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Strain Rate Dependant Material Model for Orthotropic Metals

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Abstract

In manufacturing processes anisotropic metals are often exposed to the loading with high strain rates in the range from $10^2\, s^{-1}$ to $10^6\, s^{-1}$ (e.g. stamping, cold spraying and explosive forming). These types of loading often involve generation and propagation of shock waves within the material. The material behaviour under such a complex loading needs to be accurately modelled, in order to optimise the manufacturing process and achieve appropriate properties of the manufactured component.

The presented research is related to development and validation of a thermodynamically consistent physically based constitutive model for metals under high rate loading. The model is capable of modelling damage, failure and formation and propagation of shock waves in anisotropic metals. The model has two main parts: the strength part which defines the material response to shear deformation and an equation of state (EOS) which defines the material response to isotropic volumetric deformation [1]. The constitutive model was implemented into the transient nonlinear finite element code DYNA3D [2] and our in house SPH code. Limited model validation was performed by simulating a number of high velocity material characterisation and validation impact tests.

The new damage model was developed in the framework of configurational continuum mechanics and irreversible thermodynamics with internal state variables. The use of the multiplicative decomposition of deformation gradient makes the model applicable to arbitrary plastic and damage deformations.

To account for the physical mechanisms of failure, the concept of thermally activated damage initially proposed by Tuller and Bucher [3], Klepaczko [4] was adopted as the basis for the new damage evolution model. This makes the proposed damage/failure model compatible with the Mechanical Threshold Strength (MTS) model Follansbee and Kocks [5], 1988; Chen and Gray [6] which was used to control evolution of flow stress during plastic deformation. In addition the constitutive model is coupled with a vector shock equation of state which allows for modelling of shock wave propagation in orthotropic the material.

Parameters for the new constitutive model are typically derived on the basis of the tensile tests (performed over a range of temperatures and strain rates), plate impact tests and Taylor anvil tests.

The model was applied to simulate explosively driven fragmentation, blast loading and cold spraying impacts.

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