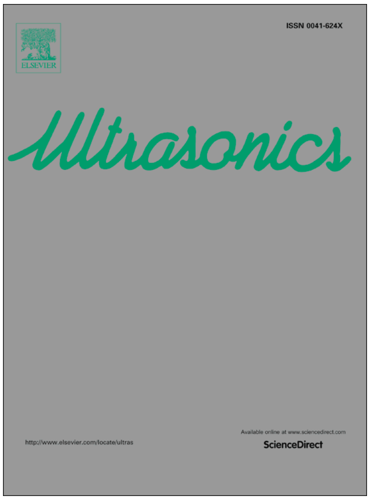

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Effect of the microstructure on the propagation velocity of ultrasound in magnetic powders.

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Abstract

We analyze experimentally and theoretically the sound propagation velocity of P-waves in granular media made of micrometer-size magnetite particles under an external magnetic field. The sound velocity is measured in a coherent (long-wavelength) regime of propagation after a controlled sample preparation consisting of a fluidization and the application of a magnetic field. Several different procedures are applied and result in different but reproducible particle arrangements and preferential contact orientations affecting the measured sound velocity. Interestingly, we find that the sound velocity increases when the magnetic field is applied parallel to the sound propagation direction and decreases when the magnetic field is applied perpendicular to the sound propagation direction. The observed qualitative relationship between the changes in the particle arrangement and the sound velocity is analyzed theoretically based on an effective medium theory adapted to account for the effect of the magnetic field in the preparation procedure and its influence on the medium contact fabric.

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1. Introduction

In disordered granular packings of non-cohesive particles, the sound propagation through the solid part of the medium can be separated into two main regimes depending on the ratio of the wavelength λ to the particle size d. In the case where $\lambda/d >\sim 10$ (low frequency waves) a sound pulse usually propagates as if the packing was an effective continuous medium in which the velocity of the pulse depends mainly on the compressive stresses acting on the packing but not on the details of the contact network [1, 2]. In the case $\lambda \leq d$ (high frequency waves), sound waves are scattered by the heterogeneities of the particle network, associated for instance to geometrical/positional disorder of the grains but also importantly to contact force disorder, force chains, weak contacts or rattlers. The pulse wave arriving at any particular location inside the packing is a superposition of waves that may have followed quite different paths. Therefore, the high frequency wave reaching a receiver of size comparable to that of the particles, placed inside the packing, is strongly sensitive to changes in the contact network and wave propagation can even in some cases be described by a diffusion equation [3, 4].

According to the effective continuous medium theory (EMT) well adapted to the low frequency (long wavelength) wave regime of propagation [5] in a granular material subjected to a consolidation stress σ_c, the velocity of sound propagation depends on the rigidity of the particle contacts, itself related to the contact deformation imposed by the macroscopic stress σ_c acting on the material. For non-cohesive granular materials, if the contact between particles is assumed to be described by the Hertz-Mindlin contact model for spheres [6], EMT successfully predicts that the velocity of sound V_p for low frequency P-waves exhibits a dependence