Wave dispersion and attenuation as a tool for material characterization and concrete quality control

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Abstract
The heterogeneity of concrete and the severe wave-microstructure interactions render the thorough investigation of ultrasonic wave propagation imperative, especially when the latter is used for material characterization and quality control. In this study, parallel to the advanced ultrasonic experiments, numerical simulations are additionally performed offering faster, reliable and accurate solutions at low cost, as well as flexibility on the design and measured properties. Cement pastes and mortars are investigated while the observed dispersive and attenuative trends are further explained with scattering theories reinforcing the characterization potential.

1. Introduction
Concrete is the most widely used material in buildings and high impact structures due to its flexibility in form shaping, its high bearing capacity and its relatively low cost of manufacturing. Nowadays, increased research is conducted on the reinforcement of the material with steel and nanofibers as well as on the replacement of its constituents by natural and non-chemical ingredients, while quite recently, concrete has successfully been used as a 3D printing material. Thus, the quality control, the early monitoring and the assessment of the material’s behaviour is necessary to assure the highest performance at later ages. In this direction, the Ultrasonic Pulse Velocity (UPV) technique is often preferred since it is easy to operate, it explicitly provides the elastic constants as well as it is indirectly correlated with the strength and quality. Moreover, it can be applied during the whole hydration process and it allows for the continuous monitoring of the material from the moment of mixing to the setting and hardening\textsuperscript{1}. Although powerful, the UPV technique is still conventionally implemented based on single pulse velocity estimations. However, the nature of concrete composed of several constituents covering several length scales\textsuperscript{2} render the investigation of frequency dependence of wave parameters (velocity and attenuation) necessary and are used in this study to reveal the strong wave-inhomogeneities interactions at certain wavelengths. Because of the inherent difficulty in explaining the results of the delicate dispersion and attenuation measurements, the aid of numerical simulations and theoretical models is imperative. In the current study, all three tools are efficiently combined, while, according to the author’s knowledge, it is the first time that the synergy between ultrasonic dispersion measurements, numerical simulations and scattering models for the description of wave dispersion and attenuation in fresh concrete is presented.

2. Results
Figure 1 presents the frequency dependence of pulse velocity (subfigure 1a) and attenuation (subfigure 1b) for two fresh cementitious media: a cement paste with w/c=0.5
and a mortar containing 30 vol. % inclusions. The curves are constructed experimentally, numerically and theoretically using the scattering model of Waterman and Truell. As it is clear, there is a good agreement between the different methods enhancing thus the characterization process. The results pinpoint air bubbles and sand grains as causes of the dispersion and attenuation frequency dependent trends, while the distinct frequency ranges where the phenomena are observed allow for the more accurate characterization of the microstructure. More specifically, the addition of inclusions in cement paste translates the whole velocity curve to higher values due to the stiffening of the medium, while it makes the initial pulse velocity increase steeper due to the enhancement of the scattering interactions. Furthermore, as shown in subfigure 1b, the low frequency attenuation (below 300 kHz) is dominated by the scattering on air bubbles, since it is much higher for plain cement paste, while scattering on the stiff aggregates characterizes the high frequency attenuation (see mortar curves).

Figure 1. Frequency dependence of a) pulse velocity and b) attenuation of fresh cement paste and mortar from ultrasonic experiments, numerical simulations and scattering theories.

3. Conclusions
In the current paper the synergy between experiments, numerical simulations and scattering models is presented. The results show a good match revealing interesting information on the influence of the microstructure on the dynamic behavior of the macrostructure. It is the first time in literature that dispersion and attenuation of fresh cementitious materials is demonstrated under three different perspectives resulting in strong qualitative and quantitative agreement.

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References