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Recording and investigation of the seismic signal generated by hypervelocity impact experiments and numerical models

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1. Introduction

Meteorite impacts can cause environmental consequences, one of which is the generation of ground motions that may exceed the magnitude of the largest earthquakes [1]. Impacts generate shock waves that attenuate with distance until they eventually turn into seismic waves. Thus, meteorite impact may be considered as a source for seismic shaking similar to earthquakes. Seismic signals have been recorded in explosion experiments [2] and in hydrocode models of large impact events such as the Chicxulub crater [3]. To determine how much of the kinetic energy E_{kin} of the impactor is turned into seismic energy E_{seis} can be investigated experimentally (by recording the acoustic emission) or by numerical models. The ratio of E_{seis}/E_{kin} is the so-called seismic efficiency *k*. The seismic efficiency depends on material properties (porosity) and is usually estimated to range between 10^{-2} and 10^{-6} [2,4]. In the framework of the "MEMIN" (multidisciplinary experimental and modeling impact crater research network) project a suite of hypervelocity impact experiments on a decimeter scale have been carried out [5]. We use acoustic emission (AE) technique and pressure gauges in high spatiotemporal resolution to determine the characteristic of elastic waves arriving at varying distances on the laboratory scale. An important complementary method to analyze wave propagation is numerical modelling. The study aims at the validation and calibration of material models against static observations (US tomography) and dynamic measurements of the acoustic signal. We consider a nonporous quartzite and a porous sandstone target focusing on the propagation speed of the seismic signals. The improved material models will enable the usage of numerical models to upscale the results from the laboratory scale to the dimensions of natural impact craters.
In a further step these data may be used to quantify the seismic efficiency of hypervelocity impacts.

2. Methods

We focus on the detection of the propagation of the elastic wave in impact experiments with a 20 cm cubed quartzite and sandstone target, a projectile size of 2.5 mm and impact velocity of 4.5 km/s. Fig. 1 shows the setup of the impact experiment block.

2.1 Experimental analysis

We used special AE transducers attached to the impacted target block in each direction at different distances from the impact point as seen in Fig. 1b. The elastic waves and the arrival of the first wave signal can be recorded and analyzed with respect to their origin. Additionally we used ultrasound tomography (US) to determine wave velocities before and after the impact experiment. We also applied pressure gauges, developed and manufactured at Fraunhofer EMI, that were placed in different depths. These additional gauges have also been calibrated to calculate mechanical stresses from voltage signals (data analysis in progress) and, thus, allow for recording the signal attenuation with distance.

2.2 Numerical modelling

For the numerical models we used the multi-material, multi-rheology hydrocode iSALE [e.g. 6] coupled with ANEOS [7] for quartzite [8]. To simulate an impact into a porous material (sandstone) we combined the ANEOS with the ε-α compaction model [6, 9]. As the wave velocity depends on porosity, which changes dynamically due to shock induced crushing of pore space, the model takes into account a linear dependency of wave velocity on porosity [9]. We determined by US measurements an elastic wave velocity for nonporous quartzite of 5000 m/s and for porous sandstone of 2800 m/s. We approximated the experimental setup in the simulations by a cylindrically symmetric geometry of the target (Fig.1c). Accordingly, the location of the sensors had to deviate from the actual location in the experiment (rectangular block) to keep the distances to the impact point the same. We recorded thermo-dynamic and mechanical parameters as a function of time.

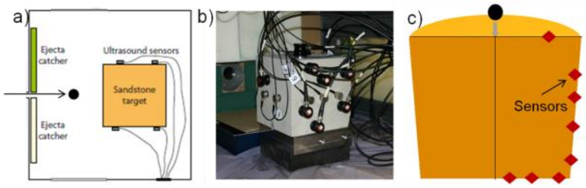

Fig. 1: a) Simplified schematic overview of the impact experiment b) Setup of the sandstone target with attached sensors for acoustic emission. c) Numerical setup of the target block with sensors.

3. Results

First-arrival-times of impact-induced waves picked from time-series recorded at experiments and numerical models with a quartzite and a sandstone target are plotted versus distance in Fig. 2. We obtained a wave velocity of about 5090 m/s experimentally and 4900 m/s numerically for the quartzite target (Fig. 2). For the sandstone target the velocity is 2900 m/s in the experiment and 2700 m/s in the numerical model (Fig.2). The pressure gauges yielded a velocity of about 2900 m/s. The dynamic measurements are all in excess of the US velocity measured before the experiment of 5000m/s (quartzite) and 2800 m/s (sandstone). Generally, we find a good agreement at different sensors between numerical models and experimental data in terms of the arrival time and signal phase. We estimated the seismic efficiency k of $2 \cdot 10^{-2}$ for quartzite and of $3 \cdot 10^{-4}$ for sandstone using the expressions in [2,4]. The seismic efficiency is significantly smaller for porous targets and thus less seismic energy is induced.

3. Discussion

We demonstrate that is in general possible to use acoustic emission technique to record the seismic signal during laboratory impact experiments. The dynamically obtained results (AE, pressure gauges and numerical model) verify static ultrasound measurements obtained before the impact event. The experimentally determined propagation speed of the seismic signal during impact events agrees well with numerical models for quartzite and sandstone targets. The propagation velocity of the elastic wave is reduced in porous material. Thus experiments on the laboratory scale enable a good validation and calibration of numerical models against experimental observations. The determination of the pressure amplitude using especially developed sensors will additionally be used to calibrate our material models. Rigorously tested materials models will enable to quantify the seismic efficiency of meteorite impacts by numerical models in targets with different properties. The present results are generally consistent with estimates from the literature. However, further improvements will allow for a much more accurate determination of seismic shaking generated by meteorite impact.

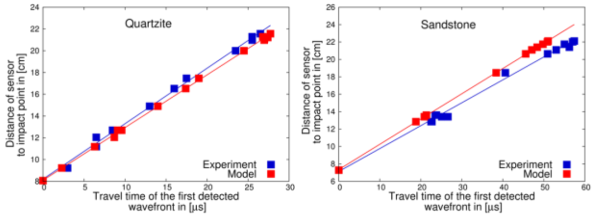

Fig. 2: Linear propagation of the elastic wave front for the experiment and the model. The plot shows the distances of different sensors versus first arrival time. The average wave velocity is measured to be around 5090 m/s (experiment) and 4900 m/s (model) for quartzite (**left**) and 2700 m/sec (experiment) and 2900 m/s (model) for sandstone (**right**).

Acknowledgements

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