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Experimental Investigation of the Formation of Complex Craters

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Abstract

The formation of complex impact craters is still poorly understood, because standard material models fail to explain the gravity-driven collapse at the observed size-range of a bowl-shaped transient crater into a flat-floored crater structure with a central peak or ring and terraced rim. To explain such a collapse the so-called Acoustic Fluidization (AF) model has been proposed [1]. The AF assumes that heavily fractured target rocks surrounding the transient crater are temporarily softened by an acoustic field in the wake of an expanding shock wave generated upon impact. The AF has been successfully employed in numerous modeling studies of complex crater formation [2, 3]; however, there is no clear relationship between model parameters and observables. In this study, we present preliminary results of laboratory experiments aiming at relating the AF parameters to observables such as the grain size, average wave length of the acoustic field and its decay time τ relative to the crater formation time.

1. Introduction

Impact craters have shaped the surfaces of planetary bodies since the formation of the Solar System, and the peculiarity of the process leading to their formation (high amount of energy release within a short time) makes them a natural tool to probe the interior of planetary bodies and reveal changes in density, strength, water content, porosity, composition, etc.

The initial transitional cavity resulting from shock-induced excavation flow (the so-called transient crater) is unstable in the given gravity field and undergoes modification (e.g. [4]). The subsequent collapse, which determines the final crater morphology, depends on the gravity field and target properties such as strength, composition, and layering, in addition to the crater size. When the crater diameter is larger than some critical threshold diameter D_{sc} that varies among planets with different surface gravities (e.g., D_{sc}~3-5 km on the Earth, ~15 km on the Moon, ~3-10 km on Mars, and ~10 km on Mercury), the transient cavity undergoes a distinct modification process, which includes uplift of the crater floor and underlying strata to form central peaks or peak rings, and failure of the rim into wide zones of stepped terraces. Such a collapse requires a stress field in excess of the failure strength of rocks to allow for plastic material flow.

1.1 Acoustic Fluidization

One current model invoked to explain such a collapse is the so-called Acoustic Fluidization (AF) model [1], which relies on the temporary softening of heavily fractured target rocks by means of an acoustic field in the wake of an expanding shock wave generated upon impact. The AF model assumes that the overburden pressure in heavily fractured material at some depth in the vicinity of the crater fluctuates due to high-pressure amplitude, high-frequency, random acoustic waves that exist in the wake of the expanding shock front. In the phase of temporary relieve of the overburden pressure the frictional resistance between fragments is reduced so that the fragments may easily shear against one another.

The Block Model (BM) [5] is a simplification of AF model that has been implemented in the iSALE shock physics code (http://www.isale-code.de). BM is described by two parameters: the kinematic viscosity of the fluidized region η, and the decay time of the block vibrations τ [5]. Theory suggests that both the viscosity η and the decay time τ are functions of the density ρ, block size h of the fragmented sub-crater rock mass, and period T of the block oscillation. In turn it has been suggested [5] that the block length parameter *h* can be scaled by a quantity describing the transient cavity depth.

This study aims at a better understanding of the mechanics of complex crater formation, by (i) constraining BM parameters in relation to crater observables, (ii) improving the BM implementation into iSALE, and (iii) on coupling the BM with fragmentation models describing how intact rocks are turned into fragments, whose size varies according to the distance from the impact point. Here we present preliminary results of a series of laboratory experiments, where we tested the development of the complex morphology in acoustically excited granular targets.

2. Method

The laboratory setup is designed to study the whole impact process, including the fluidization of the target material causing mass movements into the cavity. The impact experiments we conducted with a 6.35 mm spring-driven air gun mounted perpendicular to the target surface, which accelerates plastic (density=1.4 g/cm3) projectiles to velocities as high as 180 m/s. The experiments were equipped with headlights and two LaVision Imager sCMOS cameras. The target is a box of fine-grained material, which is fluidized by acoustic vibrations through an external artificial source (speaker system). In fact, the natural generation of acoustic noise behind the shock wave is not possible due to the scale of the experiment, where the fluidization time is short relative to the time of crater collapse.

3. Results

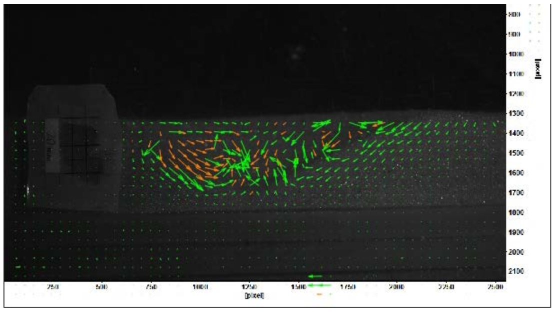

Figure 1: Particle displacement analysis for the shot of a plastic 6.35 mm projectile into a 420-840 µm glass beads target fluidized with frequency of 100 Hz.

We perform a systematic number of shots while varying the target grain size (~100-800 µm), and the frequency of the acoustic wave (50-500 Hz). The wavelength of the external acoustic wave is modulated to match the size of the particles. Particle displacements and strain of the collapse are analyzed through the Matlab tool “PIVlab” [6, 7, 8]. Figure 1 shows a cross section of the final stage of crater formation of a shot on a quarter space setup geometry, where the target is composed of glass beads (420-840 µm). The frequency of the acoustic field was set to 100 Hz.

4. Summary and Conclusions

We observe that the highest fluidization of the target material is achieved for low frequencies (100-200 Hz). A subtle displacement of grains at the crater floor can be observed, but no central peak arises. In the next shot campaign, we will investigate the influence of the wave amplitude for the development of the central peak.

Acknowledgements

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