Understanding the Effects of Microstructural Heterogeneities on Ultrasonic Wave Propagation using Finite Element Models

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Macroscopic properties in metal components are fundamentally dominated by microstructural features such as grain sizes, textures, and phases within the material. Therefore, characterising the microstructures of polycrystalline metal components is critical to verify their expected performance and structural integrity. Additional features of interests are the local heterogeneities, such as the presence of macrozones in titanium (which refer to clusters of grains having similar preferential orientations and being potentially detrimental to dwell fatigue lives of aero-engines), and large grains amidst an otherwise fine-grained polycrystalline material. Conventional characterisation methods – such as X-ray or electron back-scattered diffraction – are generally destructive, time-consuming, and costly. This prompts a real need to develop non-destructive methods for microstructural evaluation. Ultrasonic testing holds great potential for this application, as the underlying elastodynamic principles would cause key ultrasonic parameters such as attenuation, velocity, and backscatter to vary when employed on different materials with different testing conditions. There has been extensive research in the past to link these parameters with material microstructures, focusing heavily on analytical models and experimental validations. Nevertheless, the complex nature of the various interactions between ultrasound and the microstructural features of heterogeneous polycrystals are not yet fully understood. In this study, finite element (FE) models are primarily used to provide further insights toward these interactions. This is achieved through the generation of a perfectly-controlled environment of grain structures and wave propagation mechanisms, without having to introduce assumptions and/or uncertainties as present in analytical and experimental studies. Thanks to the vastly-improved capability provided by the GPU-based solver, Pogo, models of much larger scale and greater sophistication – in terms of structures and wave behaviours – can be created. Therefore, the rich contents that the FE model provides are employed to evaluate the validity of previously-derived theoretical models for microstructural characterisation, particularly on wave scattering and attenuation. This not only helps to improve the fundamental understanding of the various wave-microstructure interactions but could also contribute to the ongoing developments of practical analytical models and inspection systems to non-destructively characterise microstructure.