accelerated aging as expected (Fig. 5). For the reactive sample inhibited by LiOH, expansion was lower (0.06% at 150 days) but not completely inhibited by the LiOH solution. Expansion is also quite linear. For the control sample, expansion remained constant at 0.02% after 20 days.

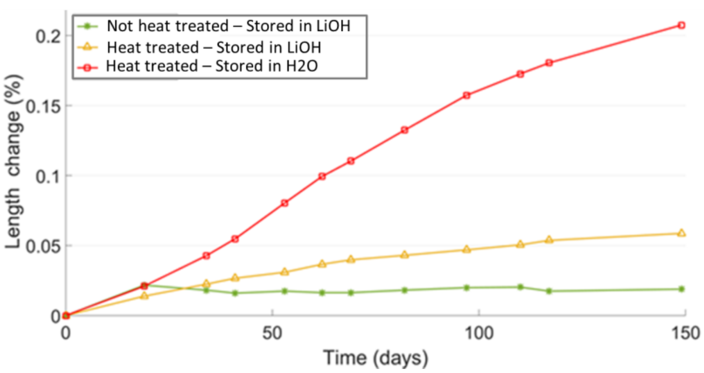

FIGURE 5: Expansion for each type of specimen

Only results of the quantitative non classical nonlinear parameter are presented (Fig. 6) in this abstract. The stability of α values, especially for the pathological specimen, means that bonds at the ITZ are not damaged and no additional micro-cracking is induced by the pathology in the cement paste despite expansion. This is confirmed by microscopy and micro-cracking analyses.

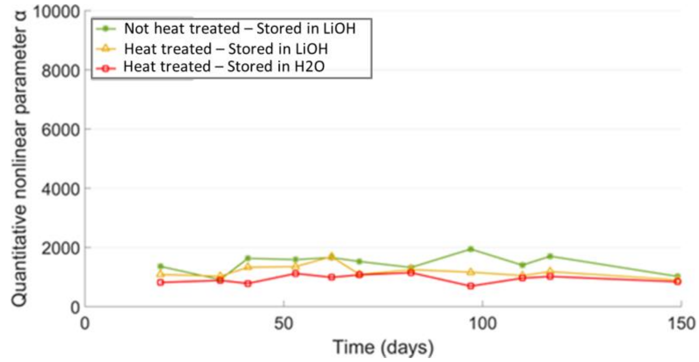

FIGURE 6: Quantitative nonlinear parameter (α) extracted from NRUS tests

4. CONCLUSION

This study has shown that DEF at early stage (under 0.21% expansion) may not be detected by linear or nonlinear ultrasonic NDTs in concrete.

However, on large parts, it is possible that boundary stresses or differential swelling of the pathology may cause mechanical damage. Further studies will have to use either small samples under loaded conditions or larger samples exhibiting differential expansion to determine if this mechanical damage can be detectable.

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