MODELLING ULTRASONIC SIGNAL BACKSCATTERING IN BONE-CEMENT

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BACKGROUND

Introduction

Backscattering is a type of diffuse reflection, it corresponds to the interference of multiple reflected waves from the scatterers or the internal microstructures. Monitoring the setting of cement with ultrasound can be performed by using backscattering analysis. In contrast to the impulse echo technique were important information of the background echo is lost, by analyzing the backscattered field with a single transducer technique, it is possible to describe the state of the material and its acoustic properties.

The backscatter parameters used in this work are based on the difference backscattering spectrum technique. The backscattered energy corresponding to two nearby zones of the material is compared. The mean backscatter-difference, consists in performing a frequency averaging of the spectrum of the backscattered power.

O'Donnell and Miller proposed in 1981 a backscattering model for the characterization of tissues. In this work, we perform ultrasonic experimental measurements in the process of the setting of cement and use this theoretical model to confirm the predictions.

We assume the hypothesis that the distance between the backscattered analysis windows is very small, and the attenuation and dispersion properties of both portions of the material are very similar. Under these conditions, the model is simplified, and the attenuation coefficient is estimated from ultrasound speed propagation and the size of the windows, during the setting process of the cement.

Scattering problem

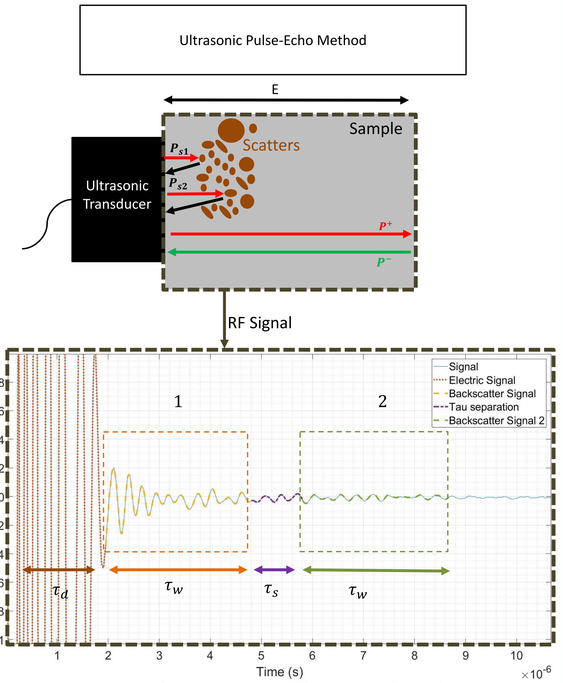


Fig 1 Schematic of sample with scatters and typical RF signal with scatters.

Backscattering modelling

Plane wave in heterogeneous medium.

- **The Backscatter Difference spectrum:**

$$D(f) = 10\log_{10} P_1(f) - 10\log_{10} P_2(f) = 10\log\left(\frac{P_1(f)}{P_2(f)}\right)$$

- **Power spectrum:**

$$P(f) = \frac{4P_0(f)E(f)V(f)\eta(f)T^2}{r^2A(f)}$$

- $P_0(f)$: Is the Power spectrum of the transmitted pulse.
- $E(f)$: Is the two-way electromechanical power conversion efficiency of the measurement system.
- $V(f)$ **:** Is the gated scattering volume of the specimen.
- $\eta(f)$ **:** Is the backscatter coefficient of the specimen.
- T **:** Is the intensity transmission coefficient at water-specimen interface.
- r **:** Is the distance from the transducer to the center of the scattering volume.
- $A(f)$ **:** is an attenuation term given by:

$$A(f) = e^{4\alpha(f)x}\left[\frac{2\alpha(f)c\tau_w \cdot e^{\alpha(f)c\tau_w}}{e^{\alpha(f)c\tau_w} - e^{-\alpha(f)c\tau_w}}\right]$$

- x**:** Is the thickness of the specimen.
- $\alpha(f)$:Is the Attenuation coefficient of the specimen.
- **c:** Is the speed of sound in the specimen.
- τ_w **:** Is the duration of the analysis gate on the signal.

- **The backscatter difference spectrum in dB is given by:**

$$D(f) = 10\,log\left(\frac{V_1(f)\eta_1(f)/{r_1}^2A_1(f)}{V_2(f)\eta_2(f)/{r_2}^2A_2(f)}\right)$$

- One parameter are determined from the backscatter difference spectrum, **MBD** is determined by frequency averaging D(f) over the analysis bandwidth.

$$MBD = \frac{\int_{f_l}^{f_h} D(f)df}{(f_l - f_h)}$$

Small d approximation

The distance d between the center of the two gated portions of the backscatter signal is:

$$d = c(\tau_w + \tau_s)/2$$

Where c is the speed of sound in the specimen(assumed to be constant over the distance d), and τ_w is the same for both gates as show in fig 1.

This assumes that: $\eta_1(f) \cong \eta_2(f)$ $\alpha_1(f) \cong \alpha_2(f)$
$r_1(f) \cong r_2(f)$ $V_1(f) \cong V_2(f)$

Using this approximations gives:

$$D(f) \cong 10\log\frac{A_2(f)}{A_1(f)} = 10\log e^{4\alpha(f)(x_2-x_1)} = 10\log e^{4\alpha(f)c(\tau_w+\tau_s)}$$

Which can be simplified further to yield:

$$D(f) \cong (40\,log\,e)c(\tau_w + \tau_s)\alpha(f)$$

For this reason the attenuation coefficient is approximately:

$$\alpha(f) \cong \frac{D(f)}{(40\,log\,e)c(\tau_w + \tau_s)}$$

MATERIALS AND METHODS

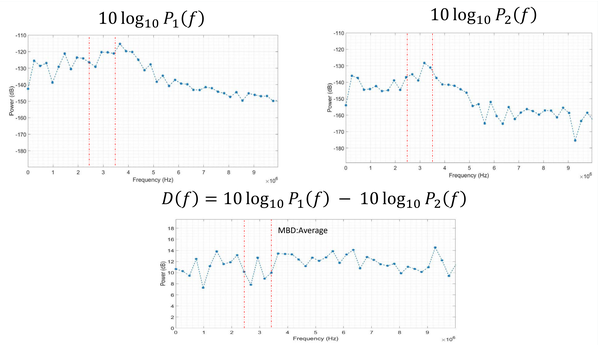


Fig 2 Example of D(f) calculation.

Experimental device

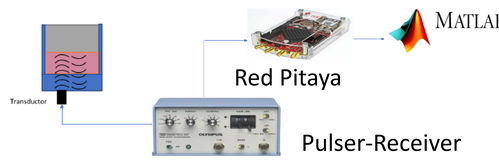


Fig 3 Schematic of experimental device.

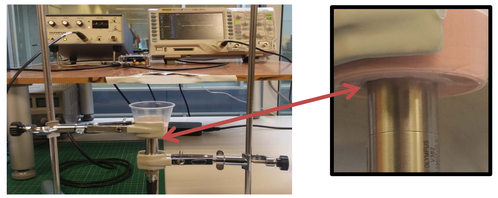


Fig 4 Picture of experimental device.

RESULTS

Experimental data

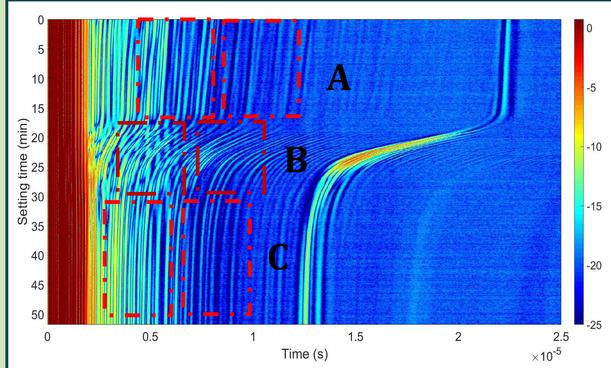


Fig 5 Experimental data, and the interest zone.

Speed of Sound and Mean Backscatter-Difference

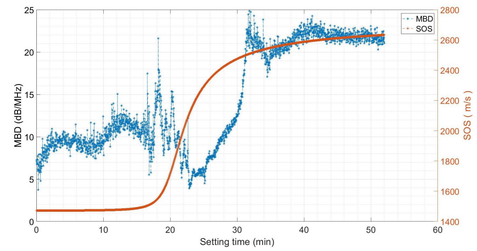


Fig 6 Speed of sound and mean backscatter difference during the drying process

Attenuation coefficient

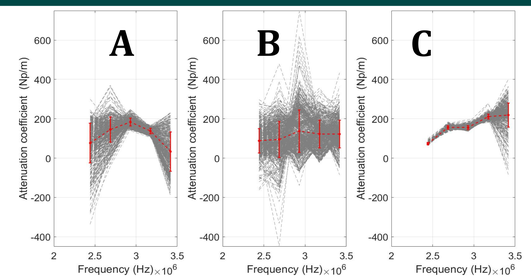


Fig 7 Attenuation coefficient in the interest zone.

CONCLUSIONS

An analysis of the backscattering model has been carried out, concluding that the Backscatter difference spectrum only depends on the attenuation coefficient, the speed of sound and the size of the Backscatter analysis window. Being able to calculate the attenuation coefficient from a Backscatter analysis.

An experiment has been carried out, where the setting of a bone cement is monitored. The Backscatter difference spectrum has been calculated and from this, the attenuation coefficient has been calculated in 3 zones.

If we observe the attenuation coefficient, we can see that in A and C, exists little dispersion, this is because in these two zones the material is stable, however in zone B, the result of the attenuation coefficient presents some large variations, since in that area the material changes as the drying time passes.

ACKNOWLEDGEMENTS

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