IMPACT SIMULATION WITH FRACTURE AND POROSITY

Martin Jutzi and Willy Benz

Physikalisches Institut, University of Bern, Siedlerstrasse 5, 3012 Bern, Switzerland

ABSTRACT

Our Smooth Particle Hydrodynamics (SPH) impact code can be used to model impact and collisions in the strength- and gravity-dominated regime (Benz & Asphaug, 1994). Here we describe the extention of this numerical tool with a porosity model. The model is based on the so called P - α model which is adapted for implementation in our code. We are now capable of performing SPH simulations including fracture and porosity and report some very encouraging results.

Key words: SPH, impact physics, porosity.

1. INTRODUCTION

Spacecraft missions and ground based observations are providing increasing evidence that many or even most asteroids are porous (Housen & Holsapple , 2003). Also comets are thought to have highly porous structures. Porosity may also play an important role in the formation of planets as the dissipative properties of porous media will enhance the collisional sticking mechanism required to build planetesimals. In order to study the effects of porosity in impacts and collisions, we have developed a numerical model suitable for the calculation of shock dynamics and fracture in porous media.

2. NUMERICAL METHOD

Our numerical tool is based on the on the Smooth Particle Hydrodynamic (SPH) method. In order to simulate solids, standard SPH was extended to include (Benz & Asphaug, 1994):

- elastic-perfectly plastic strength model
- fracture model based on the Weibull distribution of flaws

Therefore, our impact code can be used to model impacts and collisions involving solid bodies in the strength- and gravity-dominated regime. This was successfully tested at different scales.

2.1. Tests of our method

At small scales, the method was validated by simulating laboratory impacts. Our model predicts shapes, locations and velocities of the largest fragment with high accuracy (Benz & Asphaug, 1994).

A natural laboratory for studying collision physics at larger scales is provided by the twenty or more asteroid families identified in the asteroid belt. By simulating classes of collisions, our model was able to reproduce the main characteristics of such families (Michel et al. , 2003).

2.2. Extension of our numerical method: Including a porosity model

While porosity at large scales can be modelled explicitly by introducing macroscopic voids, porosity on a scale much smaller than the numerical resolution has to be modelled through a different approach. Our porosity model is based on the so called P-α model (Herrmann , 1969). The model provides a description of microscopic porosity with pore-sizes beneath the spatial resolution of our method.

According to the P-α model, the distention α is defined as

$$\alpha = \frac{\rho_s}{\rho} \tag{1}$$

where ρ_s and ρ are the density of the solid (matrix excluding the pores) and the bulk density (including the pores), respectively. Porosity is related to distention as $1 - 1/\alpha$. We use the variable α to extend the following equations/models of our method (Jutzi , 2004).

$$P \rightarrow P(\alpha) \tag{2}$$

$$S^{ij} \rightarrow S^{ij}(\alpha) \tag{3}$$

$$D \rightarrow D(\alpha) \tag{4}$$

where P is the hydrostatic pressure, S^{ij} the deviatoric stress tensor and D the variable damage. The time evolution of the distention α is given by

$$\dot{\alpha} = f(\alpha, \rho, E, \dot{\rho}, \dot{E}) \tag{5}$$

where E is the specific energy.

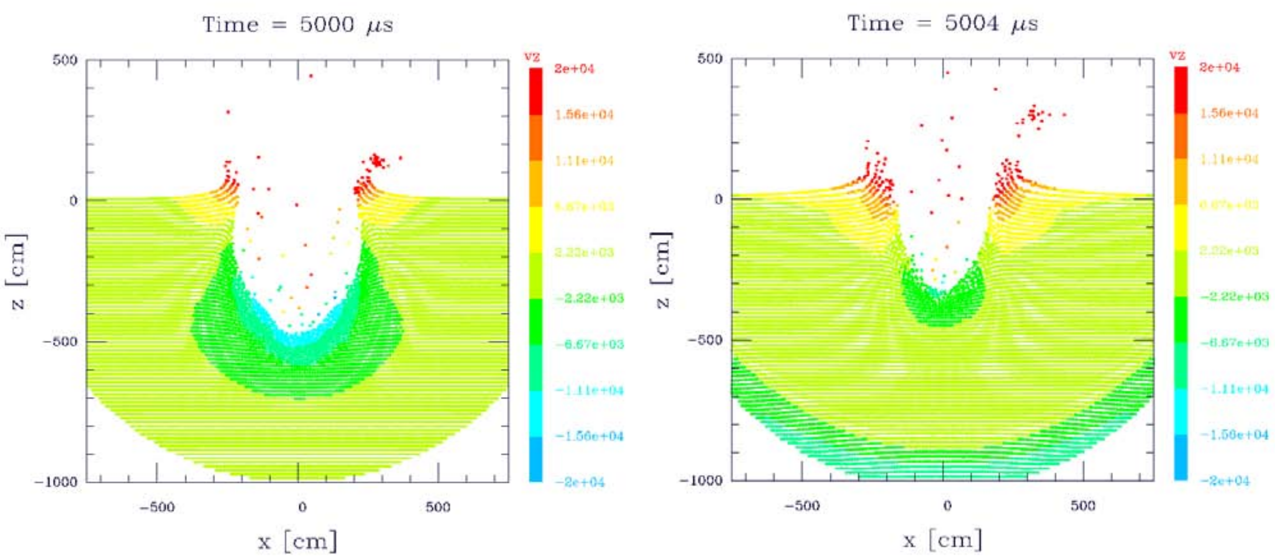

Figure 1. Comparison between simulation of an impact in porous ice (left) and nonporous ice (right)

All parameters used by our porosity model are material parameters which can in principle be measured; most of them quite easily (e.g. the so called crushcurve) even thought this is rarely done in practice. Others such as Weibull parameters, shear strength etc. are more difficult to measure.

3. PRELIMINARY RESULTS

In porous material, the stress wave produced in a impact is attenuated due to the energy expense needed to collapse the pores. Furthermore, crater and ejecta blanket formation is different in porous material. In contradiction to solid material, there is only a small amount of ejecta and the crater volume is primarily formed by compaction.

Using our model, this behavior of porous material can be reproduced as it is shown in this section. Moreover, simulations of laboratory impacts show a good agreement between the shape of craters obtained by the simulation and the experiment.

3.1. Impact in porous ice

To demonstrate the described behavior of porous material we compare an impact in porous ice (α_0=1.5) and an otherwise identical impact in nonporous ice. The impact velocity is 10 km/s. The simulations are shown in figure 1 where the colors label the vertical velocity of the particles (positive values indicate ejection).

As it can be seen, there is much less material ejected in the case with porous ice (left) than with nonporous ice (right). Obviously, the crater in the porous material is formed primarily by compaction of the material. A measure of the compaction is provided by the actual value of the distention α which is shown in figure 2.

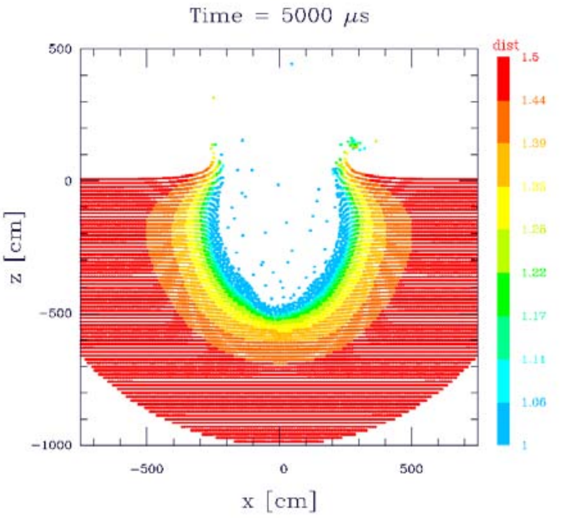

Figure 2. Impact in porous ice. The initial distention of α_0=1.5 is decreased to α=1 in a small zone around the crater. With increasing distance from the crater, distention increases until $\alpha = \alpha_0$.

3.2. Laboratory impact

In order to test our model we simulate laboratory impacts in porous material performed by Housen & Holsapple (2003). In these experiments, a mixture of sand, perlite, fly ash and water was used to obtain a highly porous ma-

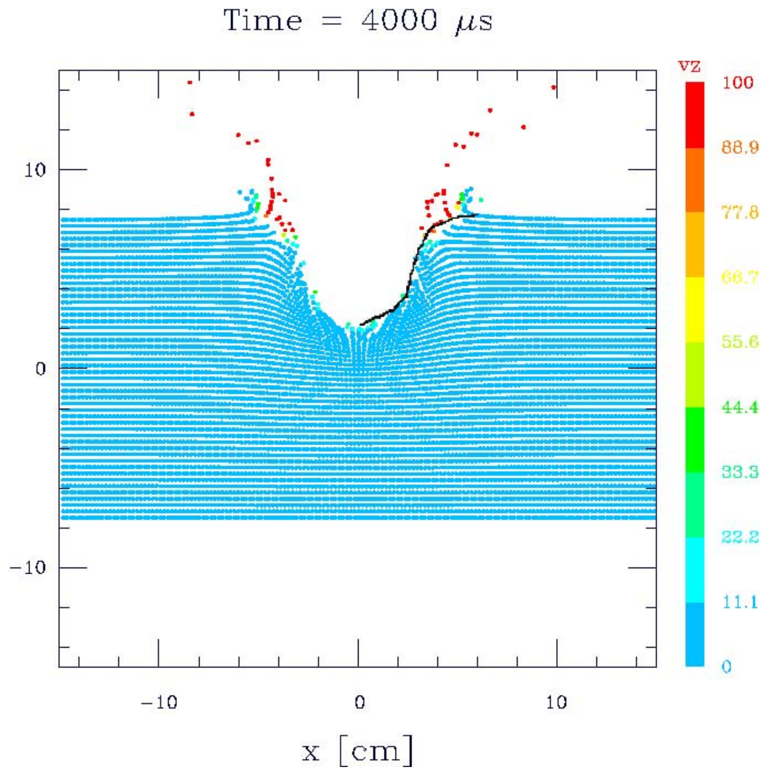

Figure 3. Simulation of a laboratory impact in porous material (α_0=3.3). The colors label the z-component of the velocity, the black line represents the experiment.

terial (α_0=3.3). As impactor served a polyethylene bullet of 1.3g with an impact velocity of 1.9 km/s. Figure 3 shows the simulation of this impact. Taking into consideration that particles with positive velocity (red) will be ejected, the agreement with the experiment (black line) is reasonable. However, not all necessary material parameters were measured and some reasonable values were chosen for the missing ones.

4. CONCLUSION

Using our extended numerical method including porosity for the simulation of impacts in porous material, we get reasonable results. The expected effects of porosity are reproduced as well as the shape of craters generated in laboratory impacts. However, to validate our model, comparisons to appropriate experiments are needed where all necessary material parameters can be measured.

5. ACKNOWLEDGEMENT

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