An Analytic Expression for the Impact Strength of Porous and Nonporous Solid Particles in the Size Range from Nanometers to Kilometers

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The presence of our planet Earth and life on the planet provides strong evidence that a mutual collision of two bodies (e.g., dust, pebbles, and planetesimals) in protoplanetary disks does not necessarily result in catastrophic disruption but it could assist in coalescence of the bodies into a planet. The outcome of mutual collisions can be predicted, provided that in advance of the collisions we acquire considerable knowledge of impact strength, which is defined as the total kinetic energies of an impactor and a target per unit target mass when the mass ratio of the largest fragment to the pre-impact target is exactly one half. Since the impact strength of colliding bodies is the main determinant of planet formation, a thorough study on the impact strength of porous and nonporous particles is crucial to better understanding the formation of planetary systems. It is, however, worthwhile noting that such a study has been so far restricted, to a large extent, to laboratory experiments with various physical and chemical properties of solid bodies. Therefore, we devote ourself to a theoretical investigation of impact strength based on Johnson-Kendall-Roberts theory of contact mechanics, Griffith theory of fracture mechanics, and Weibull theory of flaw statistics. Here, we propose an analytic expression for the impact strength of porous and nonporous solid particles that is capable of reproducing experimental results in the literature, regardless of the particles are aggregates or monoliths. It gives straightforwardly theoretical estimates of impact strength, provided that the volumes or radii of colliding particles, the volume fractions of solids in the particles, the surface energies, Young's moduli, Poisson's ratios, and densities of the solids, the radii of constituent monomers, and the Weibull moduli or the maximum flaw lengths of the particles are known. We will not only demonstrate how well the analytic expression explains experimental results with icy and siliceous materials but also discuss how the impact strength should vary with the size and porosity of particles, and, if the same material is considered, with the volume ratio of the particles.