Modelling Plasticity by Non-Continuous Deformation

Yaron Ben-Shmuel* and Eli Altus†

Faculty of Mechanical Engineering
Technion - Israel Institute of Technology
Haifa 32000, Israel
*e-mail: yaronbs@tx.technion.ac.il
†e-mail: altus@tx.technion.ac.il

ABSTRACT

Plasticity and failure theories are still subjects of intense research. Although much theoretical work has been done in the past half century to explain the metal plasticity phenomena in the micro scale, no comprehensive theory has been achieved (Lubliner, 2006). Read (1953), wrote: "Little is gained by trying to explain any and all experimental results by dislocation theory; the number of possible explanations is limited only by the ingenuity, energy and personal preference of the theorist". Molecular Dynamics (MD) simulations serve as a complement to conventional experiments (Allen, 2004), but are limited by accuracy, size of the system and characteristic time of the phenomena (Mordehai et al., Bar On et al., 2010). Thus, the MD method is far from providing a simple and general model which contains only the essential physics.

Material plasticity is an irreversible process and exhibits two fundamental properties: It exhibits residual deformation after unloading and preserves volume. On the other hand, continuum theories assume that neighbour material elements remain neighbours at all time. As will be shown by examples, the above two properties cannot be materialized without neighbour detachments, local slips and neighbour switching, i.e., Non-Continuous Deformation (NCD). Therefore the classical continuum assumptions must be either modified or generalized. Our work studies the above micro-macro conflict and aims at proposing new ways to resolve it.

In this study material microstructure is modelled by a set of point elements (particles) interacting with their nearest neighbours. Each particle can detach from its neighbours and/or connect to a new neighbour particle during plastic deformation.

Simulations on two dimensional specimens subjected to uniaxial loading were conducted. Each specimen contained 100 particles with controlled stochastic heterogeneity by a single parameter λ (disorder coefficient).

Comparison between macro stress-strain loading cycle and the microelement displacements was done by averaging the results of 200 specimens. It was found that plastic deformation takes place only when both detachments and connections are allowed. In this case, plastic energy is linearly correlated with the number of these pairs. On the other hand, macro damage which is reflected by decreasing macro residual stiffness is proportional to the difference between the two parts. In addition, particle connections have two types with different macro effects: self re-connections (between two elements which were connected in the past) and new ones. Another interesting phenomenon is a rigid body displacement of local ensemble of elements. The disorder coefficient λ affects both the average elastic modulus and average plastic energy.

REFERENCES

Allen, M. P. [2004], Introduction to Molecular Dynamics Simulation. NIC Series, Vol. 23, ISBN 3-00-012641-4, pp. 1-28.

Bar On, B., Altus, E., Tadmor, E.B. [2010], Surface effects in non-uniform nanobeams: Continuum vs. atomistic modelling. International Journal of Solids and Structures 47, 1243–1252.

Lubliner, J. [2006], Plasticity Theory, Pearson Education, Inc.

Mordehai, D., Lee, S. W., Backes, B., Srolovitz, D. J., Nix, W. D., Rabkin, E. [2011], Size effect in compression of single-crystal gold microparticles. Acta Materialia 59, 5202–5215.

Read, W. T., Jr. [1953], Dislocations in Crystals, McGraw-Hill, New York.