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MODELING NON-EQUILIBRIUM TWO-PHASE FLOW IN ELASTIC-PLASTIC POROUS SOLIDS

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The present paper is concerned with a numerical model that is developing to simulate dynamical processes in a heterogeneous two-phase medium consisting of two components – elastic-plastic porous solid and gas that occupies the domain in between of the solid. The scope of our interest is regimes of large deformations and intense loading-unloading processes when the solid and the gas have different velocities and temperatures, i.e., are in dynamical and thermal non-equilibrium. Such a model needs to describe, for example, combustion and detonation in condensed porous explosives that are manufactured by pressing granular propellants.

The model to be considered is an extension to the well-known model of Baer and Nunziato [1] for description of detonation in granular explosives. The medium in this model is treated as a two-phase continuum that consist of the solid granular skeleton of unreacted explosive and the gaseous product of combustion. Each phase of the mixture is characterized by its own vector of state parameters governed by the compressible Euler equations.

The model we develop describes the behaviour of an elastic-plastic porous material (the solid phase) filled in by a gaseous component (the gas phase). The gas can flow through the porosity of the solid skeleton. The phases exchange mass, momentum, and energy due to combustion, interphase drag, and heat conduction.

Porosity of the solid phase is defined by the gas volume fraction. Moreover, the solid phase is instantaneously characterized by the field of density, velocity, and stress tensor, the gas phase is done by own density, velocity, and pressure. We use the model of Prandtl and Reuss with the plastic flow rule given by the isotropic Von Mises yield condition to describe dynamics of the solid phase. Only minor modifications are done in this model to account for porosity. The gas phase is described by the compressible Euler equations.

The system of governing equations is closed by the kinetic equation for porosity which takes into account change in time of the gas volume fraction due to deformation and combustion of the solid skeleton.

The resulting system of equations have no conservative form. Non-conservative terms appear because of gradient of the porosity, and are named in literature as nozzling terms by analogy with variable-area quasy-1D gas dynamics. A careful treatment is required for these terms when developing numerical methods [2].

Many investigations have been undertaken to analyze mathematical properties of the Bayer-Nunziato equations, in particular with the aim of solving the Riemann problem and extending the Godunov method to two-phase hydrodynamics [2-5]. The model of elastic-plastic two-phase flow is more complicated. For solving this model we implement the method of splitting that allows us to reduce the problem to more simple sub-problems.

The splitting is done in a natural way. We separate solid phase and gas phase equations. At the first stage, the solid phase equations are solved with the Godunov-type method of [6] modified to porous solid. As the result we obtain new values of solid parameters and porosity changed due to combustion and deformation of the solid skeleton.

The second stage is to solve the gas phase equations. This is a typical problem of gas dynamics in a moving porous medium. As mentioned above, the basic problem here is the treatment of the non-conservative (nozzling) term. To settle this issue we consider the Riemann problem generalized for the case when the solid skeleton is not fixed in space, but moves with a velocity. We show that the numerical approach of [7] for solving gas flow in steady porous material can be extended to the unsteady case.

We suppose to discuss at the conference details of the numerical method and show calculation results for a set of test problems that demonstrate accuracy of numerical results and ability of the method to capture correctly basic features of shock wave processes in two-phase elastic-plastic solid and gas mixtures. We shall also present some applications related to initiation and propagation detonation wave in a porous explosive.

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