HCP granular crystals with tunable mechanics

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Abstract

Traditional granular materials, such as sand and rice, consist of discrete, non-cohesive particles that interact through friction, exhibiting complex mechanics like cluster formation, stress transfer, jamming, shear bands, and shear-induced dilatation. However, their random arrangement of spherical or ellipsoidal grains limits packing density and mechanical properties, leading to poor load transfer, inhomogeneous jamming, and strain localization. One effective method to enhance their strength is by inducing crystallization with space-filling solids, improving packing factor and load transfer efficiency. Inspired by hexagonal close-packed (HCP) crystals, I developed a new strategy to transform amorphous granular materials into fully dense, crystallized materials using trapezo-rhombic dodecahedral (TRD) grains. Firstly, 3D printed millimeter-scale TRD grains were crystallized into dense HCP granular crystals through mechanical vibrations. Subsequently, the infiltration of tacky, polyacrylic adhesive at the interfaces between the grains created sustained adhesion, enabling the formation of self-standing granular structures. Compressive tests revealed highly anisotropic properties and diverse deformation mechanisms, including nonlinear deformations, crystal plasticity resembling atomistic mechanisms, cross-slip, shear-induced dilatancy, and micro-buckling. The grains can be recycled without strength loss after mechanical tests. By further modulating the c/a ratio (like in HCP metal crystals) and grain face angle, a wider parameter space is available to control TRD grain shape evolution for tunable mechanical behavior. Once fully understood and utilized, this method has the potential to create 3D architectured materials with unique mechanical performance, offering capabilities for repair, reshaping, on-site adjustments, and efficient recycling of building blocks.

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