RECENT ADVANCES IN ULTRASOUND MONITORING OF CRACKING AND SELF-HEALING OF CONCRETE

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Abstract
Elastic waves have been long used for structural integrity evaluation of concrete materials and structures. Ultrasonic parameters are well related to crack density, deterioration of the elastic modulus, even empirical characterization of the strength. Recently, several ultrasonic studies have emerged also in the field of repair monitoring. Manual repair actions or self-healing strongly contribute to the sealing of the crack, and the regain of the mechanical properties. However, the restoration cannot be evaluated in a non-destructive manner, especially in-situ. Ultrasonic parameters exhibit strong sensitivity to the degree of filling of a single crack or of a distributed system of cracks, while they also have the capacity to monitor the self-healing process, due to the increase of elastic modulus of the healing compounds in the crack volume. The present abstract intends to give an overview of the recent developments in the field of ultrasound as a means of fracture and repair characterization. Through-the-thickness wave transmission, ultrasonic mapping, surface waves as well as air-coupled applications are reviewed as standalone methods or in conjunction with simulations in the framework of an optimal material assessment after fracture and consequent repair.

1. Introduction
While concrete is one of the most widely used construction materials, it suffers from cracking due to low tensile strength. To guarantee durability, cracks should be repaired in a timely manner. Different repair methodologies are in place, including epoxy injection, grouting as well as self-healing. Cementitious media possess the inherent ability to repair through "autogeneous" healing, which is continued hydration and calcium carbonate precipitation. Self-healing can be promoted by specific admixtures, like the super-absorbent polymers (SAPs). These agents absorb available water and gradually release it to the matrix to enhance the above mentioned processes. The self-healing results in partial restoration of the mechanical properties and sealing of the crack. However, the effectiveness of self-healing can be assessed directly only by mechanical reloading of the material, which does not allow to check the progress in the same specimen, while it is not applicable in-situ. Therefore, ultrasound is a suitable alternative, since the elastic waves physically propagate through the material and collect information about its elastic properties. In the present study, different mortar compositions including reference and SAP-loaded matrices were tested after cracking and during wet-dry cycles. Surface waves as well as through the thickness longitudinal waves are used to show the progress of self-healing through the restoration of wave properties like velocity and attenuation. At the same time, elastic wave simulations allow to conclude on the level of elastic modulus of the healing material that corresponds to the measured wave parameters.

2. Results
Fig. 1a shows a snapshot of the simulated displacement field in the case of surface wave inspection. The crack, acting as a discontinuity, does not allow the direct transmission of Rayleigh waves, while only longitudinal waves are refracted from the tip of the crack. Rayleigh waves are restorted as the crack is filled with material of considerable stiffness. In addition, in the case of through-the-thickness ultrasound, the wave velocity measured over a grid can be mapped as seen in Fig. 1b and c revealing the level of modulus restoration. The case (b) concerns the velocity map just after cracking, showing velocities as low as 1000 m/s, while the map in (c) measured at 28 days shows the generally strong velocity increase, with only traces of the original crack surface.

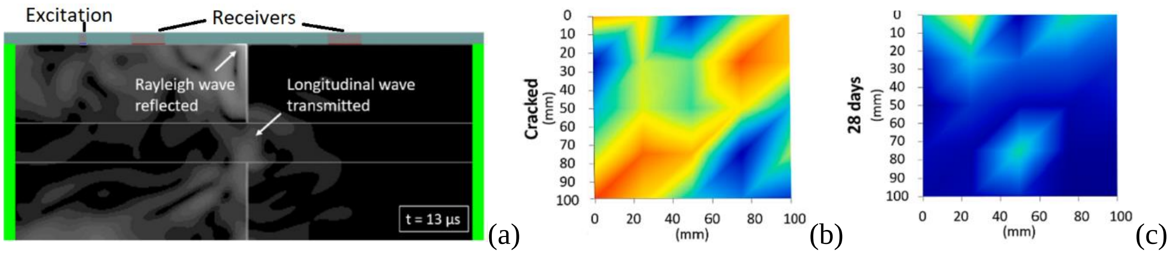

Fig.1 – (a) Simulated displacement field after surface excitation on a specimen with a central crack [1], longitudinal wave velocity map after (b) cracking, and (c) 28 days of healing cycles on a mortar cross section [2].

3. Conclusions

This study assessed the effectiveness of self-healing by means of elastic waves. Surface waves are practical for in-situ use when only one surface is accessible. Parameters like wave velocity and amplitude follow closely the transitions, from sound to cracked material and the gradual restoration due to healing. When conditions allow, through-transmission can be used, enabling also the mapping of the restoration in the whole cross-section and allowing conclusions about healing vs. the depth from the surface. Frequency is in any case an important factor of the experiment either to control the penetration of the surface waves or to increase the resolution in through-transmission.

4. References

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