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Impact of the alkali–silica reaction products on slow dynamics behavior of concrete

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ABSTRACT

Several nondestructive techniques based on acoustics are frequently used to assess the condition of engineering materials. It has been demonstrated that nonlinear acoustics is more sensitive for detecting micro-cracks. The main challenge, regarding the assessment of alkali–silica reaction (ASR) damage in concrete, remains in the efficiency of the technique to distinguish ASR from other damaging process. Based on the fact that ASR produces a swelling viscous gel, a new approach developed for finding a signature to ASR is investigated in this paper. The research was focused upon the specific behavior of ASR causing the presence of viscous gels in micro-cracks and porosity compared with mechanical damage where cracks are empty. With this approach, the concrete response to slow dynamics tests was analyzed. The Burger spring–damping model was used for interpreting the results. This research showed that the slow dynamics technique presented here can detect cracking in concrete and that the time response to an external excitation of concrete damaged by ASR is different from that of concrete mechanically damaged.

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1. Introduction

Alkali–silica reaction (ASR) causes the expansion and cracking of numerous concrete structures worldwide. The expansion is due to the formation of continuing chemical reaction products, the silica gels, which swell at moisture levels above about 85% R.H. These expansive gels create internal stresses and lead to the formation of a micro-crack network through the concrete when the material tensile strength is reached. Moreover, gels have a viscous behavior; under external and internal stresses, they slowly move in porous space and cracks and enhance the hysteretic behavior of concrete. The viscous property of gel is conserved over time even if partial crystallization occurs with ageing [1,2]. The hysteretic behavior can be observed from successive static loading cycles applied to ASR-affected concrete [3].

Assessment of concrete damage is an important issue and many nondestructive methods based on nonlinear acoustics have been proposed to evaluate it [4–9]. They have been validated in heterogeneous materials such as rocks and concrete and appeared to be very sensitive to micro-cracks induced by mechanical or thermal damage, for instance. Recently, Chen et al. have applied nonlinear acoustics to evaluate damage due to ASR in mortar samples [10,11]. They showed that the techniques of nonlinear resonance and modulation frequency allowed detecting the formation of micro-cracks in the initial phase of ASR in ultra-accelerated expansion tests. However, this approach seemed to be inefficient to specify if ASR-induced damage has a particular signature comparatively to other causes of damage (mechanical, thermal, etc.)

The aim of this paper is to identify the effects of expansive viscous gels associated with ASR on the nonlinear behavior of concrete, focusing on their specific action, when compared with mechanical damage. The presence or absence of gels in porous space and micro-cracks has an effect upon the concrete response to slow dynamics tests performed during conditioning phase where the samples are driven at large excitation amplitude for several minutes. This dynamic approach could be compared to a conventional static creep test where the material deformation submitted to constant load is analyzed with regards to time.

In all papers published on this topic, the relaxation phase has been mostly used to study the slow dynamic behavior of materials. The conditioning phase is of little interest since the response of micro-cracks during conditioning is almost instantaneous: the cracks are often empty. An approach based on creep phenomenon is presented in this paper in an attempt to detect the presence or absence of reaction products in the cracks. Nonlinear techniques are based on opening/closing of micro-cracks under high acoustic pressures. The high acoustic waves propagate through the material and cause the opening and/or closing of the micro-cracks and the inter-grain contacts. Thus, the high acoustic stress generated by the nonlinear resonance technique allowed performing a creep test directly on the micro-cracks. The assumption is then intuitively made that empty cracks will show creep behavior close to perfect elastic material and cracks fill with reaction products will show behavior close to viscous

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