Mechanical Engineering Doctoral Defense

Mechanical Behavior of Meteorites: Multiscale Characterization of the Strength and Failure Mechanism

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Abstract

Meteorites are extraterrestrial rocks that formed through various early Solar System processes. They survived catastrophic disruptions in space, endured violent passage through our atmosphere, and impacted the Earth. Meteorites offer a unique opportunity to study the compositions and physical and mechanical properties of early Solar System materials. However, studying their mechanical behavior is challenging due to their complex multiphase mineralogy and textures in stony meteorites as well as the intricate microstructure of iron meteorites. Determining their physical and mechanical properties is important to develop effective strategies to mitigate the threat of future asteroid impact on Earth.

In this research, the chemical and mineralogical compositions, physical and mechanical properties, and failure mechanisms of two distinct types of meteorites - ordinary chondrites (OCs) Aba Panu (L3) and Viñales (L6), and iron meteorite Gibeon (IVA) - were studied. OCs are predominantly composed of anhydrous silicates with lesser amounts of sulfides and native Fe-Ni metals, while Gibeon is primarily composed of Fe-Ni metals with sporadic inclusions of graphite and troilite. The OCs were investigated to understand their response to compressive loading, using a three-dimensional (3-D) Digital Image Correlation (DIC) technique to measure full-field deformation and strain during compression. The DIC data were also used to identify the effects of mineralogical and structural heterogeneity on crack formation and growth. Despite being classified as ordinary chondrites, Aba Panu and Viñales exhibit differences in compressive strength due to variations in chemical compositions, microstructure, and the presence of cracks and shock veins. DIC data of Aba Panu and Viñales show a brittle failure mechanism, consistent with the crack formation and growth from pre-existing microcracks and porosity. In contrast, the nickel-rich iron phases of the Gibeon meteorite deform plastically without rupture during compression, whereas during tension, plastic deformations followed by necking lead to final failure. The Gibeon DIC results showed strain concentration in the tensile gauge region along the sample edge, resulting in the initiation of new damage surfaces that propagated perpendicular to the loading direction. Finally, a strength scale dependence for OCs developed to predict the strength of asteroids tens of meters in size.

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