Reflection and refraction within heterogeneous 2D and 3D granular crystals comprised of elastic-plastic spheres

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ABSTRACT

We study the dynamic response of 2D and 3D heterogeneous granular crystals (lattices of close packed spheres) subjected to large amplitude impacts inducing contact plasticity. In prior work, we developed a force-displacement model to describe the dynamic compression of elastic-plastic spheres for a variety of materials [1]. We used this contact interaction model in discrete element method (DEM) simulations of the propagation of stress waves in organized granular materials. In one-dimensional chains of elastic-plastic spheres, we observed that, within certain impact regimes, the propagation speed of stress waves was both non-dispersive and not amplitude dependent, and depended only on the material properties of constituent particles [2]. These findings suggest that 2D and 3D elastic-plastic granular crystals may be able to act as "broadband metamaterials", i.e., materials that can redirect impact energy independently of the excitation amplitude or frequency content.

In this work, we show numerical results describing the impact response of 2D particle arrangements that incorporate triangular regions of particles of a different material. We extend these studies to 3D domains with conical regions enclosing particles of a different material. These geometries allow us to characterize the influence of many critical elements for the design of impact-redirecting metamaterials: the angle of reflection and the magnitude of stress waves reflected from an interface, the angle of refraction and the magnitude of the waves transmitted through an interface, and the speed of propagation of a transmitted plane-wave in directions other than the close-packed direction. This approach has been previously taken for purely elastic 2D granular crystals with triangular regions of different particles, to create an analog for Snell's law as a function of the particles' mass ratio [3]. We show that, in the elastic-plastic case, similar relations for the reflection and refraction angles can be found as functions of the ratio between the wave propagation speeds of uniform 1D chains of the constituent materials. We also find that the speed of propagation along an arbitrary direction can be predicted by extending the method used for the close-packed direction of 2D and 3D granular crystals [4, 5]. Finally, we show preliminary experimental results using a drop-weight tower, to characterize the reflected and refracted angles, and the propagation speeds measured on macroscopic particles, and compare them with numerical predictions.

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