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Revision Plan of ISO11227 Considering Oblique Impact Tests

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Abstract

The number of space debris is continuously increasing, and the risk of collision with a spacecraft is also increasing Secondary debris called ejecta is specifically threat to spacecraft, so an international standardization of the test procedure to evaluate ejecta, was developed and published as ISO11227 on September 15, 2012. This paper intends to show the necessity of oblique impact test by comparing spacecraft material oblique impact with normal impact and to consider the experimental condition of oblique impact test to revise this standard.

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Keywords: Hypervelocity impact, Space debris, Ejecta, Spacecraft material, Solar array, Oblique impact

1. Introduction

Space debris has been increasing in recent years, therefore spacecrafts are associate with a great risk of collision against it. Since space agencies in the world take measures to deal with this situation, for example, measurement, mitigation, modeling and protection. Since relatively-large debris about 10 cm and over are cataloged and tracked, space agencies can operate their space-craft to avoid these debris. However, the debris of several hundreds of micrometers to several millimeters has been a problem lately [1]. It is said that secondary debris "ejecta" is dominant in this size range. Ejecta is generated by space debris or meteoroid which collides with a spacecraft's surface [2]. Organizations try to estimate the impact risk by development of space debris environmental engineering models, but these models such as ESA MASTER and NASA ORDEM differ from one another since each organization carries out hypervelocity impact tests in different experimental conditions and procedures. Therefore, an international standardization of the test procedure to evaluate ejecta, was developed and published as ISO11227 on September 15, 2012 [3]. This standard intends to establish a common test procedure of ejecta generated from spacecraft surface, and it will be revised within 2017. Although space debris usually impacts on a surface of a spacecraft a default impact test condition is a normal impact in current ISO11227. We think that an oblique impact test should be a default impact test in revised ISO11227.

In this study we made several oblique impact tests and compared their results with normal impact ones. Finally we discuss the experimental condition of oblique impact tests which should be included in the revised ISO11227.

2. Experimental conditions

2.1. Two-stage light gas gun

To simulate hypervelocity impact of space debris, we use a two-stage light gas gun installed in Kyushu Institute of Technology. This gun has a performance to accelerate and launch a spherical (φ1 mm ± 0.1 mm) aluminum (A2017) projectile at approximately 5km/s. In the test chamber, which simulates space environment, the pressure is set to less than

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0.1 Pa, and the sabot separation section pressure is set to less than 7 kPa to allow sabot and projectile separation thanks to air drag.

2.2. Spacecraft material[4]

As spacecraft target, solar array coupon was chosen, which a composite material is constituted by the layers of cover glass, solar cell, Kapton film, CFRP skins, and honeycomb core (Fig.1). The Specification of this target is shown in Table 1. There are no data about the thickness of adhesives.

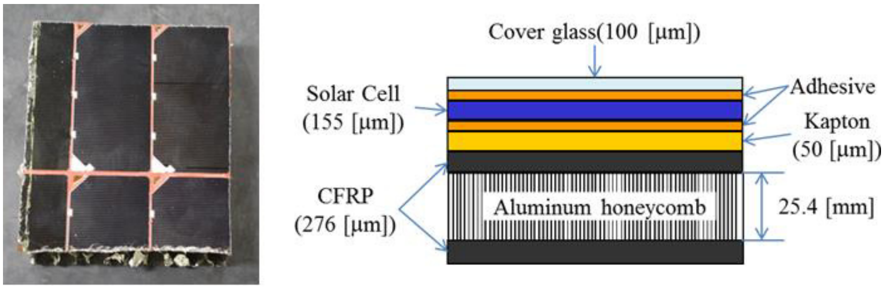


Fig.1. Solar array coupon

Table 1. Specification of solar array coupon

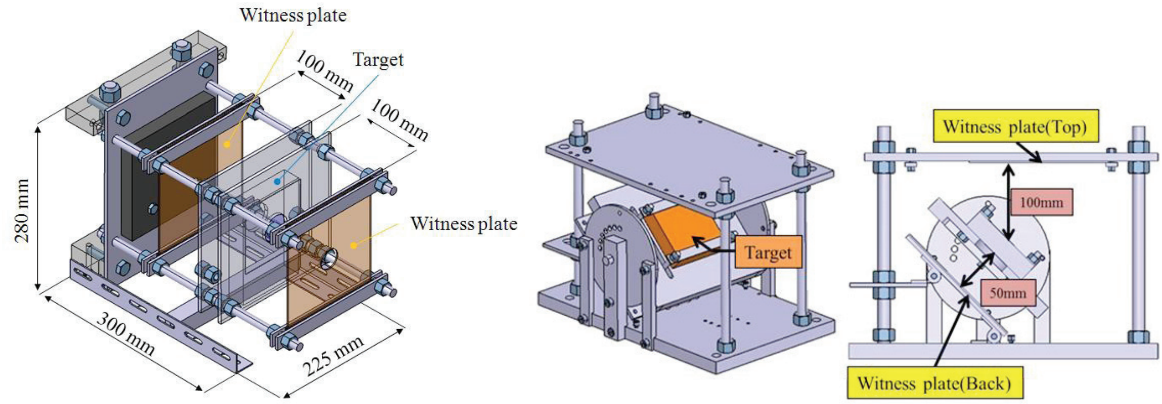
Composition of solar array panel layer		Material	Thickness [mm]
Cell	Cover Glass	CMG	0.100
	Adhesive (CG/Solar array)	DC93-500	-
	Solar array cell	Ge	0.155
Adhesive		Silicon system adhesive	-
Substrate	Polyimide seat	Kapton film	0.050
	Face seat(CFRP)	CFRP crossing material	0.276
	Film adhesive	Epoxy system film adhesive	-
	Honeycomb core	General part : 3/8-5056-.0007P Reinforcement part : 1/8-5056-.0007P	25.4
	Film adhesive	Epoxy system film adhesive	-
	Face seat (CFRP)	CFRP crossing material	0.276
		Total thickness of solar array coupon	26.257

2.3. The setup of target and witness plates on Normal and Oblique impact test

The setup of target and witness plates on normal and oblique impact tests is shown in Fig.2.

Impact angle of oblique impact was set up at 45 degrees, and to compare the results between normal and oblique impact tests, data on ejecta such as mass, size and distribution were obtained. Ejecta mass was obtained by measuring mass difference between pre-test and post-test. Ejecta size and distribution were obtained by using two copper witness plates, one of which was to catch the fragments ejected from the front surface of target (Cover glass side, see Fig.1), and the other is to catch the fragments ejected from the rear surface (CFRP skin side, see Fig.1).

On normal impact test, the front witness plate has a hole with a diameter of 30mm to allow the projectile to go through.



(a) (b)

Fig.2. Setup of target and witness plates (a) Normal impact test (b) Oblique impact test (45 deg.)

2.4. Comparison with the experimental conditions in ISO1227

In this study, we performed the experiments comply with the experimental conditions described in Clause 4 of 11227 ISO. However, on the relation of the experimental apparatus used in this experiment, there are some differences in experimental conditions. A comparison of the conditions of this experiment and the draft standard is shown in Table 2.

Table 2. Comparison of ISO11227 and this study

		ISO11227	This study (Oblique impact)
Projectile	Material	Aluminum alloy A2017 or A2024	A2017
	Size of shape	1 mm ± 0.1 mm diameter sphere	Same
	Impact velocity	5 km/sec ± 0.1 km/sec	Approx.5 km/sec
	Material	Representative of the material to be flown on the spacecraft	Solar array coupon
Target	Size	At least 50 mm × 50 mm	Same
	Thickness	Not defined	26mm
	Fixing	Held in place by fixing on the edges only Rear side left free to allow ejecta collection if perforation or rear side spall occurs	Supported by aluminum plates cut a circular hole (diameter 40 mm) in the center
	Material	JIS H3100, C1100P-1/4H, ASTM B152 C11000, EN CW004A	JIS C1100P-1/4H
Witness plate	Size	250 × 150 × 2 mm	250×150×2mm 180×150×2mm
	Distance to the target	50 ~ 100 mm	Same
	Position	Not defined	100 mm upwards from the center of a target
	Position	Not defined	50 mm backwards from the center of target

3. Experimental result

3.1. Ejecta mass

Experimental results of solar cells for normal and oblique impact tests about ejecta mass are shown in Table 3. Front (cover glass) and rear (CFRP skin) part of solar cell distinguished from one another. Comparison of ejecta mass between normal and oblique impacts test shows that the ejecta mass of oblique impact tends to be lower than that of normal impact. Ejecta mass of normal impact test ranged from 70 mg to 90 mg [5]. On the other hand, ejecta mass from oblique impact test ranged from 20 mg to 40 mg. This different between the results is primarily caused by the difference of debris clouds expansion in solar array coupon.

X-ray computed tomographic image of post-testing target in oblique impact test is shown in Fig.3. This X-ray CT equipment was installed and operated in Fukuoka Industrial Technology Center. In this impact test, when solar array coupon was setup to impact to rear side, the point of impact and through-hole were in the same straight line, which conformed to the trajectory of projectile. On the other hand, when setup to front side, the through-hole was generated in the normal direction of impact surface. In the former case, only in-line debris cloud that derived from projectile fragment was released from solar array coupon. In the latter case, only normal debris cloud that derived from target fragment was released [7].

Therefore, it is assumed that debris cloud in oblique impact on solar array coupon is released, either normal or in-line debris cloud. However, in normal impact, the trajectory of projectile and normal direction of target conforms so that the both clouds could release from target in the same direction. It is considered that these differences of debris clouds expansion caused the difference of ejecta mass.

Table 3. Solar cell experimental results

Impact angle	Impact surface	Test No.	Projectile velocity [km/s]	Ejecta mass [mg]
Normal 90 deg.	Front	11-180	5.48	62.8
	Rear	11-015	4.96	98.6
Oblique 45 deg.	Front	13-081	5.00	38.7
		13-089	5.06	22.2
		13-108	5.03	23.7
	Rear	13-096	5.10	16.0
		13-112	4.89	16.6

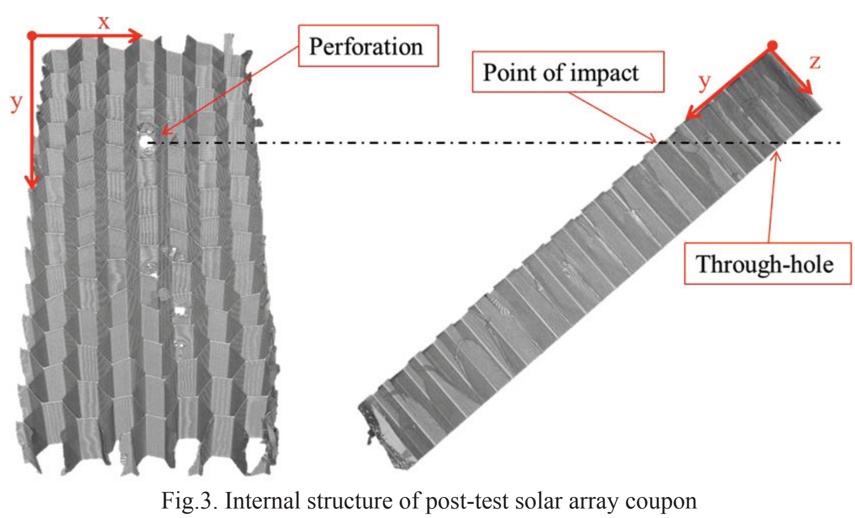
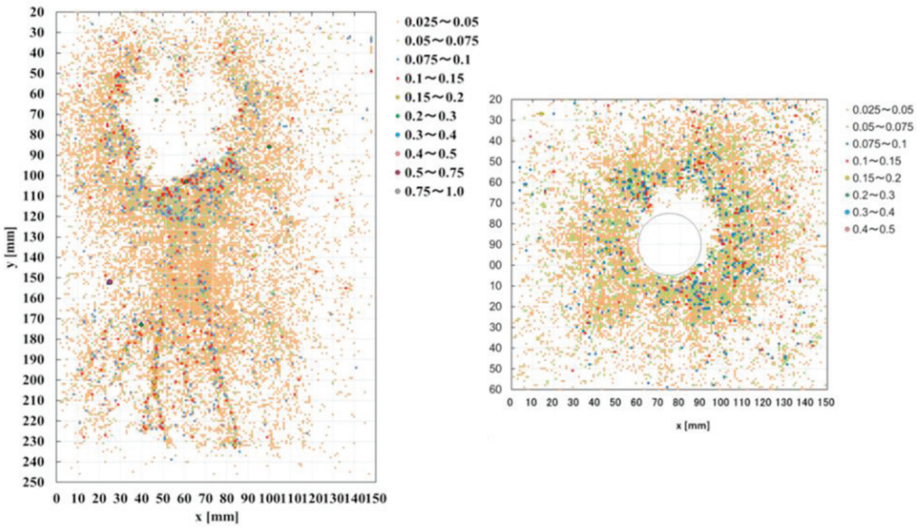


Fig.3. Internal structure of post-test solar array coupon
(tube voltage: 120kV, tube current: 150μA, voxel side length: 0.084 mm)

3.2. Ejecta distribution

Ejecta distribution of normal and oblique impact test is shown Fig.4. Ejecta size and distribution were obtained by analysing ejecta craters on witness plate using a microscope (Magnification: 60-360, Resolution: 1600×1200 pixel). A characteristic distribution represented by a circular ring was confirmed on the axis of Y between 40 mm and 110 mm and the axis of X between 30 mm and 80 mm in Fig. 4(a). A characteristic distribution like a circular ring can be also found at near the center in Fig. 4(b). This pattern could be confirmed in impact test on spacecraft material, but it could not be confirmed in the calibration test on Silica glass [6] (Fig. 5).



(a) (b)

Fig.4. Ejecta distributions on solar array coupon (a) Oblique impact test (No.13-108) (b) Normal impact test (No.11-180)

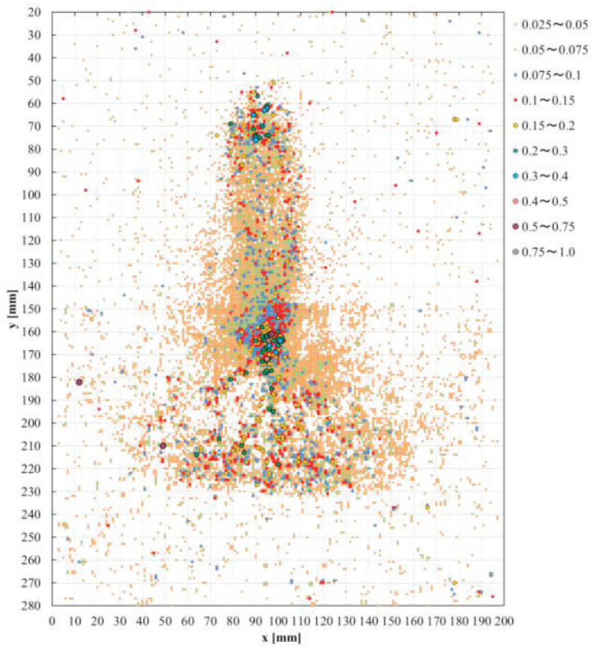


Fig.5. Ejecta distribution on calibration testing

4. Conclusion

In this study, we obtained the experimental results of hypervelocity impact on solar array coupon in oblique impact test. In addition, comparing between the results and normal impact test, we obtained several knowledge about hypervelocity impact on spacecraft material. The conclusions in this study are summarized below.

・**The difference of ejecta mass between normal and oblique impacts**

The fragments' mass ejected from solar array coupon on oblique impact test is smaller than that of normal impact test. It is assumed that this tendency is caused by a difference of debris cloud expansion.

・**The difference of debris cloud diffusion direction in oblique impact**

The diffusion direction of debris clouds is different with respect to each impact surface in oblique impact, especially, spacecraft material or composite material, like solar array coupon. These structures are not often the same materials of the front and rear surface. It is considered that the difference of impact surface have effects on the diffusion direction of debris cloud.

・**A characteristic ejecta distribution**

A characteristic ejecta distribution represented by a circular ring was confirmed in both of normal and oblique impact. However, because such distribution is not confirmed in calibration test on silica glass, it is assumed that the generation of this distribution is depends on impact surface material.

Besides above conclusions, we obtain experimental experience about oblique impact test. To revise this standard, we are necessary to confirm the repeatability. All experiments in this paper were carried out in Kyushu Institute of Technology. To confirm the repeatability, we are planning to experiment in other institute. Moreover, in space, micrometeoroid and orbital debris (MMOD) collide obliquely with spacecraft surfaces. Therefore, tests at different impact angles should be carried out to simulate MMOD impacts more accurately. However, there is not enough experimental results with spacecraft material as target and more impact tests should be carried out under various conditions to revise ISO11227. We will report these results to ISO/TC20/SC14/WG7 to discuss revision of ISO11227

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