Translational and rotational characteristics of volume energy density function for multiscale damage model

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The simplicity of macroscopic continuum mechanics theories is made possible by invoking the implicit assumption that the material microstructure could be homogenized while the temporal response could be averaged without having to consider those details unseen by the naked eye. In essence, a degree of system homogeneity is required for many of the simple laws of mechanics and physics to hold. When a material undergoes deformation, the distances between the adjoining particles will change in a non-uniform manner giving rise to non-homogeneity in addition to that caused by the microstructure. The former and latter would interact depending on the applied load and the body geometry in a complex manner. These effects are not always considered in continuum mechanics and they become increasingly more important when the specimen size becomes smaller and smaller.

The motivation for this study stems from the increasing use of semi-conductors in microelectronics where devices are microns in size. The presence of crack-like defects can no longer be treated by the discipline of conventional fracture mechanics where homogeneity and single-scale damage are invoked. It is believed that new concepts outside the frame work of classical continuum mechanics are needed to describe the behavior of micron-size specimens. Consistency will be regarded as a priority in the development of mutltiscale models where results from the different scales such macro, meso, micro, nano, etc must not only be connected but their interactive effects must be included. More specifically, the transfer of energy from the macro to the nano scale and vice versa must be considered. This action may travel back and forth several times during the evolution stages of material damage. In explosions and high speed impacts, strain rates can be in the order of 10^{-4} to 10^{-6} sec^{-1}. The a dislocation can travel up and down a tensile bar a couple of times within 10^{-4}sec. Hence, micrscopic effects can be important. A mutltiscale damage model must therefore cover an enormously wide range of defect behavior. The continuum mechanics equilibrium theories are not meant to have such capability.

The macro-meso-micro damage model presented aims to illustrate the fundamental concept of multiscaling by piecing together equilibrium theory results via force and displacement. The model is not overly complex such that the necessary physics can be retained while the computations and results are manageable and can be applied to engineering design. These contrasting demands often disqualify numerical approaches such as molecular dynamics and finite elements methods. The interpretation of the overwhelming numerical data are problematic when a complete understanding of the combined effects of geometry, loading and material is required. Qualitative understanding of physical phenomena is not sufficient for design.

Obtained in this work are the volume energy density function for a pre-cracked body damaged at both the macro- and micro-scale. The stress restraining zone serves as the transition zone where the macro damage blends into the micro damage in a smooth fashion. The size of this zone is determined by the stress (or force) and displacement compatibility conditions. Referring to a log-log plot of the strain energy density function (SED) versus the distance, two types of curves are found. Those aligned parallel with one another or have the same slope are identified with the homogenous case. When the curves rotate or change in slopes, the system homogeneity undergoes change. The degree of inhomogeneity is related to the angles of rotation. This provides a mean for quantifying the non-homogeneous microstructure behavior of the material which includes the effects of local deformation that in general will vary with the loading and geometry.

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