A Note on Shattering Fragmentation and Lateral-Confinement Effect on Impact Fragmentation of Slender Nanoprojectiles

Sreten Mastilovic

Institute for Multidisciplinary Research
University of Belgrade
Kneza Viseslava 1, 11030 Belgrade, Serbia
e-mail: misko.mastilovic@imsi.bg.ac.rs, web page: http://www.imsi.bg.ac.rs/

ABSTRACT

A set of ballistic Taylor tests is simulated by molecular dynamics (MD) to investigate some general trends of impact fragmentation. The flat-ended, nanoscale pillars are represented by a 2D cluster of atoms interacting either by Lennard-Jones potential or the embedded-atom method. These projectiles collide with a rough rigid wall with striking velocities varying in a wide range, $v \in [0.3, 100]$ km/s.

With increasing striking velocity, a projectile disintegration eventually takes place and is identified with the damage-fragmentation (D-F) phase transition [1, 2]. Correlations are explored between the largest fragment mass ($m_{\max}$) on one side and the striking velocity (i.e., the impact energy, $\mathcal{K} \propto v^2$), and the maximum values of the pressure, temperature, and effective strain on the other. Notably, the rigid-anvil hypervelocity impact is characterized by a reverse-sigmoid dependence $m_{\max} = f(\mathcal{K})$ bounded by two transitions: (i) the D-F phase transition ($\mathcal{K}_0$, $m_{\max 0}$), and (ii) the shattering transition ($\mathcal{K}_1$, $m_{\max 1} \equiv 1$). The results suggest the same set of dependences in the logarithmic space between $m_{\max}$ and the above-mentioned state parameters [3]; a unifying empirical relation is proposed.

The present 2D-MD simulations are used to explore the elusive shattering fragmentation defined by the complete pulverization of the nanoprojectile into the cloud of monatomic debris, $m_{\max} = m_{\max 1} \equiv 1$, which pinpoints the high-energy tail of the reverse-sigmoid dependence. The term "shattering" is inspired by Redner's discussion of a mathematical pathology in a solution of the linear fragmentation rate equation "in which mass is lost to a dust phase consisting of an infinite number of zero mass particles" [4]. The critical impact energy ($\mathcal{K}_1$), associated with this transition from the stochastic to the deterministic fragment mass distribution, is investigated at two different initial temperatures of the nanoprojectile (0 and 1000 K) while scaling its size in a self-similar manner by varying their diameters at the constant aspect ratio. A scaling relation is proposed that relates $\mathcal{K}_1$ to the nanoprojectile size. It is observed that, for all but the smallest nanoprojectiles, the minimum achievable $m_{\max}$ exceeds $m_{\max 1} \equiv 1$, which is discussed based on the physically-limiting striking velocity. This shattering-transition onset is seemingly an inherent material property insensitive either to the choice of the empirical potential or the initial temperature of the solid nanoprojectile.

Finally, a study of the lateral-confinement effect on fragment mass distribution indicates that the expected confinement-induced increase of the pressure and temperature results in a very peculiar shift of the Poisson hyper-exponential distribution (with respect to the results obtained by using the classic Taylor test setup). Fortuitously or not, the values of exponent(s), that define the fragment mass distribution of all but the smallest fragments, are apparently insensitive to the lateral confinement.

REFERENCES

[1] F. Kun and H.J. Herrmann, "Transition from damage to fragmentation in collisions of solids", *Phys. Rev*. E, Vol. **59**, pp. 2623–2632, (1989).

[2] S. Mastilovic, "Damage-fragmentation transition: Size effect and scaling behavior for impact fragmentation of slender projectiles", *Int. J. Damage Mech*., Vol. **27**, pp. 201–217, (2018).

[3] S. Mastilovic, "Phenomenology of the Maximum Fragment Mass Dependence upon Ballistic Impact Parameters", *Latin Am. J. Solids Struct*., Vol. **14**, pp. 1529–1546, (2017).

[4] S. Redner, *Fragmentation*, in: H.J. Herrmann, S. Roux (eds.): Statistical Models for the Fracture of Disordered, North-Holland, 1990.