MESOSCALE MODELING OF IMPACT-INDUCED SHOCK WAVES IN HETEROGENEOUS ROCKS COMPARED AGAINST EXPERIMENTAL OBSERVATIONS.

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Introduction: The presence of porosity in planetary crusts, asteroids and comets significantly affects impact cratering and shock wave propagation. It causes fast attenuation of shock pressure. In the framework of the MEMIN project, the effect of porosity in dry and water saturated sandstone on shock wave loading has been investigated [1]. We have carried out numerical simulations on the mesoscale to investigate shock wave propagation in heterogeneous materials and compared them with results from shock recovery experiments aimed at the investigation of shock effects in experimentally shocked quartz/quartzite/sandstone at low shock pressures [2], where diagnostic shock features and calibration data are lacking so far. The mesoscale models enable us to study and quantify pore collapse as a consequence of shock wave compression and provide insights of the dynamic processes beyond the static optical and electron optical observations from experimentally shocked sample material. We conducted a series of numerical experiments of shock wave propagation in porous material focusing on a detailed description and quantification of thermodynamic parameters in the vicinity of single pores and the investigation of the general response of heterogeneous material, including water-saturated sandstone, to shock wave loading.

Methods: To simulate crater formation and shock wave propagation, we have used the shock physics code iSALE [3]. iSALE uses the equation of state model ANEOS to simulate the thermodynamic response of quartzite to shock wave compression [4]. In our models individual pores are resolved and the shape is approximated by simple geometric objects such as spheres and cubes. Analogous to the experimental setup for shock recovery experiments [2], we generated planar shock waves of different pressure amplitudes by impacting a cylindrical flyer plate onto a buffer plate at velocities between 500-4000 m/s. The shock wave propagates from the buffer plate into the sample, where a number of pores is resolved representing different degrees of porosity. Besides empty pores we also investigated the effect of pores filled with water. As a consequence of the interaction of the shock wave and the crushing of pores a complex, heterogeneous pressure field arises. In our models we determined the distribution of peak shock pressures in the vicinity of the pores and measured the velocity of the shock front that is also affected by the presence of pores.

Results: The mesoscale numerical models show crushing and complete closure of pores as the immediate response to shock loading at relatively low initial pressures (< 6 GPa). Crushing of pore space is an effective mechanism for absorbing shock energy resulting in comparatively faster attenuation of the pressure amplitude than observed in nonporous materials. Despite the overall decrease of shock pressure during shock propagation through a porous material, the detailed analysis of the closure of single pores indicates localized amplification of shock pressure during pore collapse. When a pore is 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 an amplification of the shock pressure in the area where the pore was initially located before collapse. These amplifications can reach as much as 4 times of the average shock pressure in the porous material. The amplification of the shock pressure decreases with the number of pores due to wave interference caused by scattering and reflection of shock waves. Mesoscale modeling of water-saturated pores shows that shock waves travel significantly faster and pores are only slightly compacted compared to empty pores.

Discussion: In particular the collapse of empty pores leads to a heterogeneous distribution of shock pressures and temperatures. This causes heterogeneous distribution of shock features at the microscopic scale, as observed in nature and in experimentally shocked materials. The quantification of shock amplification due to pore space collapse using mesoscale modeling is in good agreement with observed localized shock effects in the shock recovery experiments on dry sandstone at low pressures. The localized pressure amplification may locally lead to significantly enhanced shock pressures and temperatures that, in turn, facilitate the formation of SiO_2 melt and diaplectic quartz glass as well as stishovite, at relatively low nominal experimental pressures (5-10 GPa). Thus, numerical simulations can reproduce and further quantify the observations from shock experiments and provide an explanation for the formation of diaplectic glass and SiO_2 melt at rather low shock pressures.

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