HYPERVELOCITY IMPACT TESTS ON EJECTA
AND ITS INTERNATIONAL STABDARIZATION

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ABSTRACT

Although a large spacecraft such as the International Space Station and other artificial satellites are launched in the earth orbit thanks to the remarkable progress in the space development, their collisions with orbital debris are an increasing concern. To examine the impact protection performance of spacecraft against orbital debris, hypervelocity impact experiments using a two-stage light gas gun and so on are necessary. There has been an active facility cross calibration program between space agencies, where tests were performed using identical targets and test conditions for each pair of tests, to assure that the results were comparable. Six distinct facility cross calibration testing campaigns have been performed between NASA and gun ranges in Germany, Russia, Japan, France, China and Canada. The test conditions for individual campaigns were negotiated at different times, so the target configuration varied between different campaigns. Projectiles with a diameter of 1 mm were used to simulate orbital debris impacting a target at velocity of 5 km/s. Copper witness plates were used as witness plates to catch the secondary debris, namely ejecta, generated due to hypervelocity impacts. The size distributions of diameter of craters made by ejecta were measured on the witness plates, and they are compared one another among a solar array coupon, CFRP honeycomb and Aluminum honeycomb in this study.

INTRODUCTION

A spacecraft is exposed to the risk of collision with orbital debris during its orbit lifetime. It is thus necessary for reliable design of spacecraft to estimate the impact flux and impact velocity of orbital debris. Space agencies developed their own orbital debris environment models, for example ESA MASTER and NASA ORDEM, that can estimate debris flux as a function of the size, impact velocity, altitude, and inclination angle of the spacecraft’s orbit. However, calculation results are not always consistent with each other due to a lack of data on the orbital debris population. The discrepancy between the results is quite large for the debris flux calculation for 100 μm - 1 mm particles [Ref.1].
The main contributor to the 100 μm - 1 mm population is ejecta, which is secondary debris released from a spacecraft surface upon the hypervelocity impact of meteoroids or orbital debris [Ref. 2]. Collisions with particles of this size region are of great concern for the survivability of a satellite. Collision with debris larger than 100 μm causes damage to the satellite surface structure and collision with debris larger than 1 mm causes serious damage to the main parts of the satellite [Refs. 2-5]. The evaluation tests of ejecta, which are important for the reliable design of spacecraft, are carried out in various facilities [Refs. 6-7]. These experimental data can, however, not be directly compared because the experimental methodologies are different each other. The standardization of the experimental methodology for the ejecta evaluation is therefore required. Mandeville proposed a new working item (NWI) on a hypervelocity impact test procedure of ejecta at Working Group 6, Sub-Committee 14, Technical Committee 20, International Organization for Standardization (ISO/TC20/SC14/WG6) around 2006. At the 14th Orbital Debris Coordination Working Group (ODCWG) meeting at Berlin during 18-20 May 2009, it was agreed that hypervelocity impact tests on ejecta would be carried out at other impact facilities including Kyushu Institute of Technology (Kyutech). The impact test results done at Kyutech were quickly reported at the 15th ODCWG meeting at ESTEC during 4-5 November 2009. Current stage of this draft standard on the ejecta evaluation test procedure is that of Final Draft International Standard (FDIS).

This paper describes the experiments performed at Kyutech and the issues raised from Working Draft (WD) to FDIS stage are discussed in order to improve the proposal for international standardization.

EXPERIMENTAL CONDITIONS [Ref. 8]

The hypervelocity impact (HVI) tests were carried out using the Small Two-Stage Light Gas Gun (STLGG) installed at the Hypervelocity Impact Test Center, Laboratory of Spacecraft Environmental Interaction Engineering (La SEINE) at Kyutech as shown in Fig.1. The projectile was aluminum alloy (Al 2017) of 1 mm in diameter. The projectile placed in the sabot was accelerated in the launch tube of STLGG. The sabot was then separated in the sabot separation section. As a result, only one projectile impacted on the target. The impact velocity was up to about 5.0 km/s. The sabot separation section and the test chamber were partitioned by a polyester film, whose thickness is 25 μm, because the ambient pressure of sabot separation section was 7.0 kPa whereas the pressure in the test chamber was 10 Pa.
To imitate orbital debris, aluminum alloy spheres of 1 mm +/- 0.1 mm in diameter were used as projectiles. In the FDIS11227 A2017 or A2024 are recommended as projectiles. Here we used widely spread materials on-board of spacecraft, which are solar array coupons, CFRP/aluminum honeycomb, and aluminum honeycomb shown in Fig. 2., as targets for hypervelocity impact tests.

According to the FDIS11227, copper plates were used as witness plates to capture ejecta emitted in frontward and backward of the target as shown in Fig.3, where JIS H3100 C1100P-1/4H is recommended for material of the witness plate, and distance between the witness plates and the target is set to be between 50mm and 100mm. The witness plates were then analyzed to evaluate impact damage due to ejecta. A front witness plate has 30 mm hole at the center where a projectile will travel through. And in this experiments the distance between the target and the witness plates is fixed to be 100 mm.
EXPERIMENTAL RESULTS

Projectile mass, ejecta mass, and impact velocity in each experiment are shown in Table 1 where the impact velocity is measured by using laser cut method. The measured ejecta mass of the solar array coupons front surface is almost the same for tests 1 and 2. However, in the other experiments, the ejecta mass differs somewhat. The damage involved in the honeycombs depends on impact position of the projectile, which resulted in different ejecta masses. For targets with the honeycomb structure, it can also be said that not only the cell impacted by the projectile was damaged but also the adjoining cells. Moreover, when the ejecta mass from the three kinds of targets is compared, it clearly appears that the amount of ejecta emitted is the most important in the tests on the rear face of the solar array coupons. The solar array coupons tested consisted of cover glass as surface material, CFRP as back material, and aluminum honeycomb for the inside structure. Therefore, when the CFRP surface (solar array coupon rear face) is first impacted, the debris cloud propagates through the honeycomb structure to finally impact the brittle cover glass surface, which emits a large amount of ejecta. On the other hand, when the cover glass surface (solar array coupon front face) is impacted at first, the debris cloud is deflected with a smaller amount of ejecta. Finally, in the case of the tests using aluminum honeycomb structure as the target, it should be noted that the amount of ejecta is the smallest, which can be explained by both the ductility of aluminum and by reflection of ejecta limited in the honeycomb structure.

Table 1 Experimental conditions and results
Images of the witness plates were captured by a microscope, and the impact craters on the witness plates were detected using the image-processing software ImageJ as shown in Fig. 5, where background subtraction manner between the pre-pictures and the post-pictures was performed with digital correlation method. Finally the impact craters were detected from the binary images produced by Image J and Fig. 6 shows the number of detected impact craters for the tests 2, 4, 6, and 8. Fig. 7 shows the size distribution of the detected impact craters for the tests 2, 4, 6, and 8.

![Fig.5 Impact crater detection](image)
Fig. 6 Distribution of craters on witness plates

(a) Front witness plate  (1) Test 2
(b) Rear witness plate

(a) Front witness plate  (2) Test 4
(b) Rear witness plate
CONCLUSION

In this study, hypervelocity impact tests were conducted on spacecraft materials by using the small two-stage light gas gun of Kyushu Institute of Technology. Moreover, the automation of the experimental data evaluation method was successfully performed. The conclusions from this study are summarized below.

(1) Impact craters created by ejecta were successfully detected on the witness plates for all the experiments. This shows that experiments as defined by the FDIS11227 can be performed.
(2) A series of processing i.e., take pictures before and after experiments, carry out position compensation, subtraction and binarization of each image could be automated.
(3) The analysis time could be shortened when using the binary image to detect the impact craters.

ACKNOWLEDGMENTS

This study is partially supported by JAXA and IHI contracts, and this work was also supported by JSPS KAKENHI Grant Number 21560819 and 24360351. The authors appreciate their financial supports sincerely.
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