Energy dependence in the fragmentation of heterogeneous materials

Gergő Pál[1,*], Imre Varga[2] and Ferenc Kun[1]

[1,*] Department of Theoretical Physics
University of Debrecen
P.O. Box 5, H-4010 Debrecen, Hungary
e-mail: gergo.pal@phys.unideb.hu
e-mail: ferenc.kun@science.unideb.hu, web page: http://dtp.atomki.hu/~feri

[2] Department of Informatics Systems and Networks
University of Debrecen
P.O. Box 12, H-4010 Debrecen, Hungary
e-mail: varga.imre@inf.unideb.hu, web page: http://irh.inf.unideb.hu/~vargai

ABSTRACT

The most important characteristics of the fragmentation of heterogeneous solids is that the mass (size) distribution of pieces is described by a power law functional form [1,2,3]. The exponent of the distribution displays a high degree of universality depending mainly on the dimensionality and on the brittle-ductile mechanical response of the system. Recently, experiments and computer simulations have reported an energy dependence of the exponent increasing with the imparted energy. These novel findings question the phase transition picture of fragmentation phenomena, and have also practical importance for industrial applications [1,2,3].

We investigate the fragmentation of plate-like objects induced by impact of a projectile in the framework of a three dimensional discrete element model (DEM). The specimen is discretized by means of a random packing of spherical particles with polydispersed size distribution. Breakable contacts are represented by beam elements connecting the particles along the edges of Delaunay triangles determined by the particle centers. Based on large scale computer simulations we uncover a robust mechanism which leads to the emergence of energy dependence in fragmentation processes resolving controversial issues on the problem: studying the impact induced breakup of plate-like objects with varying thickness in three dimensions we show that energy dependence occurs when a lower dimensional fragmenting object is embedded into a higher dimensional space. The reason is an underlying transition between two distinct fragmentation mechanisms controlled by the impact velocity at low plate thicknesses, while it is hindered for three-dimensional bulk systems. For thin plates at low velocities the crack structure is determined by the interference of elastic waves resulting in an essentially two-dimensional crack pattern with a regular structure. High velocity impact gradually excites cracking in the 3D bulk of the solid giving rise to a highly disordered crack structure and a steeper decay of the mass distribution. In 3D bulk samples the transition is hindered so that a unique exponent emerges. In spite of the observed non-universality of the complete mass distribution, identifying subsets of fragments dominated by different cracking mechanisms an astonishing universality of their mass distributions is revealed at all plate thicknesses.

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