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Experimental impacts into sandstone – observations on crater and ejecta formation

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1. Introduction

We report on a recent set of impact cratering experiments on sandstone that are part of the MEMIN research project and have been performed at the two-stage acceleration facility of the Ernst-Mach-Institut in Freiburg, Germany. These experiments were carried out (i) to observe and quantify the ejection process with high-speed cameras, (ii) to test different catchment assemblies to collect fragments in a defined manner, (iii) and to employ ultrasound sensor systems to record pressure waves in the target during and after the experiment.

2. Experimental setup

In the campaign, 2.5 mm diameter projectiles weighing 67 mg and made of the alloyed heat treatable steel D290-1 were accelerated horizontally to ~5 kms^{-1}. Pressure in the target chamber was 100 mbar. Each projectile impacted vertically onto the flat surface of a sandstone cube of 20 cm edge length. We used a fine-grained variety of the porous "Seeberger Sandstein" [1]. The cubes were equipped with two sets of multichannel ultrasound sensors for three-dimensional in-situ measurement of the passage of the shock wave through the target and real-time dynamic fracture growth. The impact and ejecta processes were monitored with two high speed cameras at 10^5 fps and $5*10^5$ fps.

The ejecta was captured with specific catchers positioned parallel to the target surface at ~25 cm distance. Different materials were tested for their capability to capture the very fine-grained high-speed ejecta: They included foam rubber, gelatin, viscous silicone, Vaseline and a phenolic foam (used for flower arrangement). The best capture results were achieved with Vaseline and phenolic foam.

3. Preliminary results

Craters 5-6 cm in diameter were formed (Fig. 1) that showed crushed sandstone grains in the central region of the crater surrounded by a rather large area of spallation. Cm-sized spall fragments were found after the experiments. The sandstone blocks were weighed before and after the experiments to determine the mass of material displaced from the crater and thus determine the cratering efficiency π_v. Results show that π_v is reduced by ~23% when the projectile impacts parallel to target layering (π_v=254) as opposed to perpendicular to target layering (π_v=328), which most likely reflects the reduction of the spallation process. Cratering efficiency is also lower compared to the MEMIN pilot experiment (π_v =419), in which a 10 mm diameter steel sphere weighing 4.1 g struck dry Seeberger sandstone at 5.3 kms^{-1} [1].

Frames taken from one of the high-speed videos (Fig. 2) show several stages of ejecta development. In the first frame, taken at ~20 µs after impact, the development of an initial ejecta cone with high-speed ejecta can be seen. Additionally, the fireball is visible as an orange flash at the top of the cone. ~1 ms after the impact, a ring vortex has developed outside the advancing curtain. The vortex is most likely due to recovery winds caused by reduced pressures behind the advancing ejecta curtain away from the point of impact perpendicular to the target surface, i.e. "upwards", as opposed to parallel to the surface ("outwards") as is expected for a ballistically advancing ejecta curtain. The fine particle fraction then becomes entrained in this vortex, as proposed by [2]. Towards the base, the ejecta is pinched off and is followed by a cloud of more dense and lower velocity target material. The pinched off shape of the ejecta at this stage may be a result of the vortex, or a result of a further low-pressure zone that formed in the wake of the projectile.

A qualitative analysis of the ejecta catchers shows that fine, high-speed particles can be found distributed radially, corresponding to ejection angles >40° from the target surface (Fig. 2), while the majority of the mass of captured material is concentrated within a 5 cm radius in the center of the catchers, consisting of fine to coarse particles and spall fragments.

It should be noted that the observation of ejecta formation in these experiments differs from results obtained by [2], who performed impact experiments into particulate targets at varying atmospheric pressures. In their experiments, the vortices caused by recovery winds were located inside the ejecta curtain as a result of the curtain advancing outwards, as opposed to upwards in the current experiments. Also, their observation of a “bulb” protruding outward at the base of the curtain is contrasted by our observations of a “pinched-off neck”.

Acknowledgements

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References

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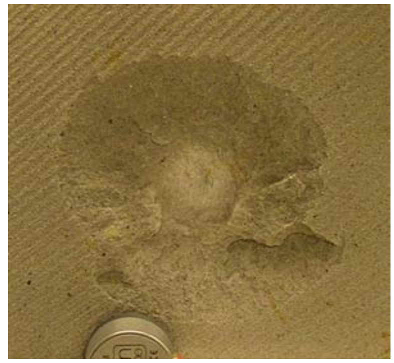

Figure 1: Experimental crater in sandstone target. Image is ~8 cm wide.

Figure 2: Two stages of the ejection process imaged at 20 and 1000 µs after impact.