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TEMPERATURE-DEPENDENT ACOUSTIC BEHAVIOR OF ICE COMPOSITES WITH ALUMINA NANOPARTICLES

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Abstract. Embedding nanoparticles into host materials offers a powerful strategy for tailoring acoustic properties, with significant implications for non-destructive testing and acoustic engineering. Cryo-ultrasonics - a technique that employs ice as a couplant - has emerged as a promising approach for inspecting components with complex geometries. However, its performance is hindered when testing metallic parts due to the pronounced acoustic impedance mismatch between ice and metal. To address this challenge, we propose enhancing the ice matrix with nanoparticles composed of the same material as the target metal, thereby improving acoustic coupling and signal transmission.
This study focuses on the role of solid alumina (Al_2O_3) nanoparticles in modifying the ultrasonic properties of ice composites, with particular attention to the effect of a nanometric interfacial water layer between the ice matrix and particles. We investigate this behavior across a temperature range from −5 °C to −60 °C using both 2D and 3D numerical homogenization simulations, and validate our results with experimental measurements. Our findings reveal that including the water layer is critical - especially at lower temperatures - for accurately predicting compressional wave velocities, significantly outperforming classical analytical models. Furthermore, we demonstrate that a 2D simulation framework provides excellent agreement with full 3D models, offering considerable computational efficiency without sacrificing accuracy.

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