

## Global Approach for the ultrasonic Structural Health monitoring of Concrete

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### Introduction

Concrete is a multi-phases heterogeneous material. It consists of a cement paste, aggregated particles surrounded by interfacial transition zones and pre-existing defects (porosity, microcracks). The density and the pre-existing defects distribution depend strongly on the proportion and composition of the grain size distribution.

Ultrasonic Characterisation (UC) and Acoustic Emission (AE) are non-destructive methods capable of a real time damage monitoring during load. This particularity has been used in this contribution. Therefore, we have performed an ultrasonic characterisation by following the changes in ultrasonic velocity and attenuation of longitudinal waves using the immersion method. AE which corresponds to the ultrasonic waves generated by a rapid release of elastic strain energy during damage events, has also been used to characterise concrete and steel reinforced concrete under mechanical loads in order to identify the damage mechanisms leading to their ruptures.

### Materials

All the samples used were processed from the following components: Lafarge Portland cement (HTS 52,5 PMES), normalised sand of 2mm maximum grain size and distilled water. The Portland cement composition is given in table 1.

Cement (g)	Sand (g)	Water (g)	W/C	S/C
1530	1530	510	0.50	1.0

Table 1: composition of concrete.

The concrete mixture was prepared in accordance with the French Standard. Concrete cylinders (140mm of length and 30mm of diameter), was compacted using a vibrating table. After casting, the specimens were covered with plastic sheets. Both mixing and casting were carried out at room temperature. The density of the obtained concrete is 2240Kg/m<sup>3</sup>. Some of the specimens were reinforced with steel fibres of 1% volume fraction. The cylinders were remoulded after two days and the mixtures have spent 28 days in a water container for hardening [1].

### Experimental procedure

A schematic diagram of the experimental set-up is illustrated in Figure 1. It consists of a servohydraulic MTS model 810 testing machine equipped with a 100 KN load-cell and AE system from Physical Acoustic Corporation, together with UC immersion system for the velocity and the attenuation dispersion measurements in through transmission. The load displacement rate used was 2µm/s. The axial extension was measured by an extensometer

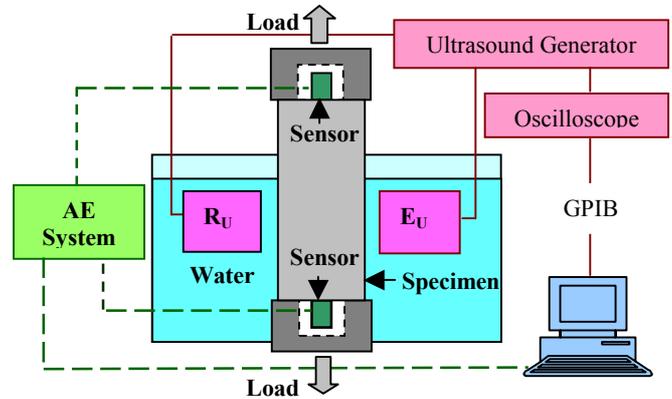


Figure 1: Schematic diagram of experimental procedure.

with a gauge of 52.5mm length. The (AE) signals were detected by two sensors which were attached to the specimen on both sides. For the ultrasonic velocity and attenuation measurements, the ultrasonic signals were generated by an ultrasound pulse generator that excites a piezoelectric emitter ( $E_U$ ) and captured with a receiver ( $R_U$ ).  $E_U$  and  $R_U$  are placed face to face in the thickness direction as shown in figure 1.

### Ultrasonic Characterisation

For the ultrasonic characterisation, the through transmission immersion technique was used with two transducers of 1Mhz central frequency. The phase velocity and attenuation dispersion of the longitudinal waves were measured using the phase unwrap method [2]. We first acquire, as a reference signal, the signal in water without specimen. Then we acquire the signal corresponding to the propagation inside the specimen through its thickness as function of the applied stress. This is done *in situ* during the tensile test until the materials failures. The phase velocity dispersion relation is given by the equation (1).

$$v_1(\omega) = \frac{v_0}{1 - \frac{\Delta\phi \cdot v_0}{\omega d}} \quad (1)$$

Where:  $\Delta\phi$  is the phase difference between the two signals,  $v_0$  is the velocity of longitudinal wave in water,  $\omega = 2\pi f$ , where  $f$  is the frequency. On both sides of each sample we rectify the surface in order to eliminate the diffraction effect of transducers. In this case the samples thickness is  $d=24.45$ mm. Equation (2), give the attenuation dispersion

$$\alpha(\omega) = \frac{\ln(T(\omega)) - \ln(G(\omega))}{d} \quad (2)$$

$T(\omega)$  is the transmission coefficient and  $G(\omega)$  is the spectrum ratio of signals obtained with and without specimen, respectively. [2]

## Results and discussion

Concrete is very sensitive to water absorption which affects ultrasonic velocity and attenuation measurements. So we have evaluated the water absorption effect on these two parameters. The effects are shown in Figures 2 and 3.

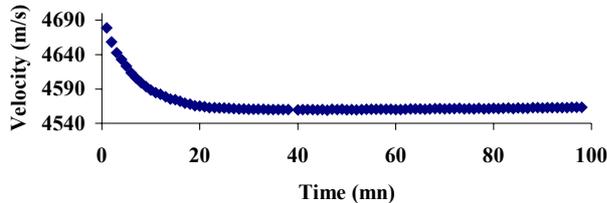


Figure 2: Absorption water effect on phase velocity.

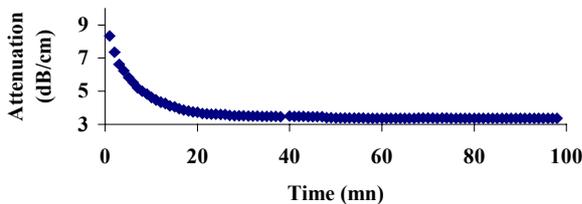


Figure 3: Absorption water effect on the attenuation.

Sine the influence of water is important, its effect was taken into account in order to highlight the stress effect. Figure 4 presents the evolution of the measured attenuation as function of the applied stress on the concrete samples without fibres during the tensile test until rupture.

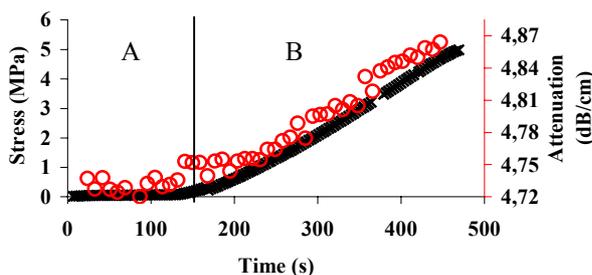


Figure 4: attenuation (circles) evolution as function of the applied stress (cross) for the concrete sample

Therefore, we see a good correlation between the increase of the attenuation with the applied stress. For this material, the velocity stays almost stable at  $4565 \pm 5$  m/s. As shown in figure 4, we can divide the test into two zones, zone A and B. Zone A corresponds to the beginning of the tensile test where the attenuation is almost constant, while zone B corresponds to an increase of attenuation with the applied stress. This can be explained by the creation of microcracks into the specimen at the pores interface. The development

and the coalescence of the microcracks drive the material to the rupture.

For the fibres reinforced concrete we observe the same tendencies in term of the attenuation evolution with the applied stress (figure 5). There is, in this case, a greater attenuation variation in comparison with the concrete without the fibres. It is worth noticing that the stress level is lower in the fibre reinforced concrete.

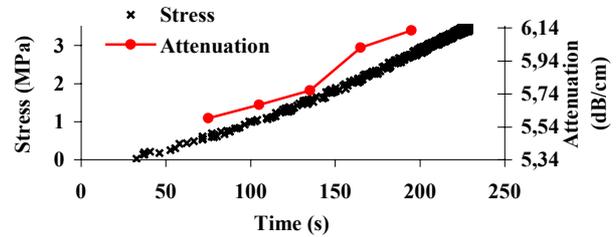


Figure 5: Ultrasonic attenuation variation as function of the applied stress on the fibre reinforced concrete.

Furthermore, the velocity variation with the applied stress was higher and more correlated to damage as we can see in figure 6, where a significant decrease of the velocity as function of the applied stress is clearly observed.

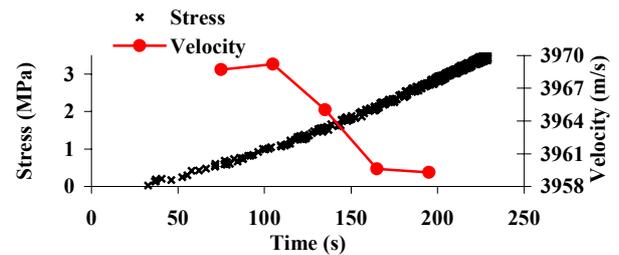


Figure 6: Ultrasonic velocity variation as function of the applied stress on the fibre reinforced concrete.

Finally, we have found that attenuation is mainly due to damage development, which has been confirmed by its good correlation with AE signals.

## Conclusion and perspective

Despite the brittle behaviour of concrete that makes damage and rupture characterisation difficult, we have shown in this contribution that the global approach using ultrasonic velocity and attenuation is an interesting and efficient tool for the structural health monitoring of concrete, which could be applied for brittle materials characterisation.

## References

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