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HYPERVELOCITY IMPACT ON PUMICE: SCALE EFFECTS ON EXPERIMENTS AND SIMULATIONS

Sidney Chocron[a]*, James D. Walker[a], Donald J. Grosch[a], Alexander J. Carpenter[a], Daniel D. Durda[b], Kevin R. Housen[c]

[a]*Engineering Dynamics Department, Southwest Research Institute, 6220 Culebra Rd. San Antonio, TX 78238, U.S.A.*
[b]*Space Studies Department, Southwest Research Institute, Boulder, CO 80302, U.S.A.*
[c]*Aeronautics and Astronautics, University of Washington, Seattle WA 98195, U.S.A.*

Abstract

Hypervelocity tests with aluminum spheres of 1 and 1.75 inch (2.54 and 4.45 cm)-diameter impacting pumice boulders at 2.1 km/s have been performed at Southwest Research Institute. The results and analysis of the impacts are the main objective of a companion paper, while this work focuses on finding the material properties of the pumice and the computer simulations of the impact. The pumice material was tested in compression both unconfined and confined. The crush-up curve was implemented in a foam model in CTH and in the Holmquist-Johnson concrete model in EPIC. Results of the simulations like depth of penetration, crater diameter, and momentum enhancement are compared with the tests. It is found that these simple models provide reasonable results for crater depth and diameter but more work needs to be performed to properly predict the momentum enhancement, i.e. the ejecta from the pumice target.

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1. Introduction

The deflection of asteroids and comet nuclei that may be on a collision course with the Earth has been the concern of NASA and U.S. congress for some years [1]. Many deflection techniques have been presented in the literature: gravity tractor [2], conventional explosives [3], nuclear explosives [4], and kinetic hypervelocity impactors among others. For hypervelocity impactors, the momentum imparted to the object has been shown to depend on the shape, the impactor material, and the size, see for example [5]. Lately the authors have been studying the momentum enhancement, i.e. the additional momentum imparted to the target because of the material ejected by the target upon impact. Walker et al. [6] measured in granite impacted by aluminum spheres a momentum enhancement of 2.2. One question that arises is if this large number for the momentum enhancement is also valid for porous objects. Pätzold et al. [7]

* Corresponding author. Tel.: +1-210-522-3698 ; fax: +1-210-522-6290 .
E-mail address: Sidney.chocron@swri.org

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and A'Hearn et al. [8] have estimated, through gravitational and ejecta fallback techniques, the densities of comets 67P/Churyumov-Geramisenko and Temple 1 as 0.55 and 0.6 g/cm^3, respectively. I.e. the comets are very porous objects, and, consequently, momentum enhancement in porous objects is of relevance for the deflection problem.

Flynn et al. [9] performed impact experiments into pumice, which is a porous material that has densities similar to that observed in comets, with small 1/8 and ¼-inch aluminum spheres at velocities up to 5 km/s. They concluded that the mass of the crater ejecta was significantly lower for porous targets vs. non-porous because the craters form by compaction and not by excavation. The momentum enhancement value they found for these impacts was $\beta = \frac{p_t}{p_p} \sim 2.3$ where p_t is the momentum of the target after impact, and p_p the initial momentum of the projectile, which is actually similar to momentum enhancement seen for consolidated materials.

A companion paper in this conference presents the impact tests with larger aluminum spheres (1 and 1.75 inch diameter) on pumice boulders. The main objective of this paper is presenting the material crush-up curve for pumice, obtained by testing the material under confined and unconfined compression. The paper briefly summarizes the impact results and, using the crush-up curve, simulations with CTH and EPIC are performed. Comparisons between tests and simulations for depth of penetration, crater diameter, and momentum enhancement are provided.

2. Material and Methods

The material used for this project is natural Featherock^{TM} pumice boulders, of the silver-gray variety. See featherock.com catalog for more details. The rock was supplied by Keller Material Ltd. (9388 Corporate Dr., San Antonio, TX 78514). Because of the nature of the rock and the fact that it is very porous and hygroscopic, some variability on the density and properties of the rock is expected.

2.1. Pumice Compression Tests

Table 1 shows the geometry, weight, and density of the six small cylindrical specimens tested in compression with an MTS universal testing machine. Note that there is as much as a 50% difference in density from specimen UP-01 to CP-05, which may be due to the rock structure or difference in water content. The density of a cubic specimen (5.9 inch or 15 cm side) that stayed indoors for many months was measured before and after exposing the specimen to heat for four hours at 100 C in an oven. The difference in weight before and after being in the oven was only 2.4 g (dry weight 2473.6 g) so specimens kept indoor seem to accumulate a negligible amount of water.

Six small cylindrical specimens were compressed with and without confinement to obtain the pressure vs. density curve, see Figure 1. All the tests except for the first two had load and unload cycles to capture the onset of permanent deformation as well as the full crush-up density and pressure. The metallic ring used for the confined tests was thick (0.5 inch, 12.7 mm) so it can be assumed to be rigid during the tests. The longitudinal displacement of the piston was measured with a clip gage that was placed on the steel plates used to compress the specimens.

Table 1. Material specimens used during the compression tests.

Specimen #	Weight (g)	Initial length (in)	Initial Diameter (in)	Initial Density (g/cm^3)	Test Type
UP-01	10.6	0.81	1.49	0.46	Unconfined
CP-02	11.6	0.82	1.48	0.50	Confined
UP-03	18.2	0.87	1.49	0.74	Unconfined
CP-04	17.6	0.86	1.48	0.73	Confined
CP-05	17.1	0.84	1.49	0.72	Confined
CP-06	15.6	0.87	1.51	0.62	Confined