Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 204 (2017) 146–153

Procedia Engineering

www.elsevier.com/locate/procedia

14th Hypervelocity Impact Symposium 2017, HVIS2017, 24-28 April 2017, Canterbury, Kent, UK

Hypervelocity impact cratering of chondritic meteorites: Implications for asteroid recoil

G. J. Flynn[a*], D. D. Durda[b], E. B. Patmore[c], S. J. Jack[c], M. J. Molesky[c], B. A. May[c], M. M. Strait[c], R. J. Macke[d]

a Dept. of Physics, SUNY-Plattsburgh, 101 Broad St., Plattsburgh, New York, 12901 USA
b Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder CO 80302 USA
c Alma College, Alma, MI 48801 USA
d Vatican Observatory, V-00120 Vatican City

Abstract

Porosities of asteroids range from 0 to >50%, with most >20%. Meteorites, which sample asteroids, have a similar range. Since porous targets react differently to hypervelocity cratering than non-porous targets, it is critical to measure the response of asteroid samples to impacts. We impacted 5 samples of the CV3 carbonaceous chondrite Northwest Africa (NWA) 4502 with a mean porosity of 2.1%, 7 samples of the ordinary chondrite NWA 869 with a mean porosity of 6.4%, and 1 sample of the ordinary chondrite Saratov with a porosity of 15.6%. Each meteorite was impacted by a 1/16" Al-sphere shot at 4.34 to 5.89 km/s at the NASA Ames Vertical Gun. Using high-speed video images we measured the recoil speed of each target and determined the momentum multiplication factor (β), the ratio between the recoil momentum of the target and the momentum of the impactor. β decreased with increasing porosity, consistent with hydrocode modeling. However, the β values are larger, with β = 3.37 for NWA 4502, 2.70 for NWA 869, and 1.49 for Saratov, than results from hydrocode modeling for 5 km/s impacts into porous rock targets. Even the most porous meteorite we impacted had substantial momentum enhancement from crater ejecta. This should be considered in design of kinetic impact missions and modeling alteration of asteroid orbits by collisions.

Peer-review under responsibility of the scientific committee of the 14th Hypervelocity Impact Symposium 2017.

Keywords: hypervelocity cratering; meteorites; asteroids; kinetic impact deflection

*Corresponding author. Tel.: +1-518-564-3163; fax: +1-518-564-2349.
E-mail address: george.flynn@plattsburgh.edu

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 14th Hypervelocity Impact Symposium 2017.
10.1016/j.proeng.2017.09.767

1. Introduction

The physical properties of asteroids are important to the understanding of the change to their orbits resulting from natural or human-induced collisions. Porosities inferred for nearly two dozen asteroids range from nearly zero to >50%, with most having porosities >20% and with a mean porosity of ~30% [1]. Comets have even higher porosities. Rosetta spacecraft measurements show a porosity of 70 to 75% for comet Churyumov-Gerasimenko [2].

Porous targets react differently to hypervelocity impact cratering and disruption than non-porous targets. Impact experiments by Love et al. [3] determined that increased target porosity leads to deeper crater penetration, lower spall velocities, and greater localization of the impact damage. Experiments by Michikami et al. [4] showed that the average velocity of crater ejecta decreases with decreasing material strength and with increasing target porosity. Nonetheless, much of the modeling of asteroid response to hypervelocity impacts uses the physical properties of compact terrestrial rocks, which is likely to introduce significant uncertainty in the outcome.

Meteorites, which sample the asteroids, have a similar range of porosities, ranging from nearly zero to >40% [5]. However, the physical properties vary significantly from one to another type of meteorite, and even from one to another sample of the same meteorite [6]. We have begun a series of hypervelocity impact cratering and disruption experiments, each focusing on a several samples of the same meteorite, and covering a wide range of porosities.

The ordinary chondrite meteorites, believed to sample the most common type of asteroid in the inner half of the main belt, based on reflectance spectra, have a mean porosity of 9% [5]. The dry and the wet carbonaeous chondrite meteorites, believed to sample the most common type of asteroid in the outer half of the main belt, have porosities of 14% and 25 to 35% respectively [5]. When compared by spectral type, asteroids have a higher mean porosity than the corresponding meteorites, suggesting the presence of macro-porosity in the asteroids in addition to the micro-porosity in the related meteorites. The Near Earth Asteroid (NEO) population includes objects similar to both ordinary and carbonaceous meteorites as well as achondrites, a group of meteorites with lower mean porosity.

Whenever an asteroid is impacted, its orbital path is altered. The extent of this alteration is important for asteroid orbital evolution modeling and for attempts to deflect an asteroid on a collision course with the Earth using a kinetic impactor. Any attempt to understand the response of the stoney asteroids to collisions requires measurements on a variety of types of stone meteorites.

2. Momentum transfer by crater ejecta

The momentum change of an asteroid in response to an impact cratering event has two components: 1) the direct transfer of momentum by the impacting projectile, and, 2) the recoil of the asteroid in response to the crater ejecta, which is directed in the half-plane away from the surface of the asteroid. The total momentum gain of the target is characterized by the momentum multiplication factor, β, given by:

$$\beta = (m_p v_p + p_e)/m_p v_p = M_t V_t / m_p v_p \qquad \text{(Equation 1)}$$

where m_p is the mass of the projectile, v_p is the speed of the projectile, p_e is the magnitude of the momentum of the crater ejecta opposite the recoil direction, M_t is the mass of the target, and V_t is the change in the speed of the target due to the impact. If the only contribution to the momentum gain is the direct transfer by capture of the projectile, then β is equal to 1. Any momentum transfer due to the crater ejecta increases the β value.

Although not intended as a deflection mission, NASA's Deep Impact spacecraft was the first kinetic impactor onto an asteroid or comet, impacting comet Tempel 1 with a 370 kg projectile at 10.2 km/s. The spacecraft observed abundant crater ejecta, but the $2x10^{10}$ J impactor kinetic energy was insufficient to produce an observable deflection.

2.1 Importance of β

Kinetic impactor deflection of an asteroid on a collision course with Earth was described in a 2007 NASA Report to Congress as "the most mature approach and could be used in some deflection/mitigation scenarios, especially for