H4

微小デブリ衝突に関する研究の状況と課題

Research Status and Action of Sub-millimeter Debris Impact Damage on Spacecraft Structure

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衛星の設計時にデブリ衝突リスクを識別する必要があるが、直径 1 mm 以下の微小デブリ衝突に関する研究例は少ない。そこで JAXA では、微小デブリに対する衛星構造材料の耐デブリ衝突性能や、その防御方法について研究してきた. 本発表ではハニカムサンドイッチパネルの耐デブリ衝突性能について報告する。ハニカムサンドイッチパネルに、ISAS の所有する二段式軽ガス銃で衝突試験を実施した。直径 0.2 mm 以上のデブリはパネルを貫通することがわかった。また、斜め衝突の場合にはハニカムコアがデブリ防御の効果を持つこともわかった。

To assess debris impact risk for the satellite, submillimeter debris impact damage has not been investigated enough to conduct satellite protective designing. JAXA is researching vulnerability of satellite structure materials against submillimeter debris impact, and proposing shielding methods. This report shows summary of submillimeter impact damages of honeycomb sandwich panels. The damage of the panel was investigated by hypervelocity impact experiments with the two-stage light gas gun in ISAS. Debris larger than 0.2 mm went through the panel. In oblique impact experiments, the honeycomb core acted like multi-layer bumper.

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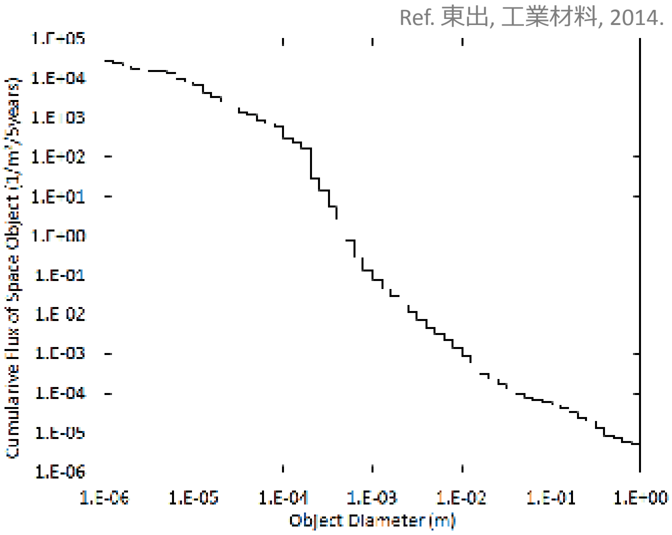
Submillimeter Debris

Ref. 東出, 工業材料, 2014.

Debris smaller than 1 mm frequently impact on spacecrafts in LEO.

Risk assessment for submillimeter debris impact should be carried out before launch to protect mission-critical components.



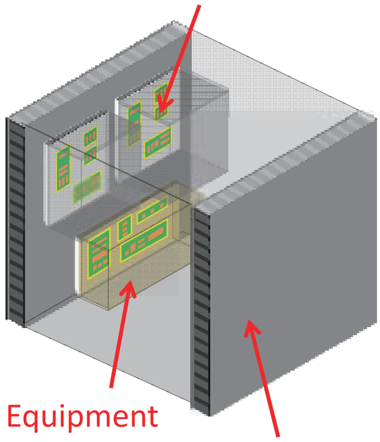
calculated by MASTER-2009 (Alt.=700km, Inc=98°)

Mission Critical Components

Many important components are installed on the interior surfaces of structure panels.

Electronic devices are usually mounted in an aluminum chassis.

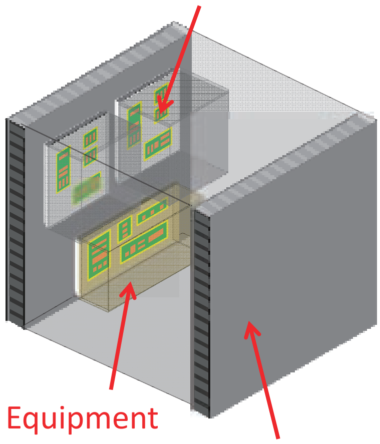
To assess the debris impact risk, it is necessary to know a damage limit of a chassis behind a structure panel.



Purpose of this study

To investigate damage of structure panel and internal equipment chassis

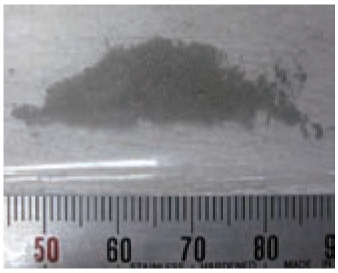
1. Ballistic limit of structure panel
2. Ballistic limit of equipment chassis' wall behind the structure panel
3. Detached spall of the chassis' wall behind the structure panel
4. Oblique impact effect



Hypervelocity Impact Experiment

two-stage light gas gun of ISAS/JAXA

projectiles (Steel, f0.3mm)



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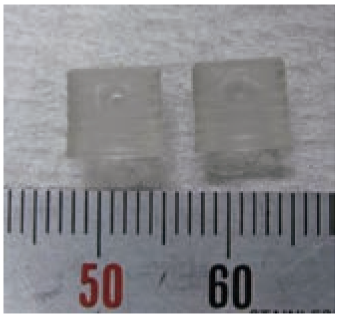
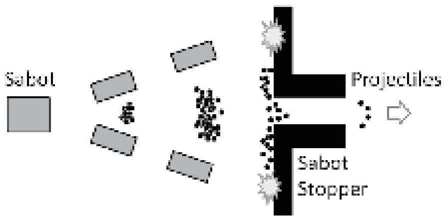
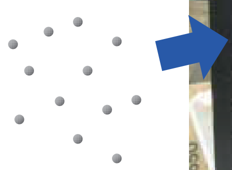




Experimental Conditions

Honeycomb Sandwich Panel
Skin: A2024, t=0.25mm
Core: A5056, h=25.4mm,
Cell Size=6.35mm,
Foil=18μm

6 km/sec

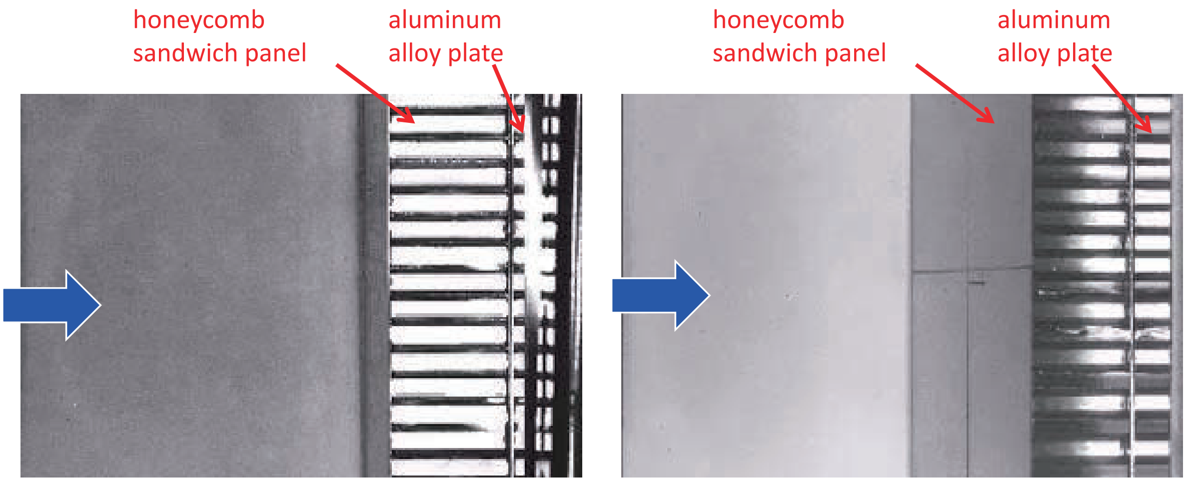


Projectile
Steel Sphere,
d_p=0.15, 0.3, 0.5, 0.8, 1.0mm

Steel was used as projectile material to simulate the impact pressure caused by alumina at 9 km/sec.

Aluminum Alloy Plate
A2024-T3

Hypervelocity Impact Experiments

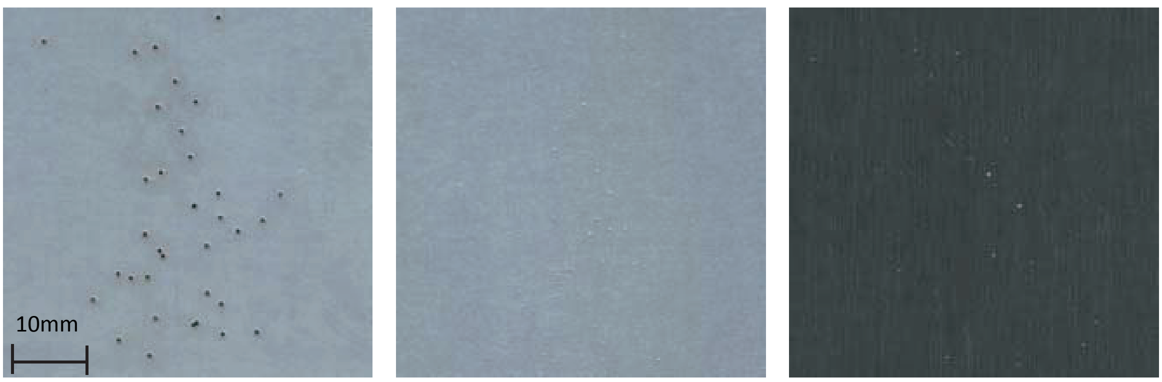


d_p=0.3mm, 5.9km/sec

d_p=1.0mm, 5.9km/sec

Results (1)

Projectile: d_p=0.15mm, Impact velocity: 5.8km/sec



Front Back A2024 plate

Projectiles of 0.15mm do not perforate the honeycomb sandwich panel.

Results (2)

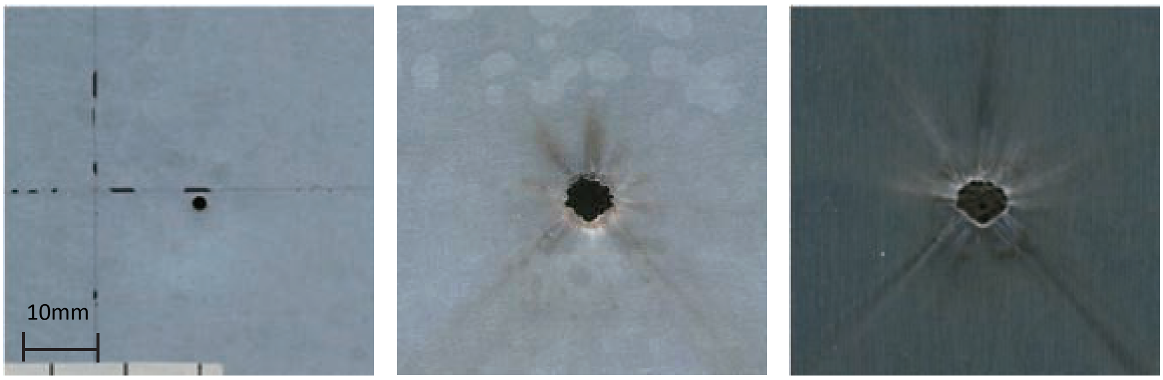
Projectile: d_p=0.3mm, Impact velocity: 5.9km/sec

Front Back A2024 plate

Projectiles changed into fragment clouds by impacts on the front face sheet.

Results (3)

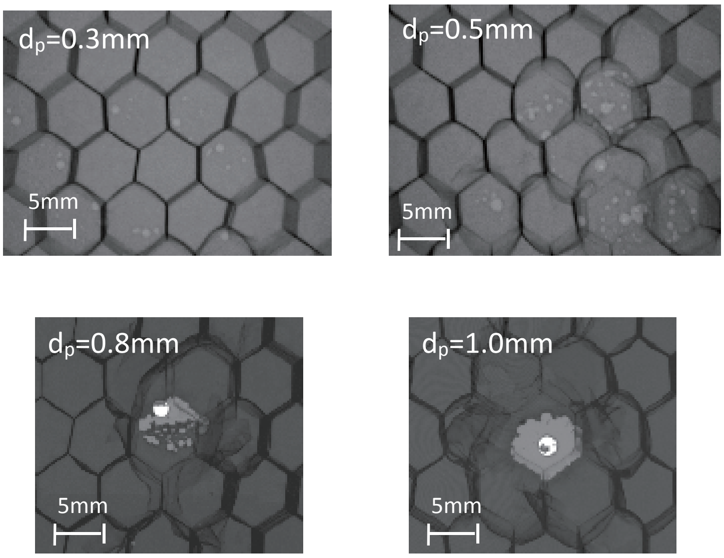
Projectile: d_p=1.0mm, Impact velocity: 5.9km/sec

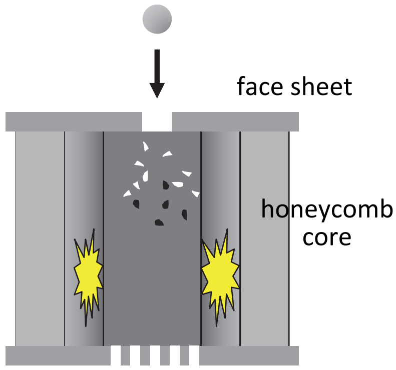


Front Back A2024 plate

The fragment cloud was restricted in the impacted honeycomb cell.

X-ray Radiographs





Honeycomb foil act as bumpers for fragment cloud.

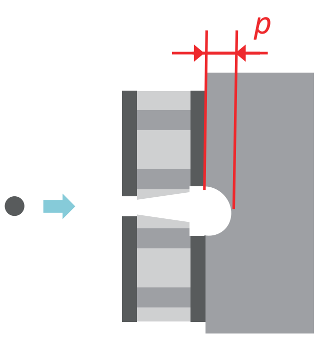
Crater Depth Equation

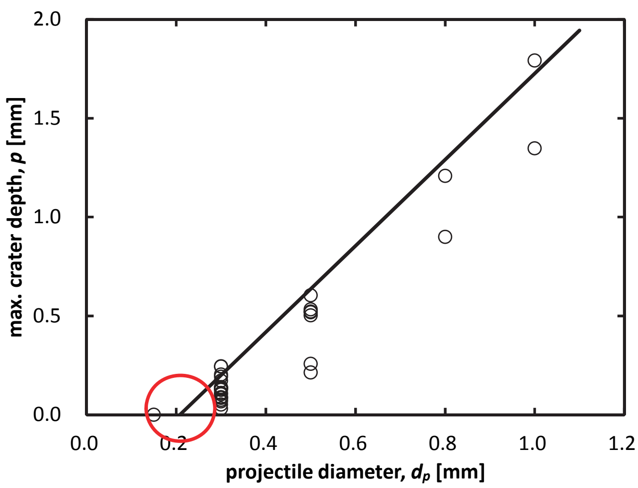
Crater depth equation

$$p \leq 2.18 d_p - 0.454$$

p : Crater depth on witness plate (mm)

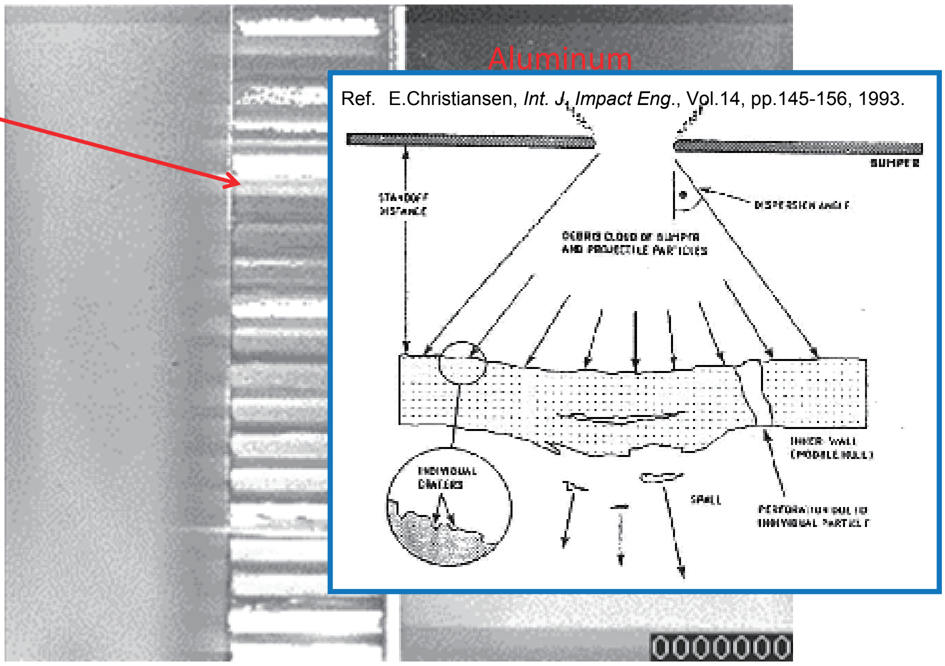
d_p : Projectile diameter (mm)





d_p=0.21mm is ballistic limit of the honeycomb sandwich panel

Detached Spall

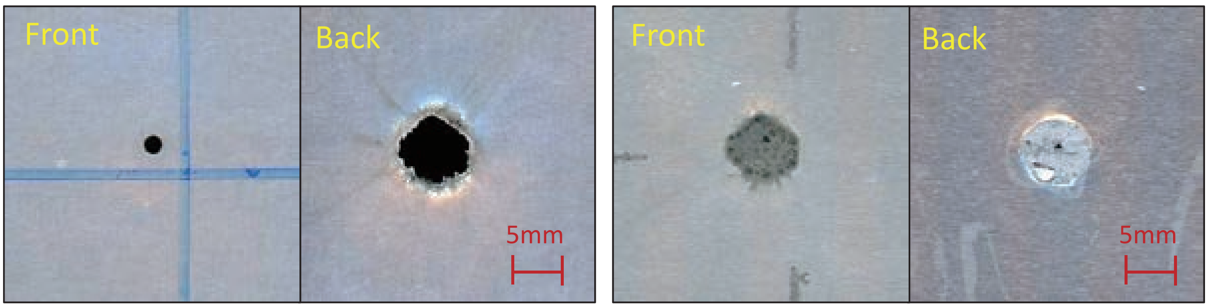


d_p=1.0mm
t_w=**2.0mm**
v_p=6.29km/s

Spall Result

Projectile: d_p=1.0mm, Impact Velocity: 6.29km/sec, Plate Thickness: 2.0mm

Honeycomb Sandwich Panel Aluminum Plate

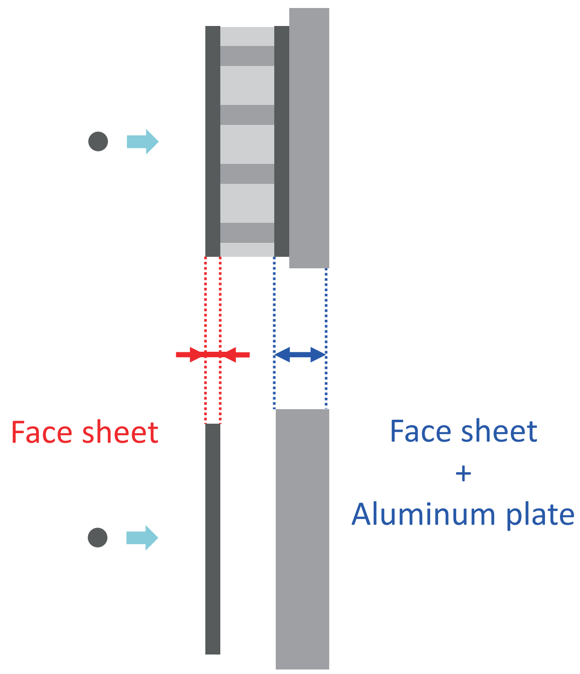


The aluminum plate was penetrated due to cratering and spalling. This condition was considered as ballistic limit of the set of the honeycomb sandwich panel and the A2024 plate.

Effect of Spall Damage

The ballistic limit thickness of the second wall of double-wall structure is proportional to the crater depth on the second wall with semi-infinite thickness.

Target set can be simplified double-wall structure.



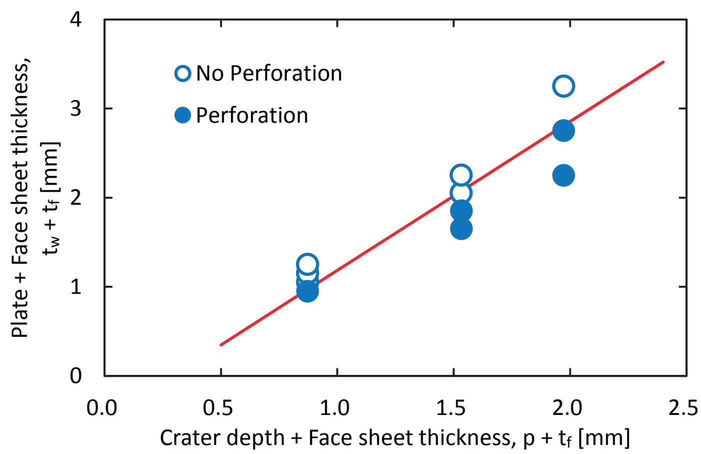
Ballistic Limit Equation

2nd wall → Face sheet + AL plate

Crater on 2nd wall
→ Face sheet
+ Crater on the AL plate

$(t_c+t_f) = 1.67\,(p+t_f) - 0.486$

$\mathbf{t_c = 3.67 d_p - 1.12}$



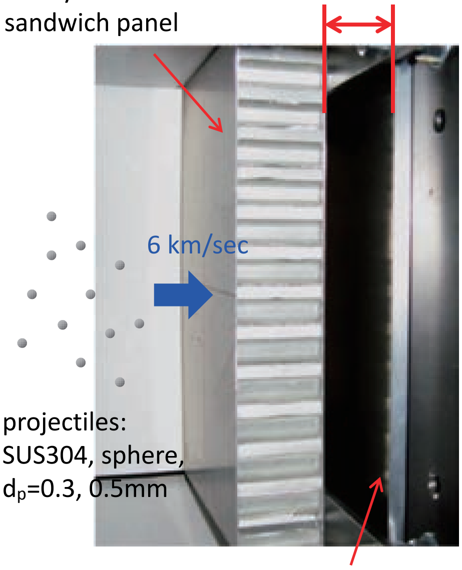
d_p: Projectile diameter (mm)

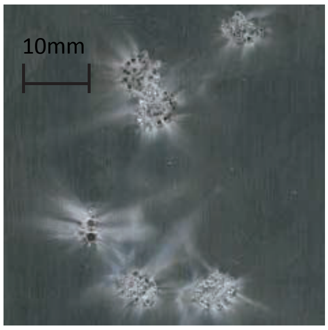
t_c: Critical thickness of aluminum plate (mm)

t_f: Thickness of front face sheet (mm)

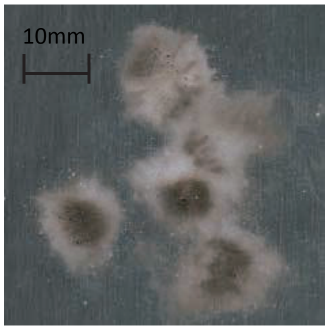
p: Crater depth on aluminum plate (mm)

Effects of Stand-off Distance





d_p=0.5mm, S=0mm



d_p=0.5mm, S=10mm

Debris cloud generated by a honeycomb sandwich panel was dispersed in stand-off spacing.

Crater Depth

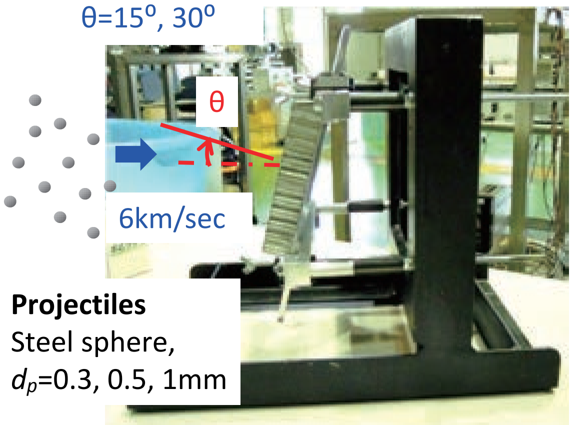
projectile diameter	maximum crater depth [mm]			
	no gap	stand-off 10mm	stand-off 50mm	stand-off 100mm
0.3mm	0.24	0.20	0.05 >	0.05 >
0.5mm	0.57	0.46	0.05 >	0.05 >

When stand-off distances were larger than 50mm, crater depths were unmeasurable because the depths were smaller than 0.05mm.

The crater depths were reduced by 15-20% by keeping the stand-off distance 10mm.

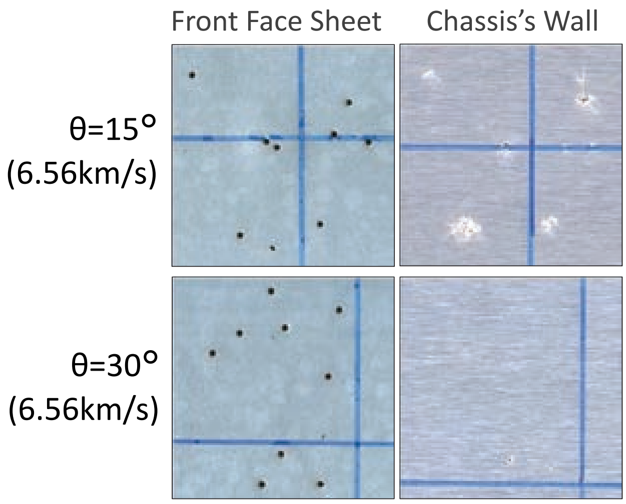
Oblique Impact Experiment

Impact angle
θ=15°, 30°



Projectiles
Steel sphere,
d_p=0.3, 0.5, 1mm

Results of d_p=0.5mm



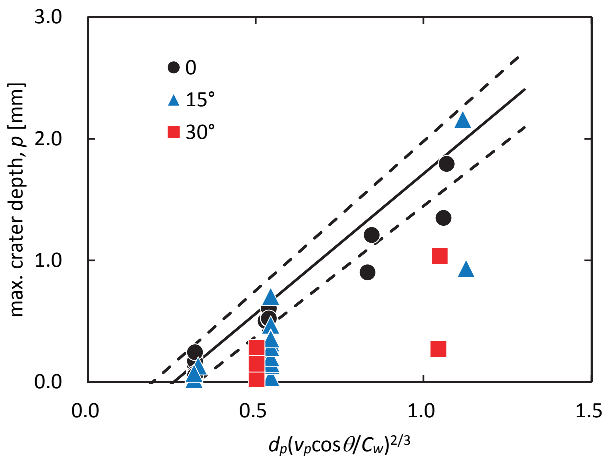
Damage to the back face sheets and witness plate became smaller at larger impact angles.

Crater Equation with Impact Angle Effect

The impact energy was assumed to be proportional to the crater volume.

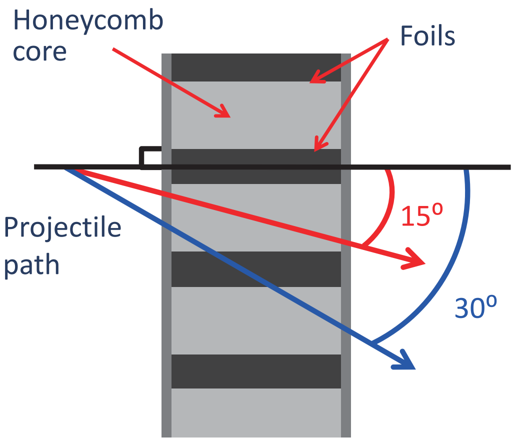
$$p \geq 2.30 d_p \left(v_p \cos\theta / C_w \right)^{2/3} - 0.588$$

d_p: Projectile diameter (mm)
p: Crater depth on aluminum plate (mm)
v_p: Impact velocity (km/s)
C_w: Sound speed in witness plate (km/s)
θ: Impact angle



The results of θ=30°were much less than the upper limit

Effect of Honeycomb Foils



θ=15°: Some projectiles do NOT paths through foils.

θ=30°: Projectiles always impact on the foils.

When the impact angle is less than 16.1°, there are some paths through no foils

If θ >16.1°, the upper limit of the maximum crater depth is considered lower than the equation.

Summary

To investigate damage of structure panel and internal equipment chassis, sets of a honeycomb sandwich panel and an aluminum witness plate (chassis' wall) were tested.

Ballistic limit of the honeycomb sandwich panel was estimated by the crater depth equation of the witness plate.

The ballistic limit equation of chassis' wall was developed from crater depth equation and detached spall limit data.

The crater depth equation was considered with the assumption that the impact energy was proportional to the crater volume. The equation is applicable when the impact angle is less than 16.1°.

Acknowledgement

The work was supported by the Space Plasma Laboratory, ISAS, JAXA.

The authors acknowledge the valuable advice given by members of JAXA Spacecraft Design Standard WG3.

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