

Research Statement

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In a broad outline, my research interests lie in the areas of acoustics and ultrasonic non-destructive evaluation (NDE). More precisely, I have studied propagation modeling in viscoelastic media, non-destructive evaluation using experimental techniques combined with model based inversion procedures, and multiple scattering by a random arrangement of elastic cylinders immersed in a fluid.

During my doctoral research work [1], I developed a method based on the transmission coefficient measurement to evaluate some acoustic properties of viscoelastic plates. Results from this work demonstrated the dispersive and attenuative nature of sound propagation in such materials and indicated that such behavior should be included in polymer and composite ultrasonic characterization based on transmission coefficient data. In this regard, I used a relationship between dispersion and attenuation that arises from causality principle and helps explain the velocity-frequency dispersion and attenuation commonly observed in some materials, such as polymers, rocks with fluid and biological soft tissues. For the attenuation obeying a power-law frequency dependence, Szabo [2] derived a set of time domain lossy wave equations and proposed a model that links together the attenuation and dispersion. Using this model, the plate properties, namely attenuation, dispersion, density and thickness were obtained simultaneously from transmission coefficient inversion. After studying the sensitivity of the proposed method to the individual parameters, the algorithm was implemented within an iterative process using the Matlab® routine *lsqnonlin*, where the Gauss-Newton or Levenberg-Marquardt algorithm is used. Statistical confidence intervals and standard deviations of the predicted parameters were also computed.

The other fundamental feature of this method is the normally incident measurement of the transmission frequency response of a plate immersed in a fluid (water or air). To realize this, I used two basic ultrasonic instruments. The first was conducted using water as a transmitting medium. Three pairs of 1, 2.25 and 5 MHz transducers were used. The second system was performed using 1 MHz air-coupled transducers and applied to certain water-sensitive and porous materials. For both systems, a long-duration chirp signal - *i.e.*, a sinusoid with linearly increasing frequency - was chosen as input, since this signal gives excitation in a well-defined frequency range. Consequently, the start and end frequencies in the chirp signal have to be chosen based on the frequency range of interest. In the first case, the chirp signal was produced with an arbitrary function generator (Agilent 33220A). In the second case, the same chirp signal was produced by an air coupled ultrasonic system NCA 1000. A temperature compensation method was also proposed to reduce the measurement error due to temperature fluctuation during the measurements and to improve measurement accuracy. Furthermore, the plane wave propagation model was convoluted by a function describing the diffraction effects analytically [3], to account for the source's finite size effects.

The procedure has been numerically validated, then applied to several polymer plate-type specimens. We verified that the thickness, velocity and density were correctly identified, with an error of 0.1, 0.2 and 1%, respectively. Regarding the power-law attenuation parameters, we highlighted that their estimation is more difficult. However, as the results suggest, estimation of the attenuation exponent is comparatively better than that for the attenuation coefficient. Moreover, we observed that the estimation of the attenuation becomes more precise when high frequency data is used.

In more recent work, I employed this method to assess its efficacy for characterizing carbone-epoxy composite materials. Specifically, I investigated the variation of propagation parameters (velocity and attenuation) with thermo-oxidative ageing. The method was found to be sensitive to these variations, with a high signal-to-noise ratio and acceptable precision and accuracy.

The last component of my dissertation research concerned the heterogeneity modeling for a healthy carbone-epoxy composite plate (without ageing). Its purpose was to better understand the transmission coefficient variations observed experimentally at high frequencies due to the non-homogeneous nature of the plate. The proposed idea was to treat the plate as a periodic absorbing multilayer structure. Simulation followed by identification of each layer parameters were carried out to adjust the model to experiment. This geometric model, although being simplified,

has provided satisfactory results but still has a capacity for refinement.

In my M. Sc. project, I addressed the issue of multiple scattering by a random arrangement of cylinders immersed in a fluid. The cylinders were distributed in a region called "slab", located between two parallel planes orthogonal to a given x-direction. The disorder inside the slab is not uniform but depends on the x-variable. My work contributed to this endeavor [4] by calculating the reflection and transmission coefficients of this space-varying slab at large frequency and low concentration of scatters, using Twersky's theory on the propagation of coherent waves in an effective medium. The idea was based upon the discretization of the properties of the space-varying slab. The reflection and transmission coefficients were obtained after inversion of a linear set of equations of rank $2N$, with N the number of layers introduced by the discretization. I then proved the boundary conditions at the interface between two different effective layers as well as between the space-varying slab and the homogeneous fluid. These boundary conditions were shown to be the usual continuity of pressure and normal displacement. The results from this method were verified numerically and successfully compared to those obtained by the WKB method.

I intend to continue my research work regarding the acoustics and ultrasonics, with articles, seminars and conferences. It is difficult to predict exactly what problems I will be working on over the next few years. Ideas evolve, research develops and new problems naturally arise. This short statement hopes to illustrate the type of problems I have worked on and demonstrate the avenues of future research that are available to me.

References

- [1] **A. El mouhtadi**, 2011. Ultrasonic characterization of viscoelastic homogeneous and composite plates, *Thesis (PhD)*, University of Le Havre
- [2] T. L. Szabo, 1994. Causal theories and data for acoustic attenuation obeying a frequency power law, *J. Acoust. Soc. Am.* **97**(1), 14-24
- [3] R. B. Thompson, T. A Gray, 1983. Analytic diffraction corrections to ultrasonic scattering measurements, *Review of Progress in Quantitative Non Destructive Evaluation* **2A**, 567-586
- [4] J.M. Conoir, S. Robert, **A. El Mouhtadi**, F. Luppé, 2009. Reflection and transmission at low concentration by a depth-varying random distribution of cylinders in a fluid slab-like region, *Wave Motion* **46**, 522-538