HYPERVELOCITY IMPACT TESTS AGAINST METALLIC MESHES

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ABSTRACT

In order to protect the International Space Station (ISS) against space debris, it is indispensable to develop a new bumper. A metallic mesh is one of potential shield materials from a viewpoint of both lightweight and flexibility. The purpose of this study is to investigate protection capability of metallic meshes by focusing on debris cloud made at the debris impact. Hypervelocity impact tests have been conducted with a two-stage light gas gun of Kyushu Institute of Technology. The typical impact velocity is 3km/sec. After the impact debris clouds are taken with three flash X-ray cameras. By image analysis we found that the stainless mesh reduced the velocity of the projectile up to 35%. Metallic meshes can fracture debris and reduce debris velocity. Metallic meshes are effective as one of shield materials.

1. INTRODUCTION

Large space structures are exposed themselves to danger of debris impacts. One of them is the ISS since its lifetime is longer than 10 years. Its protective methods against debris impacts are categorized 3 levels by debris size (E.L. Christiansen, 2003). Debris which is larger than 10cm in diameter can be tracked by optical observations and ground-based radio frequency radars. The ISS can keep away from large debris since orbits of the large debris are calculated. Debris which is smaller than 1cm can be protected by the current bumper shield of the ISS. However the protective method for debris with 1 - 10cm is incomplete. It is indispensable to develop a new bumper shield which reinforces the current bumper shield of the ISS.

The ISS has Whipple Shields. In particular, the Japanese Experiment Module (JEM) called “Kibo” has reinforced shields, Stuffing Shield, as shown in Fig.1. The Stuffing Shield consists of two aluminum plates and multi-layers stuffing.

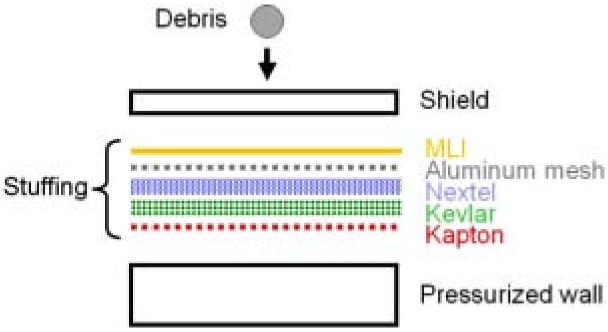


Figure 1 Stuffing Shield of the “Kibo”

The purpose of this study is development of a new shield for attaching to the ISS. If the ISS is covered with another thin shield over the current shield, the protection capability increases drastically. We choose mesh because of its lightweight and flexibility. A mesh can decrease 20-30% weight compared with the same size plate.

Using metallic meshes as bumper shields is already

Proceedings of the Fourth European Conference on Space Debris, Darmstadt, Germany, 18-20 April 2005
(ESA SP-587, August 2005)

researched (F. Horz, et al, 1992 and E.L. Christiansen, et al, 1993) but they focus on their ballistic limit curves. By focusing on debris cloud, we investigate the protection capability of metallic meshes.

2. HYPERVELOCITY IMPACT TESTS AND RESULTS

Hypervelocity impact tests have been conducted with a two-stage light gas gun of Kyushu Institute of Technology. Test configuration is shown in Fig.2. The projectile is made of polycarbonate. Its mass is 1g and its shape is cylindrical form with 10mm in diameter and length. The typical impact velocity measured by laser-cut method is 3km/sec. After the impact debris clouds are taken with three flash X-ray cameras. Three cameras flash at different times.

The details about the targets are shown in Table 1. In the table, "D" indicates the diameter of wires and "S" indicates the space between wires (Fig.3). The targets of Test 1 and 2 are constrained by the frame shown in Fig.4. The targets of Test 3, 4, 5 and 6 are constrained by 2 bolts shown in Fig.5. The targets after the tests are shown in Figs.6 – 11.

X-ray images obtained by Test 1 are shown in Fig.12. The camera A flashes at first. In Test 1, at 8.0 micro-seconds after flash the camera A, the camera B flashes. At more 11.8 micro-seconds after flash the camera B, the camera C flashes.

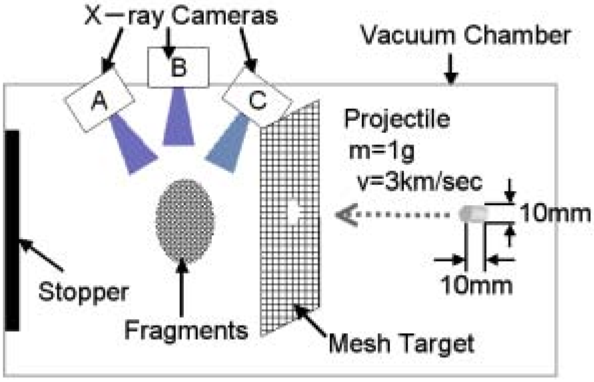


Figure 2 Test Configuration

Table 1 Targets

Test No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Material	SUS304	Copper	SUS304	SUS304	SUS304	SUS304
D [mm]	1.10	0.45	0.50	0.50	0.45	0.45
S [mm]	3.13	1.67	1.62	1.09	0.56	0.56
Areal Density [kg/m2]	3.29	1.26	1.47	1.96	2.38	2.38

Figure 3 Dimension of Meshes

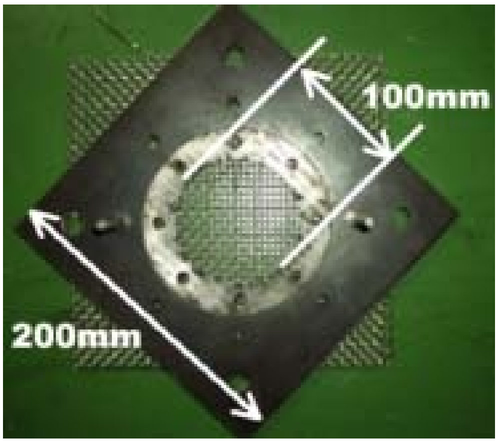


Figure 4 Constrained Condition of Test 1 and 2

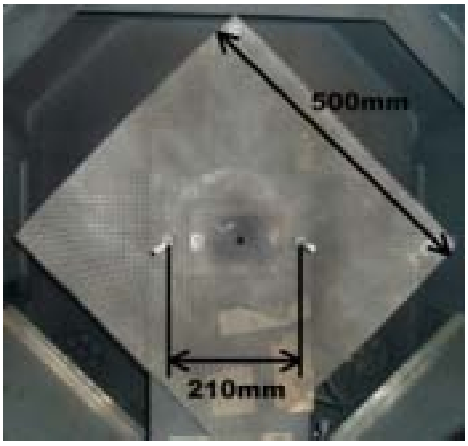


Figure 5 Constrained Condition of Test 3, 4, 5 and 6.

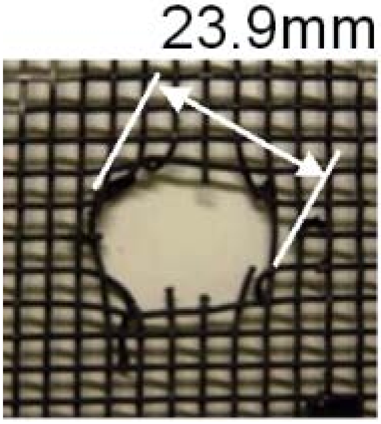


Figure 6 Target of Test 1

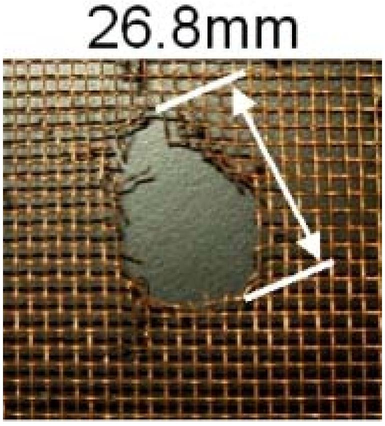


Figure 7 Target of Test 2

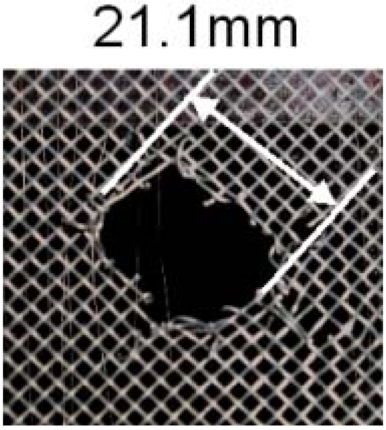


Figure 8 Target of Test 3

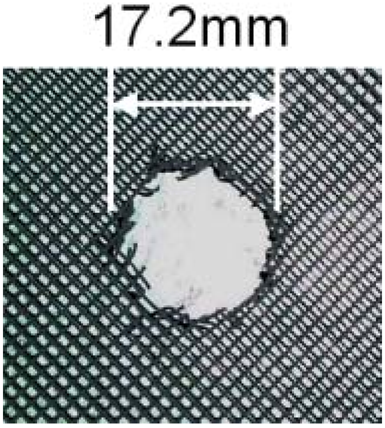


Figure 9 Target of Test 4

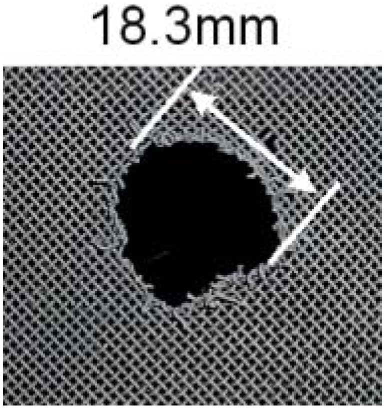


Figure 10 Target of Test 5

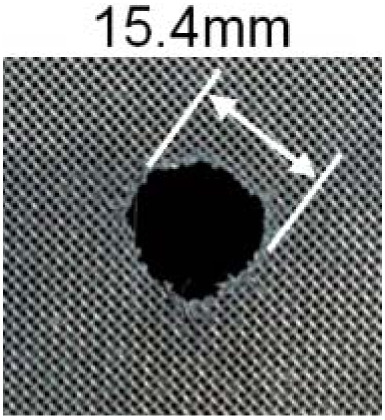
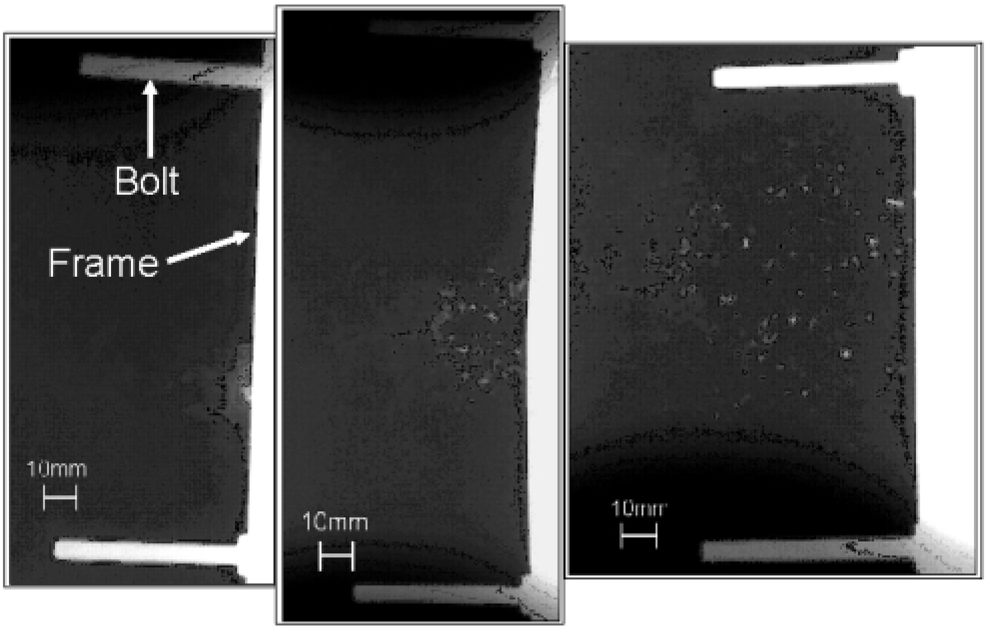


Figure 11 Target of Test 6



(a) Camera A (b) Camera B (c) Camera C

Figure 12 X-ray Images of Test 1

3. IMAGE ANALYSIS

3.1 Analysis Process

X-ray Images are analyzed as follows.

1) Measure areas (S_i) and gravity centers ($G_i(x_i,y_i)$) of all fragments as shown in Fig.13.
2) Assume that fragments are spherical shape, and estimate volumes (V_i) of all fragments by using their cross section areas (S_i) measured by Step 1)
3) Calculate the gravity center (G(x,y)) of total fragments by using (Gi) and (Vi).
4) Compare three X-ray images, and calculate the displacement of G (Δ y).
5) Calculate the velocity of fragments by using delay time of X-ray images (Δ t) and (Δ y)

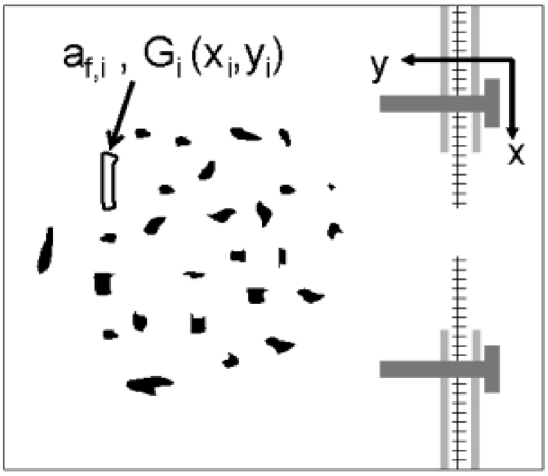


Figure 13 Image analysis of X-ray images

3.2 Analysis Results

Results of image analyses are shown in Table 2. The fragments velocities are calculated by image analyses. All targets can reduce half of the impact velocity.

The relation between the areal density and the velocity ratio is shown in Fig.14. Points which have close impact velocities are connected with lines. When the areal density increases, fragments velocity decreases.

In Tests 3, 4, 5 and 6, targets are made of the same material and their wires are close diameters. The relation between S (the space between wires of the mesh) and the velocity ratio is shown in Fig.15. When S decreases, the fragments velocity decreases.

The slopes of the line connecting Test 4 and Test 5 are steep in Figs.14 and 15. Test 4 and Test 5 have fastest impact velocities. On the ballistic limit curve, the protective capability increases in this area. The sensitivity to the change of fineness of the mesh is implied.

The relation between the hole diameter of the target and the impact velocity is shown in Fig.16. Black points show the targets constrained by the frame and gray points show the targets constrained by 2 points. Extra data are added to Fig.16. These tests failed in obtaining X-ray images but holes of targets and impact velocities were measured. The targets constrained by 2 points have small size holes. This result shows that frame constraint makes more debris clouds than 2 points constraint.

Table 2 Analysis Results

Test No.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Impact Velocity vp [km/sec]	3.22	3.22	2.88	3.31	3.28	2.81
Velocity of Fragments vf [km/sec]	1.14	1.54	1.52	1.77	1.48	1.37
vf / vp	0.35	0.48	0.53	0.54	0.45	0.49

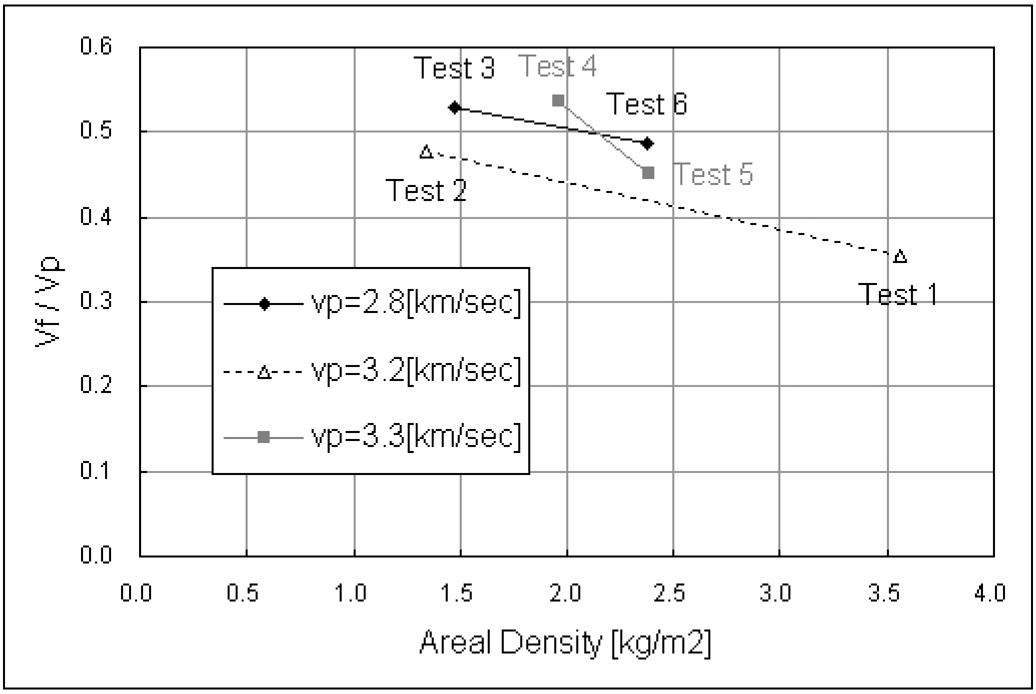


Figure 14 Areal Density – Velocity Ratio

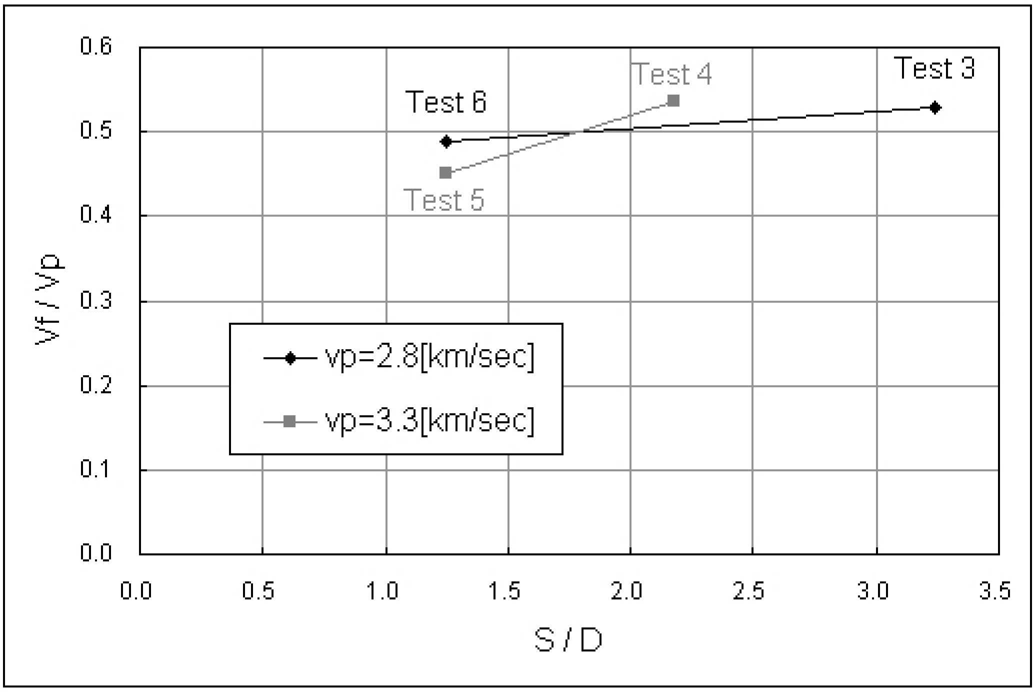


Figure 15 Space between Wires – Velocity Ratio

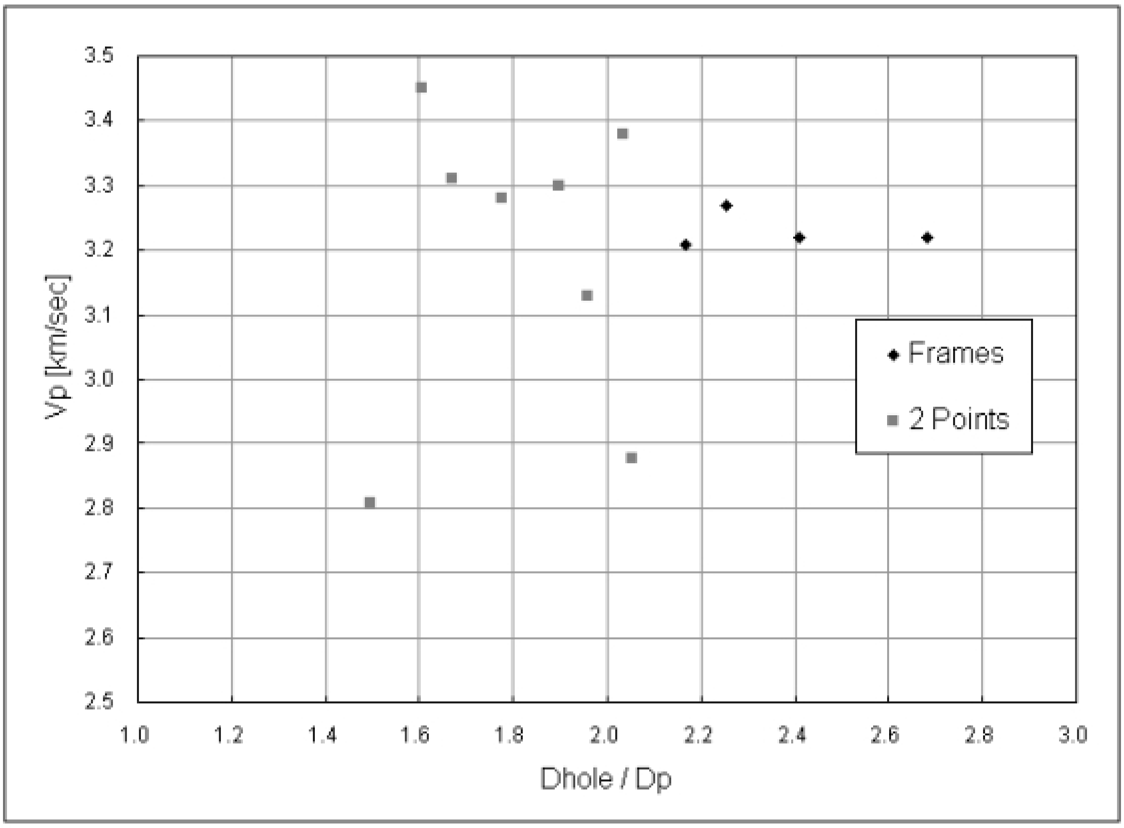


Figure 16 Hole Diameter – Impact Velocity

4. CONCLUSIONS

The purpose of this study is to investigate protection capability of metallic meshes by focusing on debris cloud. After hypervelocity impact, debris clouds are taken with flash X-ray cameras. The group velocity of fragments is calculated by image analysis of X-ray images. The analysis results show as follows.

- Metallic meshes have high protection capability.
- One of tests reduces the impact velocity up to 35 %.
- When the areal density increases, fragments velocity decreases. And the fragments velocity decrease at the narrower space between wires of the mesh.
- Targets constrained by the frame make more debris clouds compared with targets constrained by 2 points.

We found that metallic meshes fracture debris and reduce debris velocities. Metallic meshes are effective as one of shield materials.

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