IN SITU MEASUREMENTS OF IMPACT-INDUCED PRESSURE WAVES IN SANDSTONE TARGETS.
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Introduction: We present a promising method for the measurement of impact-induced pressure waves within porous solid target materials. Pressure amplitudes at different distances to the impact site give information about the decay behavior of the wave while it propagates through the target. Furthermore, these amplitudes show if the Hugoniot-elastic-limit (HEL) of the target material is exceeded at the position of measurement. In addition, the wave speed can be determined by means of the different arrival times. Moreover, the measured amplitudes and first onsets at the sensor positions can be used to calibrate numerical simulations. Measuring pressures within porous rocks is challenging and often associated with uncertainties due to the inherent inhomogeneity of the material. The sensor can be destroyed during the passage of the wave. For this reason carbon composition resistors are an appropriate tool because they are inexpensive and simple to handle. They were first used for pressure measurements by [1]. Recently, these gauges were used to measure pressure amplitudes of explosions in concrete [2]. However, this method has been applied only once to hypervelocity impacts on geologic materials [3]. In the present study the gauges were used in a hypervelocity impact experiment on porous sandstone.

Sensor description: The gauges were developed and manufactured at Fraunhofer EMI. The measurement principle is based on a change of the electrical resistance if the resistor undergoes mechanical loading during the passage of an impact-induced strong pressure wave. The carbon composition resistor is embedded in resin which leads to a uniform load transmission and prevents a punctual load caused by individual grains of the surrounding material.

The pressure gauges were recently calibrated by means of a Split-Hopkinson Pressure Bar (SHPB) to calculate mechanical stresses from voltage signals. The data are currently being analyzed. The sensor was embedded in a concrete cylinder which was fixed to an aluminum bar. A stress wave was created which propagated through the cylindrical bar and finally entered the concrete specimen so that the sensor was exposed to dynamic load. Mechanical stress and the particle velocity in the specimen were determined by means of strain gauges and an acceleration sensor, respectively.

Experiment: The impact experiment was conducted in the framework of the MEMIN research project [4, 5] at the extra-large light-gas gun (XLLGG) at Fraunhofer EMI in Efringen-Kirchen, Germany [6]. A 12 mm steel projectile made of alloyed steel D290-1 weighing 7.336 g was accelerated to a velocity of about 4.7 km/s and impacted into a large Seeberger Sandstone block with edge lengths of 80 x 80 x 50 cm. The impact was perpendicular to the layering of the sandstone. Before the installation of the sensors, boreholes were drilled into the rear surface of the sandstone. Fast-hardening cement was used to fix the sensors in the specific depths and to keep the impedance mismatch small. The sensors were placed at three different radial distances to the impact site: 250 mm, 350 mm and 450 mm (Figures 1 and 2).

Figure 1. Rear surface of the sandstone target with mounted pressure gauges.

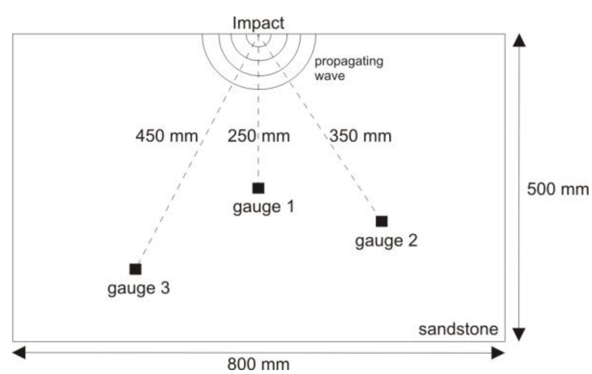

Figure 2. Sensor positions within the target.

Preliminary Results: Three voltage signals recorded by the pressure gauges are shown in Figure 3. The signal amplitude decreases, as expected, with increasing distance to the impact site due to geometric spreading, scattering and reflections within the target material. It is important to note that in the far field, where the measurements were conducted, probably no inelastic processes like pore crushing occur. The signals have very short rise times of several microseconds. The time differences between the impact and the first onsets at the sensors were used to determine the wave speed. Three different wave speeds were calculated: v_1 = 2796 ± 25 m/s, v_2 = 2907 ± 17 m/s and v_3 = 3012 ± 13 m/s.

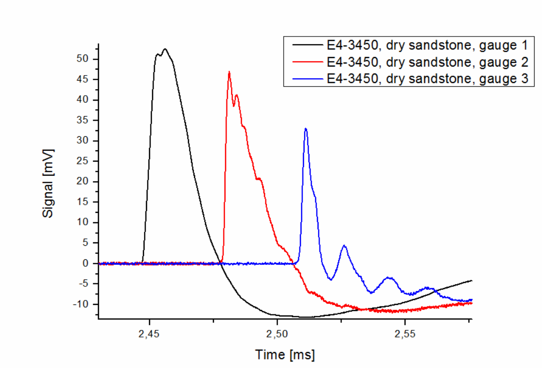

Figure 3. Three voltage signals recorded by the pressure gauges as a function of time for an impact on dry sandstone (Exp.# E4-3450). Amplitudes decrease with increasing distance to the impact point.

Discussion: The wave speeds roughly correspond to the value of 2915 m/s measured by [7] for Seeberger Sandstone. However, our data show an increase of the wave speed with increasing travel path. An explanation for this might be the stratification of the sandstone which leads to an anisotropic wave propagation. Waves which propagate in the direction of the layers are faster than waves propagating perpendicular to the layering. For gauge 1 the travel path is completely perpendicular to the stratification whereas for gauge 2 and 3 the travel path is both parallel and perpendicular to the stratification of the sandstone.

Outlook: Our results show that it is possible to detect impact-induced pressure waves within the target material by using carbon composition resistors. The calibration will lead to pressure history data at different sensor positions which give information about the peak amplitudes and the decay behavior of the wave within the target subsurface.

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