Dislocation based high-rate plasticity model and its application to plate-impact and ultra short electron irradiation simulations

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This paper focuses on the development of a plasticity model to describe high rate deformations of metals. Modeling of target mechanical response is performed in frames of continuum mechanics. Plastic flow is described as the result of an over barrier dislocation sliding in specific slip planes. Computations of shock wave propagation in fcc, bcc and hcp metals modeling in comparison with shock wave experiments are performed to verify the model. The model predicts yield strength increase on elastic precursor in aluminum monocrystal and titanium of high purity at high temperatures.

The action on a copper target of the electron beams with energy density (the total energy incident on an unit area during an irradiation pulse) 8.6 J cm⁻² and varied pulse duration has been investigated. At the considered irradiation regime the target remains in a solid state (maximal temperature is 710 K) and shear stresses can reach values of about 0.72 GPa. Depth distribution of dislocation density after irradiation has a maximum that is localized on a distance of 10 μm from the irradiated surface and the maximum dislocation density is about 6 × 10¹⁰ cm⁻² in the target. The shortening of the exposure time to 1 ns leads to the increase of the dislocation density. Further reduction of exposure time has a weak effect on the dislocation density because the shear stresses reach a limit.

1. Introduction

The properties of substances in the high rate loading conditions attract essential interest of failure, plasticity, phase and polymorphic transition physics (Hayes et al., 2004; Kanel et al., 2009; Asay et al., 2009; Vogler et al., 2009; Zaretsky, 2009; Grady, 2010). Loading methods are progressing at present. A recently developed technique uses the Z pulsed power generator to produce planar ramp compression waves of tens to hundreds of GPa with a duration of hundreds of nanoseconds into sample (Hall et al., 2001; Hayes et al., 2004; Asay et al., 2009; Vogler et al., 2009). Along with plate impact experiments since Oswald et al. (1968) and Perry (1970) alternative stress wave generators, such as electron, ion and laser beams arouse scientific interest. Such interest is connected with the structural changes in irradiated targets. Strong hardening of the near-surface layer and the ability of irregular shape elements processing make irradiation technologies essential for aircraft, automobile and reactor construction (Pauleau, 2006). Temperature effects play an important role in similar problems as the target temperature varies in a wide range (Akkerman et al., 1985; Chistyakov et al., 1993).

Today it is possible to generate sub-nanosecond concentrated energy flows (femto- and picoseconds laser irradiation with power density up to 10¹⁸ Wt cm⁻² (Bloembergen, 1999), sub-nanosecond electron beams with power density up to 10¹² Wt cm⁻² (Korovin et al., 2004)). Substance behavior at such exposure time and power density can essentially differ from...