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Ultrasound propagation in materials with elongated grains and preferred orientation: parameter analysis and complex tensor determination.

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ABSTRACT

This study investigates ultrasound propagation in materials with elongated grains and preferential crystallographic orientations. Such configuration is typical in thick-section welds, in which complex solidification processes result in a layout of columnar grains with varying preferred orientations. The aims of our work are twofold: microstructure investigation and complex elastic tensor determination. First, we investigate how microstructure parameters such as grain morphology and crystallographic orientation distribution influence ultrasonic wave velocity and attenuation. Grain morphology analysis considers the effect of dominant grain orientation, size, and aspect ratio. From the crystallographic standpoint, we assess the effect of the distribution of preferential orientations, allowing for some deviation from the perfectly transversely isotropic structure. The analysis uses numerically generated microstructures, where all these parameters can be carefully controlled, and 3D grain-scale finite element simulations to predict wave behaviour. We focus on two materials typical for the nuclear energy industry: stainless steel 316L and Inconel, both of which present a cubic crystal structure. Second, we develop a procedure for determining an equivalent complex elastic tensor for a given columnar grain microstructure. Complex wavenumbers obtained from time-domain finite element simulation serve as an input to a multidimensional optimisation procedure based on particle swarm optimisation and pattern search algorithms. As on a macroscopic scale the behaviour of the material can be modelled as transversely isotropic, five independent complex constants are sought. The method benefits from prior information based on crystal properties and Voigt averages and yields real and imaginary parts of the elastic tensor. The real part captures phase change, that is, wave velocity, while the imaginary part represents attenuation. The determined homogenised tensor allows for simulating amplitude reduction associated with ultrasound propagation through a microstructure with columnar grains at different angles. Moreover, it can be used in efficient semi-analytical or numerical ray tracing procedures to predict signal loss in heterogeneous welds with varying dominant orientations, contributing to modelling inspections and aiding the interpretation of measured data.

Keywords: Grain-scale, finite element simulation, complex elastic tensor determination.