EPSC Abstracts
Vol. 7 EPSC2012-571 2012
European Planetary Science Congress 2012

Effect of porosity on shock wave propagation in the low shock pressure range (<15 GPa) using mesoscale modelling in comparison to laboratory experiments

N. Güldemeister (1), A. Kowitz (1), K. Wünnemann (1), W. U. Reimold (1,2) and R. T. Schmitt (1); (1) Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, D-10115 Berlin, Germany. Email: nicole.gueldemeister@mfn-berlin.de. (2) Humboldt Universität zu Berlin, 10099 Berlin, Germany .

1. Introduction

Porosity plays an important role in impact crater formation and shock wave propagation. Where present, it causes fast attenuation of shock pressure.

In the framework of the "MEMIN" (Multidisciplinary Experimental and Modeling Impact crater research Network) project, the effect of porosity in dry and water-saturated sandstone on shock wave loading is investigated [1]. We are focusing on shock recovery experiments that have been carried out within one sub-project of MEMIN. The experiments are subject to investigate shock effects in experimentally shocked quartz at low shock pressure (5 – 12.5 GPa) where diagnostic shock features and calibration data are lacking at the moment. The influence of porosity on progressive shock metamorphism is investigated.

The laboratory impact experiments were accompanied by meso-scale numerical modeling in order to quantify processes beyond the optical and electron optical observational capabilities. The model enables a detailed description and quantification of thermo-dynamic parameters during single pore collapse.

2. Methods

2.1 Shock recovery experiments

Shock recovery experiments were conducted with cylinders (Ø 1.5 cm, length 2 cm) of dry Seeberger sandstone (layer 5; grain size: ~0.17 mm, porosity: ~19 vol.%, SiO_2-content: ~96 vol.%, ~4 vol.%, phyllosilicate and other accessory trace minerals). The shock recovery experiments (Fig. 1) were carried out with a high explosive driven flyer plate set-up generating a plane shock wave [2]. To avoid multiple reflections of the shock wave within the sample material and to reach the desired pressures of 5 to 12.5 GPa, the impedance method was used [2].

2.2 Numerical model

To simulate crater formation (not shown here) and shock wave propagation in the experiments described above, we have used the multi-material, multi-rheology hydrocode iSALE [3] coupled with the ANEOS for quartzite [4]. Here we focus on the application of meso-scale modeling, where individual pore spaces are resolved, to obtain a better understanding of shock wave propagation through a heterogeneous material and of the processes associated with shock-induced pore-space collapse. Therefore, we used a similar set-up as in the experiments (Fig. 1b). The heterogeneous material consists of well separated pores representing the same porosity as observed in the material for shock recovery experiments. We performed quantification of localized pressure amplification due to pore collapse and obtained a general description of shock propagation in heterogeneous material.

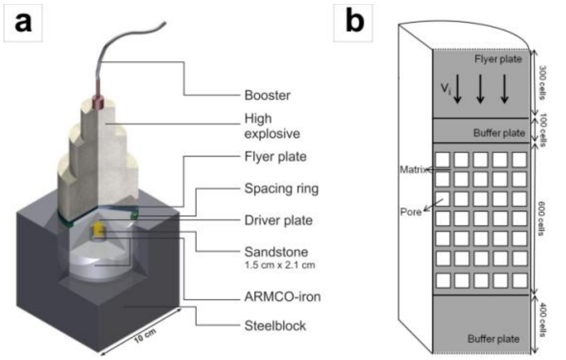

Fig. 1: Experimental set-up for the shock recovery experiments (a). Illustration of the mesoscale model set-up including the flyer or impact plate, the buffer plate and the sample with a defined number of well resolved pores (b).

3. Results

3.1 Experimental observations

Some of the relevant induced shock effects observed with increasing shock pressure include (i) already at 5 GPa, pores are totally closed (Fig.2). Dark vesicular melt of phyllosilocate composition occurs at ~1.6 vol.%. (ii) At 7.5 GPa, two additional kinds of phyllosilocate-based melts, a lighter, vesicular melt and another containing large iron particles, could be observed. The total amount of melt (all types) increases to 2.4.%. (iii) At 10 and 12.5 GPa, the amount of melt (all types) increases to at 4.8 %. Diaplectic quartz glass could be observed locally near to the target-surface (Fig.2).

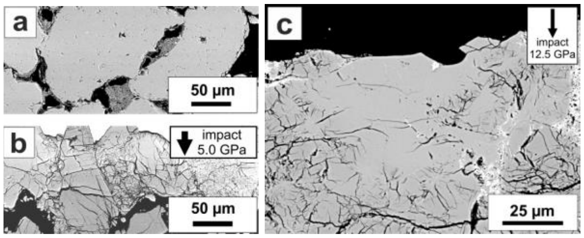

Fig. 2: Comparison of (a) unshocked and (b) shocked (5 GPa) Seeberger sandstone samples; note the total closure of pore space (BSE images); (c) Formation of diaplectic quartz glass in the sandstone shocked to 12.5 GPa (homogeneous zone without fractures) close to the upper sample surface (BSE image).

3.2 Mesoscale modelling

The numerical models on the mesoscale show an immediate crushing of pore space and a resulting complete closure of pores as the immediate response to shock loading, already at low initial pressures (<6 GPa). Despite the overall decrease of shock pressure during the propagation through a porous material, the detailed analysis of the closure of single pores indicate a localized amplification of shock pressure during pore collapse. When a pore has been completely closed, a secondary shock wave is generated that propagates from the original center of the pore. The secondary shock wave superposes the release wave and the initial shock wave, which results in pressure amplification in the material that originally surrounded the pore. Considering similar pressure ranges as used in the experiments, these amplifications can reach as much as 4 times the average shock pressure in the porous material. This is seen in Fig. 3, which depicts the distribution of maximum shock pressure relative to the initial shock pressure after the collapse of a single pore, and a set of pores. The higher pressures can be observed in the zone where the pore was initially located. Note, the material, and thus the respective tracer, experienced a relative motion downward. Localized zones (red) of pressure amplification after shock wave propagation through a representative sample with randomly distributed pores are shown in Fig. 3c.

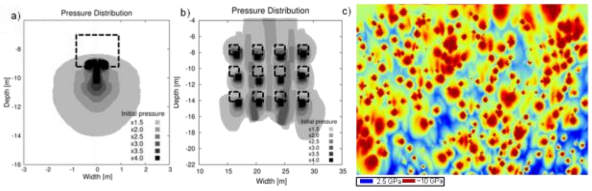

Fig. 3: Peak pressure distribution for a single pore and a set of pores with an initial pressure of 6 GPa (a,b) and for a more realistic sample with initially randomly distributed pore space (c). Pore space is completely crushed.

4. Discussion

The shock compression of porous sandstone is distinctly different from that of non-porous rocks, especially at low shock pressures and the crushing mechanism is strongly dependent on the individual porosity. In particular the large contrast in the shock impedance between quartz grains and pores leads to a distinctly heterogeneous distribution of shock pressures and temperatures in the target until the pores are completely closed. This causes a heterogeneous distribution of shock features at the microscopic scale, as observed in nature and shock experiments. The quantification of shock amplification due to pore space collapse using mesoscale modeling is in good agreement with observations in the shock experiments on dry sandstone at (5.0 to 12.5 GPa). Despite low shock pressures (10 GPa) diaplectic glass was observed that usually forms at about 35 GPa in shocked quartz single crystals [2]. The mesoscale models showed that an amplification by a factor of 3-4 can occur in the vicinity of a pore. The localized pressure amplification may locally lead to much enhanced shock temperature that would facilitate the formation of melt, PDF and diaplectic glass, even at these relatively low nominal experimental pressures. The mesoscale model analysis of pore crushing as well as the experimental data indicates that total closure of pores is already achieved at <6 GPa.

Acknowledgements

This work was funded by DFG, FOR-887, WU 355/6-1 and Re 528/8-2.

References

[1] Kenkmann T., Wünnemann K., Deutsch A., Poelchau M. H., Schäfer F., and Thoma K.: Impact cratering in sandstone: The MEMIN pilot study on the effect of pore water. Meteoritics & Planetary Science, Vol.46, pp.890–902, 2011.

[2] Stöffler D., and Langenhorst F. 1994. Shock metamorphism of quartz in nature and experiment: I. Basic observation and theory. Meteoritics & Planetary Science 29:155-181, 1994.

[3] Wünnemann K., Collins G. S., and Melosh H. J.: A strain-based porosity model for use in hydrocode simulations of impacts and implications for transient crater growth in porous targets. Icarus, 180:514–527, 2006.

[4] Melosh H. J.: Hydrocode equation of state for SiO_2. Meteoritics & Planetary Science, Vol. 42, pp.2035–2182, 2007.