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Experimental hypervelocity impacts: Implication for the analysis of material retrieved after exposure to space environment Part I. Impacts on aluminium targets

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ABSTRACT

During the last three decades a wide variety of surfaces have been brought back to Earth after being exposed to space environment. The impact features found on these surfaces are used to evaluate the damages caused to spacecraft and can give clues to the characteristics of the orbital debris and meteoroids that created them. In order to derive more precisely the particle parameters and to improve the analysis of projectile remnants, we have performed an extensive analysis of craters caused by the impact of high velocity particles on thick ductile targets, using a micro-particle accelerator. We show that from the geometry of the craters and from the analysis of the remnants it is possible to derive the main characteristics of the projectiles. In particular, using up-to-date instrumentation, scanning electron microscope (SEM) and Energy Dispersive X-ray (EDX) spectrometer, we found that even small residues inside craters can be identified. However, this study shows that a velocity resolution better than 1 km/s would be appropriate to obtain a fair calibration of the impact processes on a ductile target. This would allow to decipher with precision impact features on ductile surfaces exposed to space environment.

1. Introduction

As is well known, space environment is hostile to spacecraft [1]. Threats come from all its components, in particular from micrometeoroids and space debris. It is therefore vital to understand the damage they can cause and to take adequate measures to design a spacecraft able to resist these damaging effects. Moreover, accurate debris and meteoroid flux models are crucial for the design of manned and unmanned space missions. For particle sizes smaller than a few millimetres, knowledge on the environment can only be gained by in-situ detectors. For many years, dedicated experiments designed to sample debris and meteoroids in low Earth orbits have been deployed in space, for instance on the Long Duration Exposure Facility (LDEF) and the MIR space station [2–4]. In addition to these particle detectors, a wealth of information was obtained from retrieved spacecraft hardware such as surfaces recovered from the Solar Max satellite in 1984, LDEF in 1990 [5], the large solar arrays panels of the Hubble Space Telescope (HST) [6–8], the MIR [9–11] space station and recently the International Space Station (ISS) [12]. These data not only give information on the meteoroid and debris environment but also provide a better knowledge of the hypervelocity impact phenomena on materials exposed to space [13–15]. However it is still

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difficult to derive with precision, from the analysis of impact features, the parameters of the projectiles and their possible origin. In the past, a great deal of laboratory impact simulations have been done using dust particles accelerators, but only few results have concerned the amount of projectile residues left over after impact [16–18]. At the best, residue analysis allowed to determine the projectile origin in only 70% of impact craters [7].

Samples from MIR and HST solar cells retrieved after more than 8 years of exposure to space environment showed a large number of oblique features, mainly for impacts smaller than 1 mm, because larger ones had seen their material ejected losing the evidence of ellipticity [19,20]. These craters are not uncommon, they represent more than one third of observed impacts smaller than 1 mm. So, the difficulty in interpreting this kind of impacts led to hypervelocity impact tests in laboratory. These tests were performed in order to find a possible link between the incidence angle of a projectile and the geometry of the resulting crater [21,22]. In addition, a larger amount of projectile residue is found in oblique craters compared to circular ones. Then impacts tests were used to find out a relationship between impact parameters and the amount of projectile residue left after the impact. The aim of this study is to refine criteria allowing an assessment of size, velocity and origin of a projectile from parameters which could be measured on the impact craters formed on aluminium targets.

We describe in the next section the experimental approach used. Section 3 presents the analysis of impact features while Section 4 is devoted to the analysis of the results. The discussion is presented in Section 5 and we conclude in Section 6.

2. Experimental approach

2.1. Acceleration of microparticles

One of the best, if not the only one, method to accelerate small particles to hypervelocities consists in the use of an electrostatic accelerator. The Max Planck Institute for Nuclear Physics in Heidelberg has been operating such a facility for many years [23,24]. It uses a potential of 2 million volts to accelerate small particles to velocities up to 20 km/s. The micron-sized (0.2 μm to 2.5 μm in diameter) conductive carbonyl-iron dust particles are stored in a dust reservoir. A high voltage applied to a tungsten electrode within the dust reservoir positively charges some of the particles. Then on leaving the charging system the particles are accelerated by a 2 MV potential difference provided by a Van De Graaf generator. The beam of dust produced in this manner can be focussed so that the particles strike a target within a circle of 1–2 mm radius. Before striking the target, particles pass through cylindrical capacitors, inducing a signal proportional to velocity and charge. So particles of given mass and velocity are measured and can be selected by a filter which deflects unwanted particles [25].

The velocity of a particle is given by

$$v = \left(\frac{2Vq}{m_p}\right)^{1/2} \quad (1)$$

where q is the charge of the particle (C), m_p is the mass of the particle (kg), V is the accelerating voltage (V), and v is the velocity of the particle (m/s).

It is not possible to identify a posteriori the crater caused on the target by a particle of a given size and velocity. Therefore we selected five velocity ranges (typically 2 km/s wide) and we allowed a large number of particles (500–1000) of different sizes within each velocity interval. Fig. 1 shows the typical velocity distribution of particles according to their size, as delivered by the accelerator. The target position was changed for each velocity interval. This procedure makes the analysis of the impact features somewhat difficult and requires a careful analysis in order to link projectile parameters to impact craters. More details are given later in Section 5.

2.2. Target material and size

The targets are 2 cm × 2 cm wide and 50 μm thick foils of pure (99.99%) aluminium. They can be considered thick when compared to the size of the projectiles (semi-infinite). In these conditions the side and rear walls play no

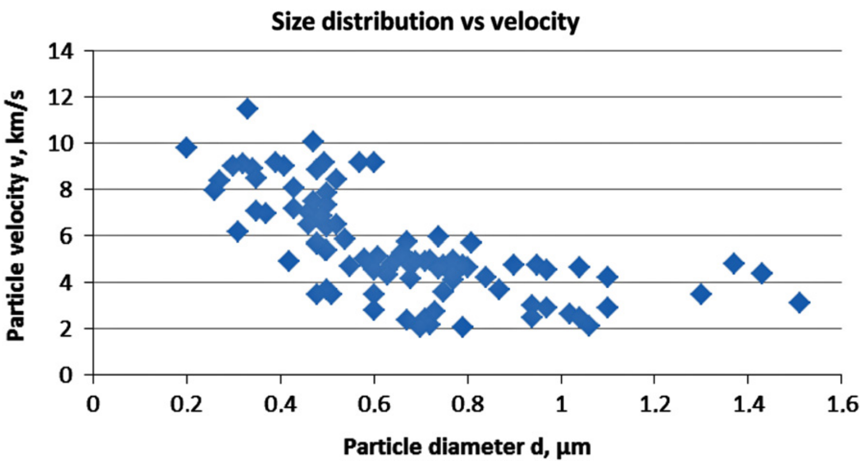

Fig. 1. Velocity distribution of particles as a function of their diameter given by the electrostatic accelerator.