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MODELLING DYNAMIC BEHAVIOUR OF ORTHOTROPIC METALS

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Significant amount of work has been done on modelling of material behaviour under shock loading, where the investigation has been focused on the isotropic metals. On the other hand, a pronounced material anisotropy of many common engineering materials has been observed and extensively studied at quasi-static strain rates. However, the influence of anisotropy on material behaviour at high strain rates, including shock wave propagation, has only recently attracted attention, see for instance [1]-[5]. The model proposed in [5] is intended for modelling of dynamic behaviour in the presence of shockwaves for orthotropic metals, such as Tantalum and rolled aluminium alloy (AA7010).

The model was developed in the framework of finite configurational mechanics and irreversible thermodynamics with internal variables [6], where the plasticity and damage were described by separate constitutive/dissipative laws.

The multiplicative decomposition and isoclinic configuration [7] used in the model provided three components of the velocity gradient, thermodynamically consistent with Mandel stress, so that stress power was defined as a sum of elastic, damage and plastic part. Each part of the model was defined in terms of isotropic scalar functions of thermo-mechanical variables and a set of structural tensors, which corresponds to desired level of anisotropy (two structural tensors are used for representation of material orthotropy). Three scalar functions, also known as thermodynamic potentials, used in the model are: free energy; thermodynamic plastic potential; and thermodynamic damage potential. Evolution of plastic deformation and damage in this model were controlled with MTS model [8] and modified Klepaczko criterion [9], respectively, which are fully thermodynamically consistent.

This model was implemented in DYNA3D and our in-house non-linear transient SPH code, MCM (Meshless Continuum Mechanics) and validated through the series of simulations of plate impact and Taylor anvil tests performed for aluminium AA7010, tantalum and OHFC copper. The numerical results agree well with the experimental observation.

Current research is focused on a further model development, especially to include microstructural effects, which allow for accurate reproduction of the early stages of shock wave formation. Recent experimental observations, as well as molecular dynamics simulations, have shown that the amplitude of the elastic precursor wave initially has far greater amplitude than was previously seen. In the recent literature, this phenomenon is referred to as superelastic behaviour. In order to capture the superelastic behaviour accurately, the objective of the current work is replacing the existing plasticity model. One way to achieve this objective arises from the multiscale approach and analysis of the dislocations kinetics, where the evolution of the dislocations density has been investigated as the basis of the plasticity part of the model (similar forms have been proposed by Malygin [11] and Mayer [12]).

The multiscale approach considered within this work is based on the atomistic stress tensor given in the form of the Virial stress and its applicability to a dynamic shock loaded system. The Virial calculation allows for calculation of the continuum scale Cauchy stress tensor using variables that are purely defined on the atomistic scale:

$$\boldsymbol{\sigma}_{av} = -\frac{1}{V}\left[\sum_{\alpha} \overline{\boldsymbol{f}_{\alpha}^{int} \otimes \boldsymbol{r}_{\alpha}} + \sum_{\alpha} m_{\alpha} \overline{\boldsymbol{v}_{\alpha}^{rel} \otimes \boldsymbol{v}_{\alpha}^{rel}}\right] \quad \textbf{(1)}$$

where the terms on the right hand side of Eq. 1 consists of atomistic variables including the force on an atom originating from the surrounding atoms, the displacement of the particle from the centre of mass of the system, particle mass and the relative velocity of the particle. The use of an atomistic stress tensor is of interest as it provides a potential route for multiscale calculation along with the physical basis of the derivation and application potentially allowing for effects, such as the Swegle-Grady power law to be explained in the model.

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