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Editorial

Special Issue on Ultrasonic Modeling for Non-Destructive Testing

Michel Darmon

Université Paris-Saclay, CEA, List, F-91120 Palaiseau, France; michel.darmon@cea.fr

1. Introduction

This Special Issue of Applied Sciences focuses on advancing modeling methods for the ultrasonic Non-destructive Testing (NDT) of materials. Ultrasonic techniques are employed for non-destructive purposes to evaluate the properties and damage states of structures devised for numerous applications (engineering, building materials, medicine, etc.). The advantages and inconveniences of ultrasonic testing compared to other NDT methods have been widely reviewed [1]. The coexistence of all the different NDT methods can allow the inspection of different kinds of structures and damages [2]. The scope of this Special Issue ranges from ultrasonic wave techniques for classical non-destructive evaluation, the structural health and condition monitoring of structures, existing or novel methods for imaging, ultrasonic characterization, non-linear acoustics, acoustic emission, laser ultrasonics, additive manufacturing, medical applications, and sensors, to, signal and noise analysis.

The current Special Issue notably aims to explore advances in ultrasonic modeling methods for understanding or predicting NDT inspections. Different authors present novel achievements in the understanding and modeling of ultrasonic waves for NDT applications. High-quality research and review papers on theoretical, practical, and validation aspects were accepted, leading to a collection of 20 published papers. These are briefly reviewed here, classified into different topics. A brief overview of the main developments in the field is recalled in each topic.

2. The Feasibility of Using Innovative NDT Methods on Complex and Various Materials

Ultrasonic NDT methods can investigate different kinds of material properties (mechanical, chemical, physical, biological, etc.) with various physical states/compositions (e.g., solid, liquid, heterogeneous [3], inhomogeneous, complex, and moving media). Ultrasonic NDT is broadly used on metals, plastics, composites and ceramics. Ultrasonic testing has even been used on wooden elements using tomography or acoustic emission [4] and fabrics [5].

In this Special Issue, the first paper from Malla, Mehrabi et al. reviews the efficiency of two classical NDT techniques in detecting embedded FRP Reinforcements: Ground-Penetrating Radar (GPR) and Phased Array Ultrasonic (PAU). GPR can detect GFRP (Glass–Fiber Reinforced Plastic) bars/strands and CFRP (Carbon–FRP) strands to some extent, with a detectability potential increasing with the emission center frequency, whereas PAU can only identify GFRP and CFRP strands.

Liu and Lacidogna proposed a non-destructive method based on the Southwell procedure that considers the temperature effect to evaluate the critical load, critical thickness, and service life of internally corroded shells under external pressure. The technique appears more practical than other methods, and its accuracy suits engineering applications.

It is also important to efficiently evaluate the repair of industrial structures. Feng and Ferri Aliabadi demonstrated the utility of using embedded PZT transducers to detect damage along the bond line and on the surface of a composite repair patch. The fabrication of the PZT sensors was validated using electro-mechanical impedance results.

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Noise reduction in experimental data acquired with an ultrasonic system is also challenging. Burrascano et al. used the Hammerstein model identification technique based on swept sine excitation signals to model nonlinear systems. The robustness of the model parameter estimation in the presence of measured noise was evaluated, and a technical solution to moderate the noise effects and improve the model parameters estimation was proposed.

3. Acoustic/Elastic Bulk Waves Propagation and Scattering

The main principles of elastic or ultrasonic wave propagation and scattering in solids can be found in several classical textbooks [6–9]. Simulating an NDT measurement generally requires modeling the propagation and scattering of ultrasonic waves from targets/flaws/damage/interfaces [10]. Developed simulation tools may rely on different mathematical/physical theories or assumptions; for instance, semi-analytical, numerical, and hybrid models [11] may be used for direct simulation and model benchmarking to ensure their confidence level [12,13].

Van der Neut et al. developed a theory to obtain the Green function in a lossless layered isotropic elastic medium from two-sided data. To that aim, they introduced an alternative Marchenko equation and two other equations using both reflection and transmission data.

Since the ultrasonic wave propagation field can be seen as spatio-temporal data, Gantala and Balasubramaniam developed two different spatio-temporal deep learning (SDL) models that simulate forward and reflected ultrasonic wave propagation in 2D. The training was ensured by using data obtained from finite element simulations.

In order to simulate the ultrasonic inspection of embedded cracks in 3D configurations, an experimental and theoretical comparison of 3D models was performed by Darmon, Toullelan and Dorval: they notably compared the analytical Physical Theory of Diffraction to a hybrid method in terms of flaw scattering. Based on the spectral finite element method, the hybrid method can provide a finer prediction in configurations involving small flaws or head waves (first arrival waves [14] of a complex nature that are complicated to simulate analytically [15,16]).

For NDT applications, ultrasonic wave generation can involve physics other than piezoelectricity. In the framework of photoacoustics, Hou, Glorieux, Marsh et al. numerically investigated the efficiency of laser-excited ultrasounds (surface and bulk elastic waves) using phased arrays by comparing a finite element method to k-wave simulations and by varying the array characteristics.

The simulation of the scattering of waves from obstacles in fluids also remains a significant issue [17]; it requires first- modeling ultrasonic wave propagation in fluids [18]. Schmelt and Twiefel extended the spec-radiation method based on acoustic holography to consider propagation in multiple fluid layers. This technique was experimentally validated on a wooden particleboard assumed to behave as a fluid.

Nagaso, Moysan et al. developed a high-performance ultrasonic simulation tool for inhomogeneous moving fluids. The CFD simulation of a real experiment of liquid metal jet mixing was performed, and the moving fluid's temperature (varying in time) served as the input toa spectral finite element model for wave propagation. The authors showed that an ultrasonic transmission measurement system can monitor the principal flow fluctuation.

4. Lamb Waves in Plates

Guided waves are increasingly employed for structural health monitoring [19] due to their ability to propagate over long distances. It has, notably, a wide spectrum of applications for different materials such as rails or composites [20] for aviation aircraft.

Davey, Assier, and Abrahams proposed a semi-analytical model to asymptotically derive the reflection of Lamb waves in a semi-infinite elastic waveguide. Their method deals with singularity at traction-free elastic corners with an internal angle greater than π by adding into the Lamb mode expansion newly considered corner modes that satisfy boundary and radiation conditions.

Kazys and Žukauskas proposed to employ ultrasonic linear air-coupled arrays that are electronically readjusted to optimally excite and receive A0 and S0 guided wave modes in thin plastic films. The feasibility of such a measurement was evaluated through 2D and 3D guided waves simulations with a single transducer and a linear phased array.

Singh, Bentahar, El Guerjouma et al. modelled the scattering of an incident A0 guided wave mode from an impacted damaged zone (conical-shaped geometry with decayed elastic stiffness properties) in a quasi-isotropic composite plate. The simulation was experimentally validated by comparing the scattering directivity, and it enabled the geometrical characterization of the impact.

Capineri, Bulletti, and Marino-Merlo analyzed errors in the impact location by varying the number of piezoelectric sensors from four to eight and using the S0 mode in an aluminum plate. A good compromise between the number of sensors and the error in impact localization was obtained with six sensors.

5. Imaging for Medical and Engineering Applications

Inversion theory and artificial intelligence (AI) are growing research domains for imaging/localizing damage. Imaging techniques can classically employ array transducers [21] for applications in the NDT of materials.

Ultrasonic imaging is also crucial for medical applications [22]. Zhang et al. proposed a new technique to image the human thorax's acoustic velocity distribution using ultrasound travel time tomography. A forward model employed shortest-path ray tracing, and the supervised descent method was applied to a training set, leading to successful numerical experiments.

Vallee, Chaix et al. investigated the application of the topological energy method to leaky Lamb waves. To validate the method, measurements were carried out on a single immersed plate, successively considering—the plate edge and a notch as defects. The two kinds of flaws were precisely localized using the proposed imaging method.

To design automatic tools for crack characterization, Fradkin, Darmon et al. proposed a code including a signal-processing module based on a modified total focusing method and AI modules, leading to a crack characterization report (size, localization, and orientation). It has been promisingly tested on two similar datasets, including planar notches, both embedded and surface-breaking.

Xu et al. designed an ice-coupled ultrasonic tomography to image flaws in complex-shaped parts. Ice-coupling allows for a reduction in the acoustic impedance mismatch, as compared to the immersion method. Applying the k-space pseudo spectral method, full matrix capture, and a frequency-domain full waveform inversion (FWI) based on the L-BFGS method, the ice-coupled ultrasonic FWI technique demonstrated a promising ability to detect several kinds of flaws in complex parts.

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