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Assessment of Acoustic Emission localization accuracy on damaged and healed concrete

Eleni Tsangouri [a,b,*], Grigorios Karaiskos [a], Arnaud Deraemaeker [c], Danny Van Hemelrijck [a], Dimitrios Aggelis [a]

[a] Vrije Universiteit Brussel, Mechanics of Materials and Constructions (MeMC), Brussels, Belgium
[b] SIM Flanders, Zwiinaarde, Ghent, Belgium
[c] Université Libre de Bruxelles (ULB), BATir Laboratory, Brussels, Belgium

HIGHLIGHTS

- The ultrasound source localization error is measured using Acoustic Emission as damage occurs in concrete.
- The localization error decreases after the autonomous healing of concrete.
- The integrated monitoring method will be applied on the healing concrete of the future.

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ABSTRACT

The accuracy of ultrasound source localization is measured on damaged and autonomously healed concrete. A piezoelectric transducer is fixed into concrete and emits high-amplitude and short-duration pulses transformed into complex stress waves as they travel through concrete (pulse transmission). Eight Acoustic Emission (AE) sensors, attached on concrete surface, locate the pulse source spatially and chronically. It is shown that the transmitter localization progressively loses its accuracy with 3D spatial error up to 15% in the presence of crack 300 μm wide. The source localization error diminishes to 3.4% as the crack autonomously heals. The study aims at developing a monitoring system that accurately senses damage and can be applied on the next generation of smart engineering concrete in order to autonomously and repeatedly repair its cracks through piping network with supply of healing agent.

1. Introduction

1.1. The monitoring techniques at the service of autonomous healing

Traditionally, once a crack is accurately detected in concrete [1], repairing additives are manually injected into the crack void [2]. Sealing and partial superficial restoration is obtained because the additives cannot easily penetrate throughout the entire crack's depth. Autonomously healed concrete, developed the last decade, aim at replacing the manual repair agent injection by embedding encapsulated repair agent into concrete during casting. The healing process is activated only in the nucleation and extension of a crack that ruptures the brittle capsule and triggers the release of the agent into the crack void [3]. The latter repair method is more efficient than the previous manual processes since the crack is automatically filled internally and the restoration is accomplished at the early damage stage.

Different monitoring techniques are involved in order to evaluate the healing efficiency [4]. In previous studies, the conditions under which the healing is triggered are assessed by Acoustic Emission (AE) that detects the source location of the ultrasound wave emitted as the capsule ruptures [4]. In addition, the ultrasound pulse velocity technique utilizes the emission of a pulse from a piezoelectric transducer (i.e. transmitter), that travels throughout the material and is received by a similar piezoelectric transducer (i.e. receiver). The received signal is used to quantify the structural integrity of concrete beams that are autonomously healed [5]. Additionally, the use of digital image correlation (DIC) provides an accurate localization of healed areas on concrete [6]. The assessment of healing mechanisms on concrete becomes

* Corresponding author at: Vrije Universiteit Brussel, Mechanics of Materials and Constructions (MeMC), Brussels, Belgium.
E-mail address: etsangou@vub.ac.be (E. Tsangouri).

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Table 1
The concrete mixture.

Concrete composition	Content
Sand 0/4	670 kg/m^3
Gravel 2/8	490 kg/m^3
Gravel 8/16	790 kg/m^3
Cement CEM I 52.5 N	300 kg/m^3
Water	150 lt/m^3

complicated in the presence of several cracks. In this case, cracks form, widen and close (due to healing) simultaneously. An integrated monitoring system that combines the DIC and AE techniques has been used in previous studies to monitor the progressive damage evolution of several cracks on concrete [7].

Nowadays and based on the well-established combination of the autonomously repaired concrete with integrated monitoring experimental methods, the next generation of concrete is introduced namely self-healing vascular network concrete. The intelligent material design considers a sensing system (by means of optical or acoustic sensors) that detects damage and a piping network embedded into concrete that continuously supplies repair agent at any place across the concrete structure achieving repeatable autonomous crack restoration [8]. The distribution of the healing agent at different locations and at specific moments in time when appropriate, requires the presence of an inspecting mechanism that detects and triggers the healing activation and thus guarantees repeatable repair of concrete. The key features of this innovative technology applied on concrete is the timely warning when cracks appear or propagate, their accurate localization and the evaluation of the damage level obtained by use of advanced monitoring systems [8]. The accuracy of the sensing information, contributes to the cost-efficiency and long term repair of the crack [9].

1.2. Focus on the Acoustic Emission technique: the challenge due to concrete complex fracture

In literature, there is extensive research done evaluating the damage on concrete using acoustic wave propagation technique either in active (ultrasonics) or passive (AE) form [10–12]. Several techniques, based on the longitudinal or Rayleigh wave velocity [13], the Acoustic Emission [14], the elastic wave tomography [15], are well-established providing accurate damage localization.

Wave source localization performs well in sound specimens even though concrete cannot be considered as a homogeneous material. The material components widely vary in size: the aggregates may have a diameter greater than 10 mm and the sand or other additives may have a diameter lower than 1 mm. The steel bar/fiber reinforcement and the potential encapsulated healing agent/embedded agent network contribute to the material's heterogeneity. Still in literature the location of damage in sound specimens or structures has been detected with suitable engineering accuracy [16,17]. However, the damage development complicates the wave propagation on concrete and concrete composites [18,19], reducing the wave transmission and speed characteristics. Due to quasi-brittle concrete nature, the fracture process initiates with micro-crack defects that accumulate forming macro-cracks that arrest or propagate and interact with other defects/cracks in the vicinity [20]. Taking into account that the knowledge of the elastic wave speed is crucial for the source localization, it is certain that the accuracy of source localization is compromised.

This study aims to investigate whether the source localization accuracy is suitable as a guide for repair in a self-healing network even at severely cracked conditions. The case of a plain pre-cracked concrete beam under mode-I fracture is considered. The emission source is an embedded aggregate-size piezoelectric transducer that is fed by a short-duration and high-amplitude voltage pulse. The localization accuracy in the presence of a crack that nucleates,

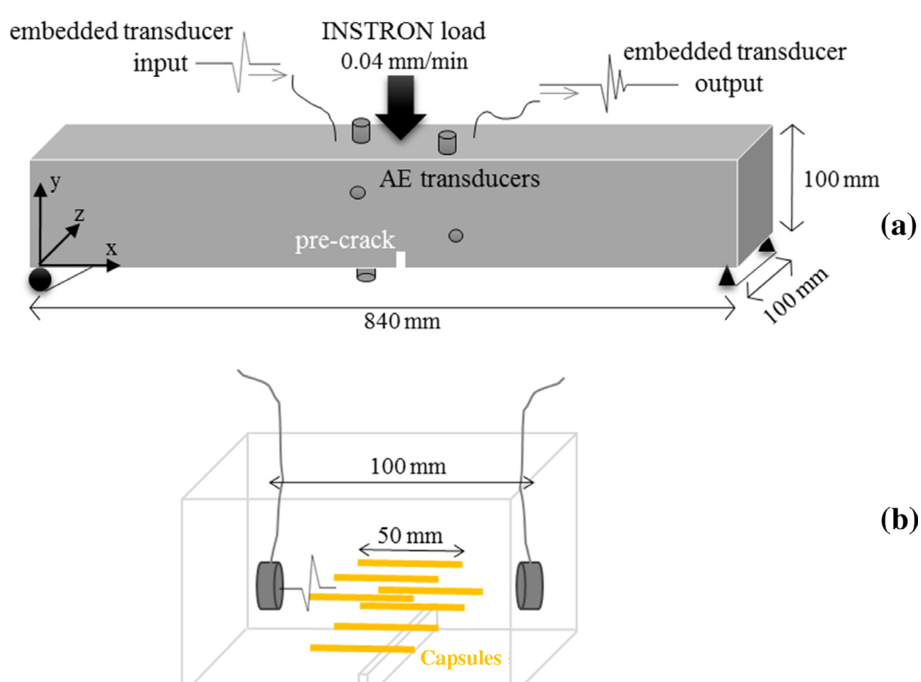

Fig. 1. a) The side view of the beam and the configuration of AE sensors. The wires at the top are connected to the embedded transducers; b) the central zone: the long tubular borosilicate glass capsules (in yellow) are placed above the notch and the embedded piezoelectric transducers (colored in grey) are fixed at either side of the notch. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)