8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Multiscale thermomechanical modelling of high speed dry friction in hydrodynamics

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Key Words: *shock-driven dry friction, dynamic friction, multiscale approach, subgrid model, heat transfer, thermal blow-up, elastoplastic behaviour, high pressures, high sliding velocities, hydrocodes coupling.*

ABSTRACT

The purpose of the present work is to develop a robust and predictive sub-grid model of dynamic friction for use in hydrocodes. Dynamic friction refers to the physics that governs the tangential force acting across a material interface after the passage of a shock wave. It plays a key role in shock-driven systems where metal interfaces are submitted to relatively large contact pressures and severe heating [1].

Shock-induced frictional properties remain largely unknown although various experimental techniques have recently been developed [2], [3]. Severe loading conditions lead to extremely localized thermomechanical processes. These local phenomena may profoundly change the state of interface during the dynamic slip process : on a very thin sheared layer (0.1μm) important strain rates are obtained with major irreversible plastic deformation. Metal interfaces are also submitted to a warm-up phase due to frictional heat production, and plastic work. It leads to an important and localized increase in surface temperature, that may lead in extremely short time to the fully melt temperature regime and to the formation of a thin molten metal film.

Although they are widely used for the numerical simulation of high speed impact problems, the current generation of hydrocodes either neglect friction or rely on simple empirical models in which the frictional stress is related to the normal stress and/or the sliding velocity through the Coulomb's law. Such a classical law of friction is not valid and can not be used when shear stresses are limited by yielding conditions. Under severe loading conditions, the interfacial flow stress Y is determined using a SCG (Steinberg-Cochran-Guinan) model [4]. The constitutive model must take into account work hardening, pressure effect, thermal softening and melting. Shear stresses (yield strength) will thus strongly depend on the thermomechanical history at the interface. We therefore need to understand the evolution of the thermomechanical fields and their relationship to the observed slip response.

On a numerical point of view, the main difficulties are related to the localization of the thermomechanical processes and to the control of the thermal blow up. Accurate modeling of dynamic friction under dry sliding conditions therefore requires the use of a sub-grid model and the developpment of adequate coupling conditions between the local and the global models.

The sub-grid model provides new insights in the understanding and computational modeling of shock-induced metal-on-metal dry friction. It accounts for frictional contact, elastoplastic behavior, yielding and work hardening, heating by friction and plastic work, thermal softening and melting, as well as dynamics effects. Temperature and dynamic elastoplasticity are obtained at a local scale through a nonlinear time implicit numerical solver.

This local model adequately describes interfacial slip and predicts the existente of two mechanisms for dynamic friction: asymptotic melting and slide-then-lock. [3], [5]

Initially based on [6], its formulation has been updated in order to be consistently coupled to an industrial hydrocode for predicting the macroscopic behavior of the full structure such as the propagation of slip induced shear waves and the global chronology of the interface slip.

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