Influence of Microvoids and Grain Heterogeneity on Ultrasonic Longitudinal Wave Propagation in Polycrystalline Metal

Anuj Yadav*[1] and Mira Mitra†[1]

[1]Indian Institute of Technology Kharagpur – India

Abstract

The field of ultrasonic non-destructive testing (NDT) has seen significant advancements, with much of the research focusing on material microstructural characterization, particularly the determination of mean grain size, grain size distribution, and elastic modulus in polycrystalline metals. However, limited literature is available regarding the characterization of microvoids within the microstructure using ultrasonic NDT (1,2). Microvoids often form during additive manufacturing and casting processes, posing a critical concern as they can act as precursors to crack growth. Early detection of these voids is essential to ensure the structural integrity and reliability of metallic components. The present study investigates the scattering of ultrasonic longitudinal waves caused by microvoids combined with grain heterogeneity in polycrystalline metals using a finite element (FE) method. Initially, 2D microstructure geometries of Inconel 600, measuring 30 mm $\times$ 10 mm, are generated using Neper software. Realistic imperfections are introduced by incorporating irregularly shaped microvoids at random locations within the microstructure using in-house code. Multiple models are developed with varying mean void diameters (40 μm to 70 μm in 10 μm increments), grain sizes (300 μm to 600 μm in 100 μm increments), and porosity levels (random values ranging from 0% to 7%). These microstructure models are then imported into ANSYS APDL for finite element-based wave propagation analysis. Simulations are conducted on a high-performance computing platform in parallel computing mode. To excite longitudinal waves, a Hanning tone burst load with a central frequency of 1 MHz is applied to all models. The simulations capture the combined scattering effects of grains and voids heterogeneity. The numerical results for zero-porosity models with varying mean grain sizes are first validated against the existing unified theory (3,4), showing good agreement. The analysis reveals that longitudinal waves effectively detect microvoids when wave scattering due to grains is less significant compared to voids. Results indicate that increasing porosity reduces longitudinal wave velocity and increases wave attenuation. Additionally, wave characteristics are significantly influenced by the increasing mean diameter of microvoids. These findings highlight the sensitivity of ultrasonic waves to microstructural imperfections and their potential for non-destructive evaluation. The study provides valuable insights into the interaction between ultrasonic waves and microstructural features, paving the way for advanced assessment of material porosity and grain boundary integrity in engineering applications.

References-

*Speaker

†Corresponding author: mira@aero.iitkgp.ac.in

1)- O.J. Cook, N. Huang, R.L.W. Smithson, C.M. Kube, A.M. Beese, A.P. Argüelles, Uncovering microstructural heterogeneities in binder jet printed SS316L through ultrasonic testing and X-ray computed tomography. Mater. Charact. **197**, 112697 (2023)

2)- Propagation characteristics of ultrasonic in SLM manufactured AlSi10Mg. Ultrasonics, 135 (2023), Article 107134

3)- FE Stanke and GS Kino. A unified theory for elastic wave propagation in polycrystalline materials. The Journal of the Acoustical Society of America, 75(3):665–681, 1984.

4)- A Van Pamel, CR Brett, P Huthwaite, and MJS Lowe. Finite element modelling of elastic wave scattering within a polycrystalline material in two and three dimensions. The Journal of the Acoustical Society of America, 138(4):2326–2336, 2015.