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CORRELATION BETWEEN INTERFACIAL TRANSITION ZONE CHARACTERISTICS AND ULTRASONIC WAVE VELOCITY AND ATTENUATION IN CONCRETE

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ABSTRACT

Correlation between Interfacial Transition Zone (ITZ) characteristics (Young modulus and thickness) and ultrasonic wave velocity and attenuation in concrete is investigated. The ITZ is the thin layer at the aggregate/mortar interface in concrete. This zone has very low mechanical properties due to its high porosity. Cracks due to thermal or mechanical damage emerge from it [7].

Ultrasonic wave velocity and attenuation are widely used for NDE of concrete because they are sensitive to the concrete's state of health [2] [3] [4]. Due to the very high heterogeneity of concrete's microstructure (aggregates and porosity of different sizes, microcracks, …), the ultrasonic wave is multiply scattered. That causes attenuation and dispersion of the propagating wave [5].

Until now, the multiple scattering of ultrasound in concrete was always studied without considering the ITZ. In this study, numerical simulations point out the effects of imperfect contact at the aggregate/mortar interface on ultrasonic wave propagation. A numerical model which accounts for realistic characteristics of ITZ is thus developed [1]. It is validated through quantitative comparison with experimental attenuation values. It is then used to link ITZ characteristics to measured velocity's decrease due to thermal damage.

Keywords: Concrete, Interfacial Transition Zone, Ultrasonic wave velocity, Attenuation, Imperfect Contact

NOMENCLATURE

ITZ	Interfacial Transition Zone
CL	Contact Level
E	Young modulus
P-/S-wave	Compressional/Shear wave

1. INTRODUCTION

A reliable diagnosis about the state of health of concrete structures is crucial to avoid financial loss and to ensure safety of users during its life cycle. Ultrasonic wave-based NDE methods have shown great potentials over the recent years [2] [3] [4]. Links between mechanical properties with the ultrasonic wave propagation could be used to predict the residual life duration. However, concrete exhibits a complex microstructure. The amplitude of the propagating wave is attenuated due to: (a) energy transfer to the scattered waves by heterogeneities (aggregates, porosity, …), (b) energy absorption due to the viscoelastic properties of mortar and (c) ultrasonic beam divergence. The present study discusses attenuation due to the only contribution of multiple scattering that is, such as the effective velocity, directly linked to the microstructure of concrete.

Those two ultrasonic parameters were shown to be good indicators of concrete's evolution [2] [3] [4] [5]. Correlations were established between them and the concrete's status (temperature, stress, saturation, …) but no correlation exists between them and the microstructure's description. Focusing on the microstructure of concrete, there is a thin layer at the aggregate/mortar interface, called Interfacial Transition Zone (ITZ), that is highly porous. As this zone has very low mechanical properties, all cracks emerge from it after thermal or mechanical damages. The contact at the aggregate/mortar interface cannot therefore be considered as perfect. Numerical simulations have pointed out the effects of imperfect contact at different levels on ultrasonic wave propagation.

This work aims to link measured ultrasonic parameters to the characteristics of the ITZ: its Young modulus and thickness. A direct numerical model based on a simple rheological spring-mass system is developed and validated with experimental data.

2. NUMERICAL SIMULATIONS SETUP

The numerical simulations of wave propagation were carried out with Prospero, a 2D finite-difference-based software developed at the LMA by B. Lombard [9].

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3.1. Modeling of the Interfacial Transition Zone

A rheological model consisting of a combination of normal and tangential linear springs and masses is used to model the imperfect contact between mortar and aggregates. This approach was discretized and inserted into Prospero. Globally, the ITZ can be characterized by two parameters: the Young modulus and the thickness. A new parameter was defined in order to have just one variable involved in the model: the Contact Level (CL).

$$CL = \frac{E(ITZ)/E(mortar)}{thickness} \tag{1}$$

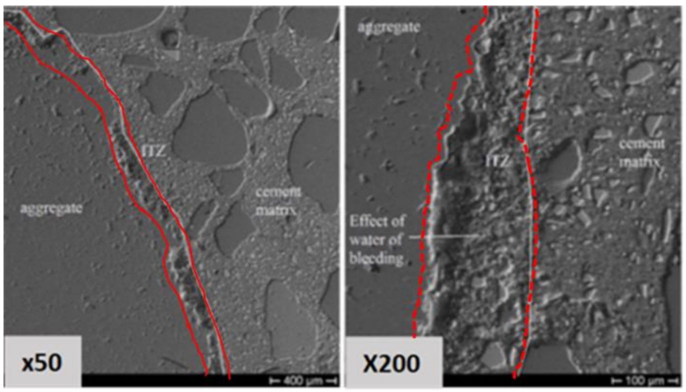

FIGURE 1 : Image of ITZ from microscope [8]

Figure 1 shows an image of the aggregate/mortar interface from electron microscope: the high porosity rate of ITZ (dark area) is recognizable.

3.2. Description of the simulations

Numerical simulations with different levels of contact at the aggregate/mortar interface were carried out. The aggregates are randomly distributed monodisperse discs of 12mm diameter with a surface density of 40%. The size of the computational domain is 40cmx25cm. The transmitted compressional plane wave is centered at 500kHz. A grid of 31 by 16 receivers allows to compute the average ultrasonic wave attenuation and velocity.

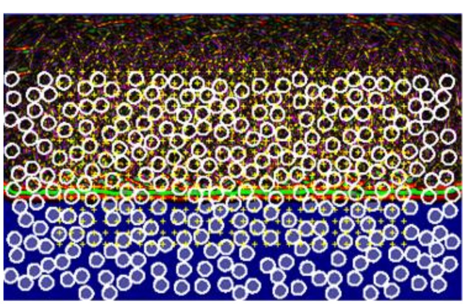

FIGURE 2 : Snapshot of numerical wave propagation: "green/red" color code = P-waves and "yellow/magenta" color code = S-waves [1]

Figure 2 shows a snapshot of numerical wave propagation in the modeled concrete in Prospero software. Energy transfer from ballistic wave to multiply scattered waves can be observed.

3. RESULTS AND DISCUSSION

3.1. Validation with experimental values

For undamaged concrete (see Fig. 3), experimental values of attenuation vary from 12Np/m to 22Np/m for CL ranging from 600m^{-1} to 1100m^{-1}. Those values correspond to ITZ thicknesses ranging from 90µm to 165µm with a Young modulus of 10% of the mortar's one. Those values of ITZ thicknesses are in the order of magnitude found in the literature [6] [7] [8].

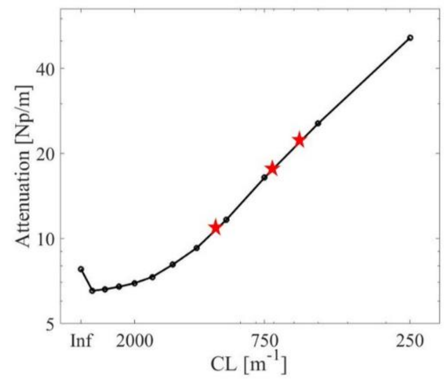

FIGURE 3 : Numerical attenuation curve and experimental values (red stars) - at 500kHz [1]

3.2. Evolution of ultrasonic velocity with ITZ

Correlation between velocity's evolution, thermal damage and ITZ characteristics is established for temperature ranging from 20°C to 100°C in Figure 4. With an assumption of constant Young modulus (=10% of mortar's modulus), the ITZ thickness varies from 80µm to 400µm. With an assumption of constant thickness (=100µm), the ITZ Young modulus varies from 12.5% to 2.5% of the mortar's modulus.

Some values seem to be overestimated: actually, the ITZ is not homogeneous so that the mechanical properties may vary within its thickness. In addition to this, the zone cannot always be clearly delimited.

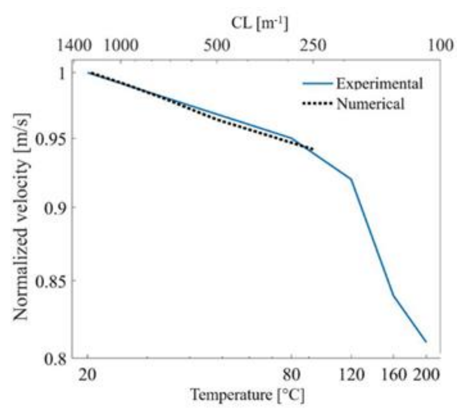

FIGURE 4 : Normalized measured velocities for different levels of thermal damage and numerical velocities for different levels of contact

4. CONCLUSION

This study establishes a correlation between the ITZ characteristics and the measured ultrasonic parameters (velocity and attenuation). The developed direct numerical model accounts for realistic properties of ITZ. It was validated through a quantitative comparison with experimental attenuation values of about 17Np/m. It was then used to link velocity's evolution, due to thermal damage, with ITZ characteristics. The results are encouraging and constitute a first step toward the inverse problem of quantitative evaluation of concrete's microstructure.

ACKNOWLEDGEMENTS

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