著者

Masuyama Shingo, Matsumoto Shie, Faure Pauline, Nakamoto Hiroshi, Akahoshi Yasuhiro, Koura Takao, Matsumoto Haruhisa, Kitazawa Yukihito

journal or publication title

Procedia Engineering

volume

58

page range

543-549

year

2012-09

URL

http://hdl.handle.net/10228/00007226

doi: info:doi/10.1016/j.proeng.2013.05.062
Feasibility of Standardized Ejecta Evaluation for Spacecraft Surface Materials

Shingo Masuyama¹, Shie Matsumoto¹, Pauline Faure¹, Hiroshi Nakamoto¹, Yasuhiro Akahoshi¹*, Takao Koura¹, Haruhisa Matsumoto², Yukihito Kitazawa³

¹Kyushu Institute of Technology, Sensui-cho 1-1, Tobata-ku, Kitakyushu, Fukuoka 804-8550, Japan
²JAXA, Tokyo, Japan
³IHI Corporation, Tokyo, Japan

Abstract

Although a large spacecraft such as the International Space Station and other artificial satellites are thriving in the space environment due to the remarkable progress in the space development sector, their collisions with space debris are a growing concern. To examine the impact proof performance of spacecraft to space debris, hypervelocity impact experiments using a two-stage light gas gun and so on are necessary. However, space debris impact experiments are conducted in different manners dependent on the countries and the facilities. Therefore direct comparisons of the experimental results among different facilities are often difficult from the same viewpoint. In this study, the authors aim at assessment of international standardization of the hypervelocity impact experiments procedure. Projectiles with a diameter of 1 mm were used to simulate space debris impacting a target at 5 km/s. Copper witness plates were used to catch the secondary debris, namely ejecta, generated during the experiments. 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.

© 2013 The Authors. Published by Elsevier Ltd. Selection and peer-review under responsibility of the Hypervelocity Impact Society.

Keywords: Space debris, Two-stage light gas gun, Ejecta, Hypervelocity impact

1. Introduction

A spacecraft is exposed to the risk of collision with space debris during its orbit lifetime. It is thus necessary for reliable design of spacecraft to estimate the impact flux and impact velocity of debris. Space agencies developed space 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 space debris population. The discrepancy between results is particularly noticeable for the debris flux calculation for particles ranging from 100 μm to 1 mm in diameter [1]. The main contributor to the 100 μm ~ 1 mm population is ejecta, which is secondary debris released from a spacecraft surface upon the impact at hypervelocity of meteoroids or space debris. 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 defence structure and collision with debris larger than 1 mm causes serious damage to the main parts of the satellite [2-5]. The evaluation tests

* Corresponding author. Tel.: +81-93-884-3177
E-mail address: akaho@mech.kyutech.ac.jp
of ejecta, which are important for the reliable design of spacecraft, are carried out in various facilities [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. The FDIS (Final Draft International Standard) 11227 for the ejecta evaluation test procedure is currently under discussion at the ISO (International Organization for Standardization). The FDIS11227 for the ejecta evaluation test procedure proposes the experiment calibration regarding the testing device features and regarding the material to be used for the ejecta evaluation.

This paper presents the experiments performed at the Kyushu Institute of Technology (Kyutech) that took into consideration the parameters defined in the FDIS11227 i.e., device features were set to correspond to the FDIS and materials used on a spacecraft were used as targets for the ejecta evaluation. Then, the issues raised from WD(Working Draft) to FDIS stage are discussed in order to improve the proposal for international standardization.

2. Experimental setup

2.1. Small two-stage light gas gun

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. The experimental setup is 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. The sabot then separated in the sabot separation section. As a result, only one projectile impacts on the target. The impact velocity reached about 5.0 km/s. The sabot separation section and the test chamber are partitioned by a polyester film, whose thickness is 25 μm. Based on clause 6 of FDIS11227, a total of four kinds of materials were used as targets. These materials were chosen because of their use on-board of spacecraft and were: synthetic fused silica, solar array coupons, Carbon Fibers Reinforced Plastic (CFRP)/aluminum honeycomb, and aluminum honeycomb. The ambient pressure of sabot separation section was 7.0 kPa whereas the pressure in the test chamber was 10 Pa.

![Test chamber and Two-stage light gas gun](image)

Fig. 1. Kyutech’s small two stage light gas gun.

2.2. Projectile

To imitate debris, aluminum alloy spheres of 1 mm +/- 0.1 mm in diameter were used as projectiles. In the FDIS11227 A2017 or A2024, A2017 are recommended as projectiles. A2017 was used as projectile in the tests because it was available. The projectile used in this study is shown in Fig. 2.

![Aluminum alloy (A2017)](image)

Fig. 2. Aluminum alloy (A2017).
2.3. Targets

Widely spread materials on-board of spacecraft were used as targets i.e., solar array coupons, CFRP/aluminum honeycomb, and aluminum honeycomb, which are shown in Fig. 3. The information for target materials and geometries are shown in Table 1.

![Fig. 3. Targets. (a) Solar array coupons, (b) CFRP/aluminum honeycomb, and (c) aluminum honeycomb.](image)

| Target | Solar array coupon | CFRP/aluminum honeycomb | Aluminum honeycomb |
|--------|--------------------|-------------------------|-------------------|
| Size [mm] | 76 × 205 × 26 | 100 × 150 × 25 | 100 × 150 × 25 |
| Mass [g] | 47.1 | 33.6 | 33.9 |
| Density [g/cm³] | 0.116 | 0.134 | 0.136 |
| Front sheet thickness [mm] | 0.581 | 0.376 | 0.100 |
| Rear sheet thickness [mm] | 0.276 | 0.376 | 0.100 |
| Cell diameter [mm] | 10.5 | 10.5 | 10.5 |
| Cell foil thickness [mm] | 0.0530 | 0.0530 | 0.0530 |

2.4. Witness plate

According to the FDIS11227, copper plates were used to capture ejecta emitted in front and back of the target. The witness plates were then analyzed to evaluate impact damage. Since it is predicted that the target used for the experiments will be penetrated, witness plates were installed in the front and back of the target. Center of the front witness plate was drilled with a hole of 30 mm in diameter to allow the projectile to go through. The witness plates were set up parallel to the target at a distance of 100 mm. The witness plates are shown in Fig. 4 and the set-up of the target and witness plates is shown in Fig. 5.

![Fig. 4. Witness plates. (a) Front witness plate and (b) back witness plate.](image)
3. Experimental results

3.1. Ejecta mass

Impact velocity measured by the razor cut method, projectile mass and ejecta mass in each experiment are shown in Table 2. 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. For honeycombs, the damage involved to the structure depends on where the projectile impacted, which resulted in different ejecta masses. For targets with the honeycomb structure, it has also been observed that not only the cell impacted by the projectile was damaged but also the adjoining cells. Moreover, when the ejecta mass from the four 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 cover glass surface, which is a brittle material that is thus prone to emit a large amount of ejecta. On the other hand, when the cover glass surface (solar array coupon front face) is impacted first, the debris cloud also propagated through the honeycomb structure but when it reached the CFRP surface, the debris cloud is deflected creating a smaller amount of ejecta. Finally, in the case of the tests using aluminum honeycomb structure as the target, it can be observed that the amount of ejecta is minimum, which can be explained by both the ductile nature of aluminum and by the honeycomb structure that can better deflect forces.

Table 2. Experimental results.

| Test number | Target                  | Projectile material | Witness plate             | Impact velocity [km/sec] | Projectile mass [mg] | Ejecta mass [mg] |
|-------------|-------------------------|---------------------|---------------------------|--------------------------|----------------------|-----------------|
| 1           | Solar array coupon (Front) | A2017               | C1100P-1/4H (Buffing)     | 5.37                     | 1.5                  | 68.8            |
| 2           |                         |                     |                           | 5.48                     | 1.5                  | 62.8            |
| 3           | Solar array coupon (Rear) |                     |                           | 4.62                     | 1.3                  | 98.6            |
| 4           |                         |                     |                           | 5.23                     | 1.4                  | 70.9            |
| 5           | CFRP/aluminum honeycomb |                     |                           | 4.97                     | 1.6                  | 41.1            |
| 6           |                         |                     |                           | 5.18                     | 1.5                  | 19.6            |
| 7           | Aluminum honeycomb      |                     |                           | 4.79                     | 1.5                  | 10.3            |
| 8           |                         |                     |                           | 5.56                     | 1.5                  | 30.1            |
3.2. Evaluation of ejecta

Images of the witness plates were captured by a microscope to detect the impact craters. They were detected using the image-processing software ImageJ. ImageJ can display, edit, analyze, process, save, and print 8-bit color and grayscale, 16-bit integer and 32-bit floating point images [8]. However, as shown in Fig. 6, when the taken pictures were changed into binary images, not only the impact craters were detected but also the intrinsic witness plate’s flaws. Thus, to complete the impact craters detection, a background subtraction was performed before changing the pictures into binary images.

![Fig. 6. Impact crater detection by Image J. (a) Original image and (b) detection image.](image)

Since taking pictures at the exact same place is impossible, if the background subtraction of the picture taken before and after the experiment is carried out, the existing flaws of the copper plate did not disappear completely as shown in Fig. 7 (a). To counter this effect, the position of the pictures taken before and after the experiment was rectified by using template and pixel matching and then, the background subtraction was performed, Fig. 7 (b). Binary images are shown in Fig. 8.

![Fig. 7. Background subtraction image comparison. (a) Without correction. (b) After correction.](image)

When position correction is carried out and background subtraction is performed from Fig. 7, the number of intrinsic witness plates’ flaws decreases even if some of them are still visible in the binary images, Fig. 8. Therefore, position compensation followed by background subtraction is effective to decrease the number of the visible intrinsic witness plate’s flaws in the final image. Moreover, this system allows the analysis of the witness plates in only two days. The impact craters were detected from the binary images produced by Image J and Fig. 9 shows the number of detected impact craters for the tests 2, 4, 6, and 8. Fig. 10 shows the size distribution of the detected impact craters for the tests 2, 4, 6, and 8.
4. Conclusions

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.

- **Feasibility of the FDIS11227**
  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.

- **Image processing automation**
  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.

- **Shortening of the analysis**
  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.

References

[1] Fukushige, S., Akahoshi, Y., Kitazawa, Y., Goka, T., 2007. “Comparison of Debris Environment Models; ORDEM 2000, MASTER 2001 and MASTER 2005,” III Engineering Review Vol. 40 No. 1 February, pp. 31-41
[2] Goka, T., 2010. “Initial Results from the Space Environment Data Acquisition Equipment on board the International Space Station,” The 4th Science symposium by an astronomical observatory.
[3] Kitazawa, Y., Noguchi, T., Michael J. Neish, Yamagata, I., Kimoto, Y., Ishizawa, J., Fujiwara, A., Suzuki, M., 2007. “Passive measurement of dust particles on the ISS (MPAC),” The 3rd Space environment symposium, JAXA - SP - 06 - 035, pp 113 - 116.
[4] Rival M., J. C. Mandeville, 1999. “Modeling of ejecta produced upon hypervelocity impacts,” Space debris 1, pp. 45 - 57.
[5] J. C. Mandeville, M. Bariteau, 2004. “Contribution of secondary ejecta to the debris population,” Adv. Space Res. 34, pp. 944 - 950.
[6] William P. Schonberg, 2001. “Characterizing Secondary Debris Impact Ejecta,” International Journal of Impact Engineering 26, pp.713-724.
[7] Muriel Bariteau, Jean Claude Mandeville, Frank Schäfer, 2001. “Ejecta Production Mechanisms on Painted Surfaces,” ESA SP 473, pp.249-251.
[8] rsbweb.nih.gov/ij/
Fig. 10. Size distribution of impact craters. (a) Front witness plate. (b) Back witness plate.