NUMERICAL MODELING OF PORE SPACE COLLAPSE DUE TO SHOCK WAVE COMPRESSION

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Introduction: Porosity in target rocks affects impact cratering on various scales ranging from differences in crater shape and size (macroscopic scale), e.g. [1,2], to shock phenomena preserved in impacted rocks (microscopic scale), where un-shocked grains are located just off highly shocked or melted material [3]. The process of pore closure consumes energy (plastic work) increasing the amount of irreversible work that is done due to shock wave compression and thereby evolving higher post-shock temperatures and internal energies [4]. On macroscopic scale this results in smaller craters in porous targets [1,2,5]. Microscopic studies on experimentally impacted porous quartzite [6], and samples from real crater structures, e.g. Coconino Sandstone at Meteor Crater, Arizona [7], suggested already decades ago that pore closure and shock wave propagation due to high impedances contrast between pores and solid components results in very heterogeneous distribution of crystalline polymorphs or other shock wave features within one sample.

It is therefore of particular interest to investigate pore closure due to shock wave compression in detail to obtain a better understanding of wave propagation and shock modification in sedimentary (porous) rocks and to aid the interpretation of samples from craters in sedimentary targets that have experienced shock loading. This work is also of great importance for the analysis of impact experiments on sandstone blocks that have recently been conducted in the framework of the MEMIN project [8].

Numerical Modeling: Shock wave propagation in heterogeneous materials has been investigated by numerical modeling on all scales: the effect of strong impedance contrast at mineral boundaries was analyzed numerically [9,10]; simulations of the crushing of ice-filled pores by shock wave compression were discussed in the context of the development of a multiphase equation of state [10]. Recently a macroscopic strain-based compaction model for porous rocks was developed [2]. In addition to these activities in this study we present the simulation of a planar shock wave propagating across a single pore of various geometries. We investigate how shape, size, distribution and multiple pores affect the structure of the wave and the resulting peak shock pressures observed in the immediate proximity to the pore.

Model setup: First tests were modeled with the hydrocode iSALE-2D [2]. iSALE is a multi-material multi-rheology extension to the continuum fluid dynamics code SALE [11]. In our preliminary models a planar shock wave of different initial pressure amplitudes hits on a single pore space of varying size and shape located within competent rock.

We used ANEOS [12] to compute the thermodynamic state as a function of density and internal energy. Constitutive properties, such as yield strength *Y*, were kept constant throughout the entire model run (*Y*=const.). Pore geometries were chosen in the style of real pore spaces within rocks, so we modeled more angular shapes similar to gaps between grains (e.g. sandstone) as well as elongated to more round shapes which may be compared with structures in limestone (see Fig. 1)

In the presented examples the computational grid is 500×500 cells, while up to 4500 cells were allocated as void (vacuum) representing the pore. Initial shock pressures range from 16-35 GPa. The impulse length of the shock wave was infinite throughout the duration of the simulation.

Shock wave propagation on pore spaces: Fig.2 shows examples of various model-runs. When the shock wave first reaches a pore it is reflected at the surface, inducing a reverse wave that interacts with the initial shock wave, resulting in a pressure decrease. The stresses acting on the surface of the pore cause a progressive decrease of the volume of the pore. When the pore has reached a critical volume or is completely closed, a maximum increase in pressure is induced at pore closing position, which spreads circular into the target. In summary, we distinguish four phases of pore collapse

a. Reflection (Fig.2, first row)
b. Pore shrinking (Fig.2, second row)
c. Pore collapse with maximum pressure increase (Fig. 2, third row)
d. Spreading of collapse induced pressure wave (Fig.2, fourth row)

Preliminary results: Pressures, temperatures, and internal energies were recorded in space and time by tracers, Lagrangian particles, which were initially placed in the grid at every node.

First results of a local increase of peak shock pressures due to pore collapse are shown in Fig.3. The diagram depicts maximum shock pressures in a volume surrounding the pore for different pore geometries as a function of time. Along the curves all processes such as wave reflection (reduction of peak maximum shock pressure – phase a), shrinking of the pore (phase b), and pore closure (overall maximum – phase c) can be identified. The initial geometry of the void takes enormous effect on pressure distributions in the immediate vicinity. In particular the peak shock pressure is for all geometries, except for the elongated void (a), higher than the pressure of the initial shock wave. For the cubic void (b) it is almost an order of magnitude higher.

Simulations with different initial shock wave pressures result in an increase of very similar factors, e.g. the rhombic structure caused an increase of ca three-times of the initial shock pressure. However, due to the planar approximation in the models, these results are only of qualitative value rather than providing quantitative estimates of the local pressure increase due to pore collapse.

Conclusion and Perspectives: The presented examples are the result of numerous tests and simulations with different settings that should be understood as first attempts to model pore collapse. Further simulations are planned with an array of pores, where effects on the propagating shock wave will interfere. We also plan to use 3D-models in order to provide accurate estimates of pressure increase due to pore collapse. Also the resistance of pores against failure (strength) may be an important parameter. Finally, we want to consider pore water in our models as well. The overall goal is to quantify shock features in inhomogeneous (porous) targets and to develop an advanced macroscopic porosity model, based on [2], where the presence of a liquid phase is taken into account. Experimental data from the MEMIN project [8] will be included in this analysis.

References: [1] Love, S. G. et al. (1993) Icarus, 105, 216-224. [2] Wünnemann K. et al. (2006) Icarus 180, 514-527. [3] Kieffer S. W. (1971) JGR 76, 5449-5473. [4] Zel'dovich, Y. B., and Raizer, Y. P. (1967) Physics of Shock Waves and high Temperature Hydrodynamic Phenomena, Academic Press, New York, Vol. 2, Chap. 11, p.712-716. [5] Housen, R. K., and Holsapple, K. A. (2003) Icarus, 163, 102-119. [6] Grieve A. F. et al. (1996) MAPS 31, 6-35. [7] Kieffer S. W. et al. 1976) Contrib. Mineral. Petrol. 59, 41-93. [8] Kenkmann et al. (2007) 38th LPSC, same volume [9] Hertzsch et al. (2002) Proceedings Asteroids, Comets, Meteorites, ACM 2002, 855-858 [10] Heider and Kenkmann (2003) MAPS 38, 1451-1460 [11] Ivanov B.A. (2005), 36th LPSC, #1232

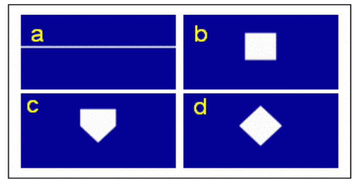

Figure 1: Examples of pore geometries used in model-runs.

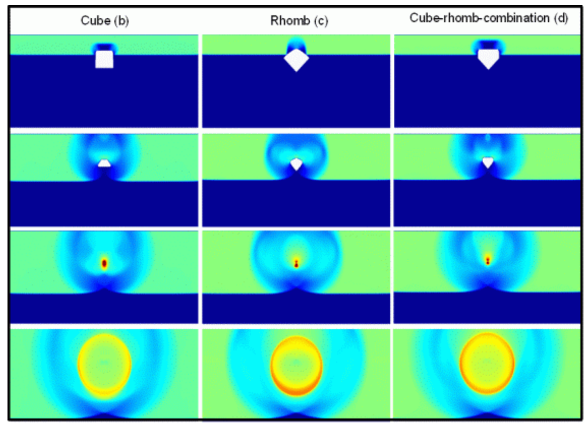

Figure 2: Snapshots of model-runs for different pore space geometries (cube, rhomb and cube-rhomb combination), initial shock wave pressure was 30 GPa.
a) reflection phase, b) pore shrinking induces secondary pressures at void surfaces accompanying reflections, c) pore has reached critical volume or is completely closed – highest pressure increase, d) spreading of the secondary pressure wave.

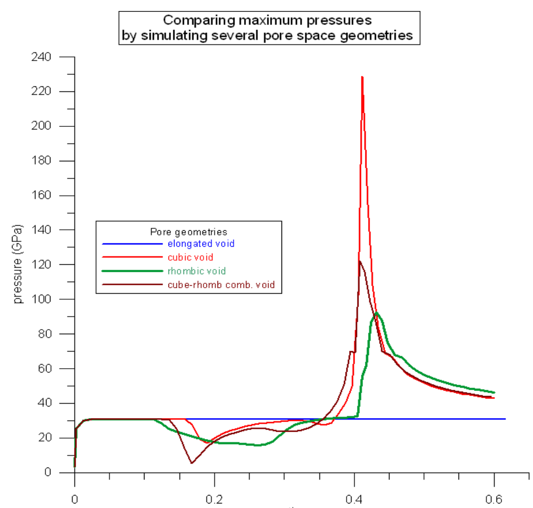

Figure 3: Maximum pressures for modeled geometries in a volume around the void as a function of time.