EPSC Abstracts
Vol. 12, EPSC2018-96, 2018
European Planetary Science Congress 2018
© Author(s) 2018

Experimental Investigation of the Formation of Complex Craters

E. Martellato (1), K. Wünnemann (1,2), M.A. Dörfler (3), B. Schuster (3), and T. Kenkmann (3)
(1) Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Berlin, Germany, (2) Institute of Geological Sciences, Freie Universität, Berlin, Germany, (3) Institute of Earth and Environmental Sciences, Geology, Albert-Ludwigs-University Freiburg, Germany (email: elena.martellato@mfn.berlin)

Abstract

Complex crater formation is a poorly understood mechanism 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. One of the suggested mechanisms, the Acoustic Fluidization (AF) model [1], assumes that heavily fractured 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 a number of studies of complex crater formation [2, 3], however, there is no clear relationship between model parameters and observables. In this study, we present 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

A hypervelocity impact [4] relies on the collision of a cosmic body with a planetary surface. The initial cavity resulting from shock-induced excavation flow (the so-called transient crater) is unstable in the given gravity field and undergoes modification. The subsequent collapse 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} characteristic of a planet (e.g., D_{sc}~15 km on the Moon), 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]. It is based on the assumption that the target is heavily fractured and described by a time-varying Bingham fluid. The system of rock debris (constant block size) is excited by acoustic waves in the wake of an expanding shock wave generated upon impact. The overburden pressure in heavily fractured material at some depth in the vicinity of the crater fluctuates due to the high-pressure amplitude, high-frequency, random acoustic waves. 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 coupling the BM parameters in relation to observables. Here, we present preliminary results of a series of analogue laboratory experiments, where we tested the material properties of acoustically excited granular targets, and the development of the complex morphology.

2. Method

The fluidization of the target was induced by an external artificial source, since the natural generation of acoustic noise behind the shock wave is not possible at small scales, where the fluidization time is short relative to the time of crater collapse. Two different devices were adopted to test material fluidization. In the first experimental setup (at the Institut für Geo- und Umweltnaturwissenschaften, Albert-Ludwigs-Universität Freiburg), the device was a subwoofer coupled to the bottom of the target, see also [6]. The target was a box of fine-grained material placed on top of two supports. Part of the setup was: (i) a 6.35 *mm* spring-driven air gun mounted perpendicular to the target surface accelerating plastic (density=1.4 g/cm^3) projectiles to velocities as high as 180.4±3.73 *m/s*; (ii) headlights, and (iii) two LaVision Imager sCMOS cameras.

In the second experimental setup (at the Museum für Naturkunde Berlin), the external device was an electro dynamical exciter for stimulating bending waves on plates and was attached to the bottom of the target. The target was cylinder of fine-grained material, which was suspended and attached to a tripod through a system of springs. This system was designed in order to increase the number of degree of freedom of the material movement caused by the external source. A viscosimeter (rotational viscosimeter PCE-RVI 2, V1-R) was used to measure the variation of the viscosity as a function of frequency and amplitude.

3. Results

In the first setup configuration, we conducted a 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 analysed through the Matlab tool "PIVlab" [7, 8, 9]. 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 (150-250 μm).

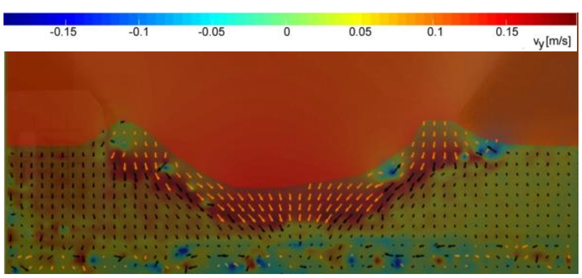

Figure 1: Particle displacement analysis for the shot of a plastic 6.35 *mm* projectile into a 150-250 μm glass beads target fluidized with frequency of 100 *Hz*.

In the second setup configuration, we performed a systematic measurement of the target material viscosity, varying systematically and independently frequency (Figure 2) and amplitude of the induced acoustic field, as well as the fine-grained material type (quartzsand: 100-500 μm; glass beads: 90-150 μm). The viscosity is the average of 5 minutes of acquisition. The curve trends of the two target materials have a minimum at ~ 60-100 *Hz*.

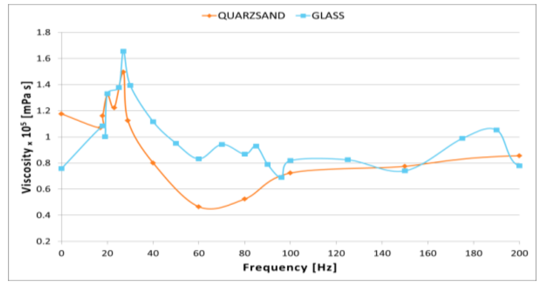

Figure 2: Comparison of the viscosity as a function of frequency of the external source, for quartzsand and glass beads. An amplitude of 2.3 V was used for the systematic frequency variation.

4. Summary and Conclusions

We observe that the highest fluidization of the target material is achieved for low frequencies (100-200 *Hz*) in both experimental setups. The frequency range is in accordance with [6]. They found that 80 *Hz* was the most effective frequency in fluidizing glass target material. So far, no central peak was observed in shot experiments. The next shot campaign will be carried out with the second experimental setup.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 709122.

References

[1] Melosh, H.J.: Journal of Geophysical Research, Vol. 84, pp. 7513-7520, 1979.
[2] Bray, V.J. et al.: Meteoritics & Planetary Science, Vol. 43, pp. 1979-1992, 2008.
[3] Collins, G.S. et al.: Meteoritics & Planetary Science, Vol. 43, pp. 1955-1977, 2008.
[4] Melosh, H.J.: Impact Cratering: a geological process, Oxford Univ., 1989.
[5] Wünnemann, K. and Ivanov, B.A.: Planetary and Space Science, Vol. 51, pp. 831-845, 2003.
[6] Dörfler, M. and Kenkmann, T. 49th LPSC, abstract #1484, 2018.
[7] Thielicke, W. and Stamhuis, E.J.: Journal of Open Research Software, Vol. 2, pp. e3, 2014.
[8] Thielicke W. and Stamhuis EJ.: PIVlab-Time-Resolved Digital Particle Image Velocimetry Tool for MATLAB, Figshare, 2014.
[9] Thielicke, W.: The Flapping Flight of Birds - Analysis and Application. PhD Thesis, 2014.