D6

超高速飛翔体衝突により生ずるイジェクタのサイズ分布

Size distribution of ejecta resulting from hypervelocity impacts of projectiles

○西田政弘，林 浩一（名工大），長谷川直（宇宙航空研究開発機構）
○Masahiro Nishida, Koichi Hayashi (NITech), Sunao Hasegawa (JAXA)

デブリ衝突によってイジェクタが発生し，それらが二次デブリとなるため，イジェクタの構成や生成メカニズムを知ることは重要である．イジェクタに影響を与える要因として，ターゲットの材料特性や温度，飛翔体の衝突速度，衝突角度，材料特性，形状や衝突速度が考えられるが，それらを調べつつある．講演ではこれまでの研究成果の一部を紹介する．発生したイジェクタについては，実験後，チェンバーから回収し，その形状，質量，面積質量比を測定した．高速度カメラによる画像およびターゲット前方に設置した検証板の衝突痕からイジェクタの噴出角度も調べた．

Space debris often strikes spacecraft and space stations at very high velocities, forming ejecta fragments. A significant fraction of the secondary debris in LEO results from such ejecta fragments. Therefore, it is important to understand ejecta composition and mechanisms of ejecta formation. We can expect that many factors, such as temperature and material properties of targets, impact velocity, impact angles, material properties and shape of projectiles, will affect the ejecta formation and composition.
We are now examining the effects of such factors, and I will present some of our results. After impact experiments, the mass, size and aspect ratio of the ejecta fragments collected from the test chamber were measured. The ejecta cone angles were examined using a high-speed video camera and indentations on witness plates in front of the targets.

第5回スペースデブリワークショップ
5th Space Debris Workshop, Jan 22-23, 2013

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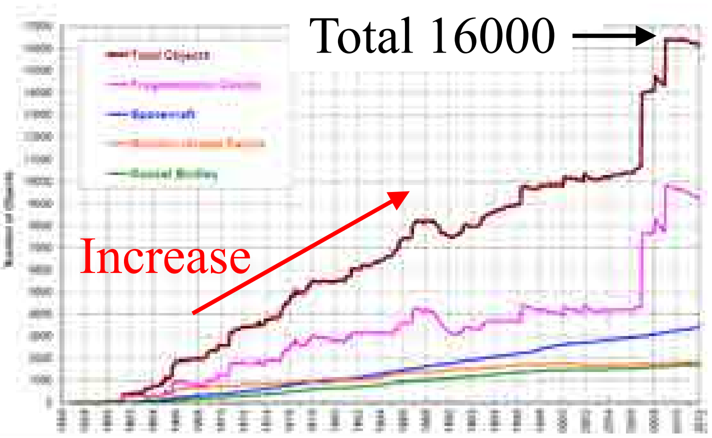
Space Debris

Image of space debris

Low Earth orbit (LEO)

NASA Orbital Debris Program Office
http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html#leo

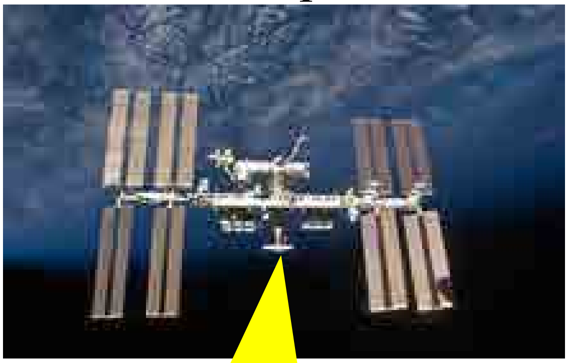
Number of cataloged objects



Debris Quarterly News, Vol. 16, Issue 1, 2012

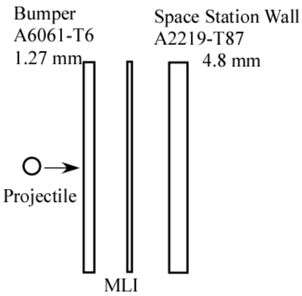
Space debris
over 100 mm = 11,000

International Space Station



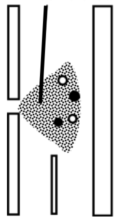
NASA
http://spaceflight.nasa.gov/gallery/images/shuttle/sts-127/html/s127e011212.html

Bumper shields



Whipple bumper

Debris cloud

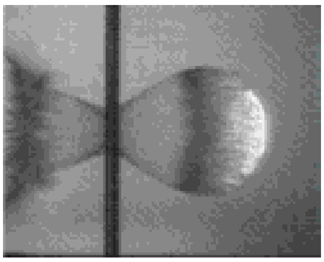


Thin-plate perforation

Debris Cloud & Ejecta Study for Thin Plates

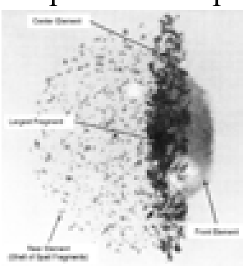
Formation of debris clouds

6 mm Al sphere → Al plate 2 mm
6.7 km/s



K. Thoma, *et al.*, Proc 3rd European Conf on Space Debris, 2001, p. 555-567

12.7 mm Al sphere → Al plate 0.59 mm
6.26 km/s



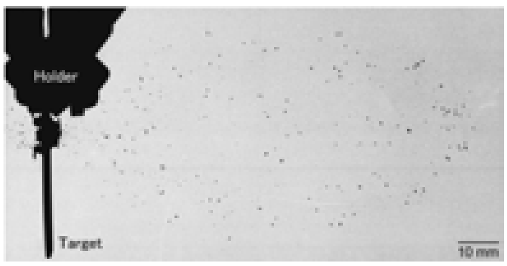
A.J. Piekutowski, Int. J. Impact Engineering, 1997, p. 639-650

Improvements to bumpers

7.9 mm Al sphere → CFRP$[0^{\circ}/45^{\circ}]_6$
1.7 km/s

R. Kubota, *et al.*, J. JSEM, 2010, p. 110-115

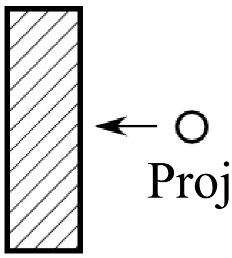
1.01 mm Al sphere → SiC-fiber/Al composite
4.31km/s



H. Tamura *et al.*, Int. J. Impact Engineering, 2011, p. 686-696

Penetration of Thick Targets (1 of 2)

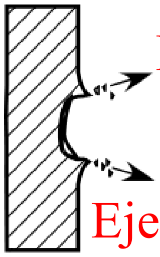
Thick targets



Composition of ejecta

Numata, Kikuchi, Sun, Kaiho, Takayama, Proc JSSW, (2006), pp. 221-222.

Cratering

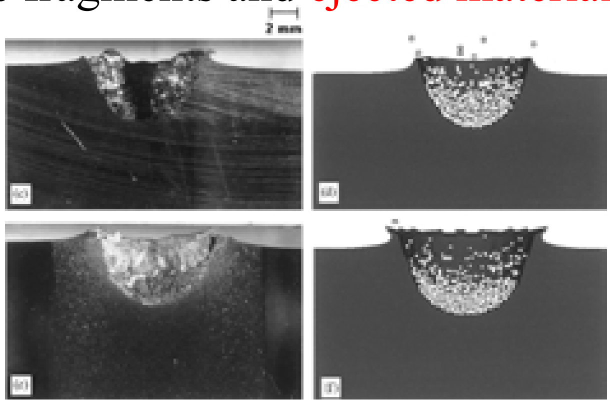


Projectile fragments

Ejecta

Secondary debris in LEO

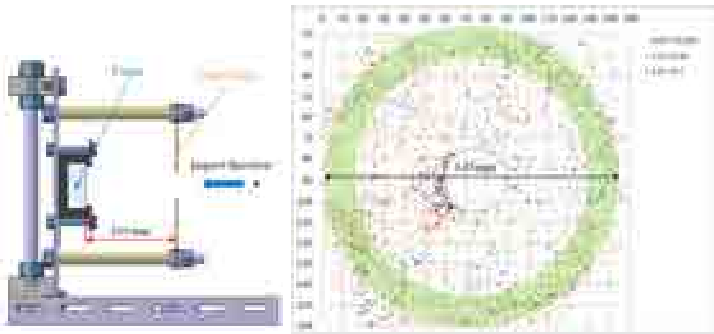
Projectile fragments and ejected materials



Murr, Int. J Impact Eng., (2006), pp. 1981-1999.

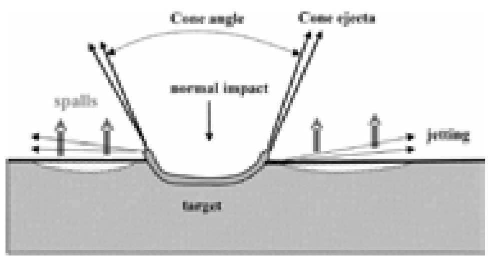
Penetration of Thick Targets (2 of 2)

Distribution chart of impact craters



Sugawara, K *et al.*, 60th International Astronautical Congress, IAC-09-A6.3.06, Daejeon, 2009.

Ejecta production mechanism on a brittle target



Siguier, J.M. & Mandeville, J.C., Proc. IMechE, 221, G, pp. 969-974, 2007.

Draft ISO (ISO/TC20/SC14/CD11227)

International standardization (ISO/DIS11227 "Space Systems – Test procedures to evaluate spacecraft material ejecta upon hypervelocity impact")

Important factors

- Temperature of targets (Nishida *et al.,* Int. J. Impact Eng., 2012, ISTS2013)
- Shape of targets
- Material properties of targets
- Impact velocity of projectiles

(Nishida *et al.*, Int. J. Impact Eng., 2013) [applies to the two items above]

- Material properties of projectiles (Nishida *et al.*, J. JSEM, 2012)
- Shape of projectiles
- Impact angle of projectiles (Proc. DYMAT, 2012)

Objectives of Our Research

To investigate effects of such factors on ejecta & crater shape

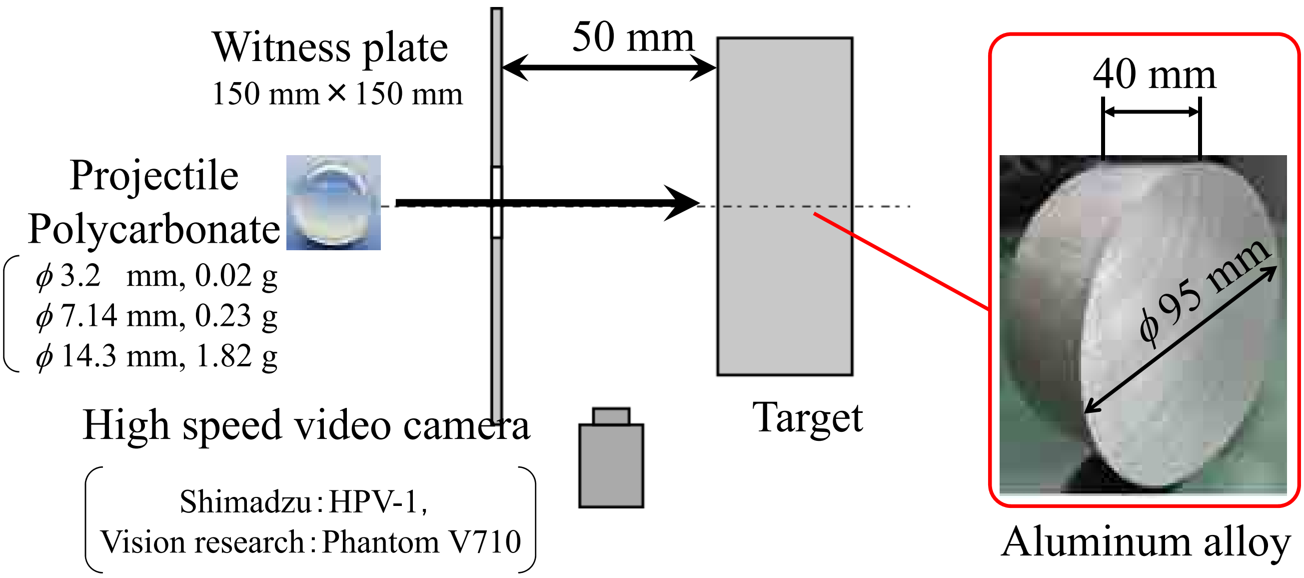
Long Term Goal of Our Research

- Understanding ejecta composition and mechanisms of ejecta formation when projectiles strike thick targets at very high velocities
- Obtaining basic data for new orbital debris models

Effects of Material Properties of Targets

Nishida, et. al, Int. J. Impact Engineering, Vol. 54, (2013), pp. 161-176.

Experimental Setup



	A1100-O	A1100-H	A6061-O	A6061-T6
Tensile strength [MPa]	80	84	124	322
Yield stress [MPa]	42	48	61	287
Vickers hardness	24	35	38	110
Elongation [%]	60	46	30	9

Two-Stage Light Gas-Gun

(ISAS, JAXA)

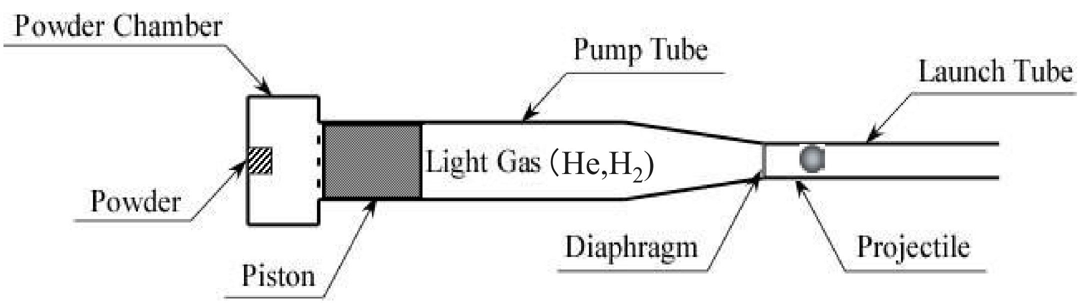
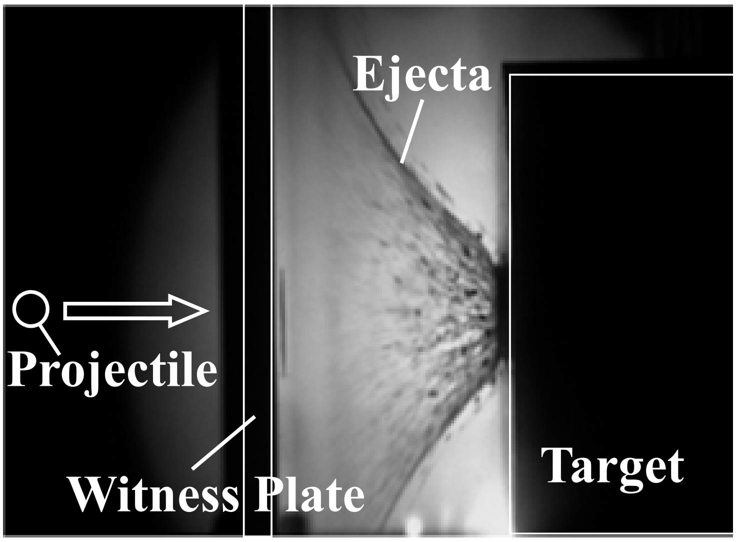


Image by High-Speed Video Camera

A1100-H, 1.98 km/s



16 μs after impact

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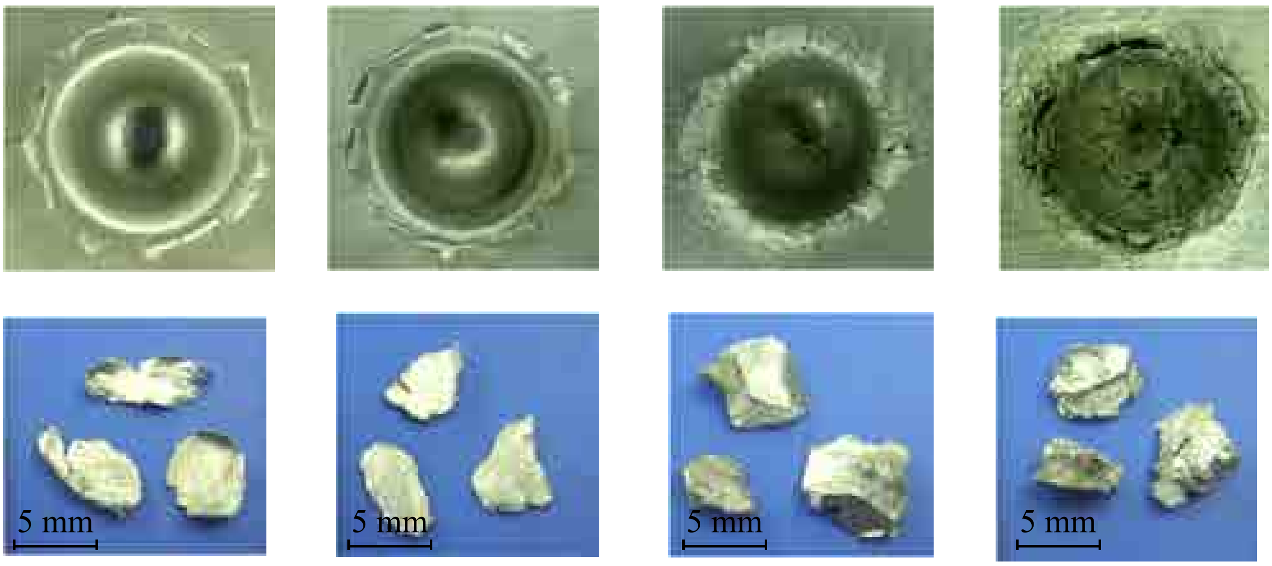
Crater and Ejecta

A1100-O	A1100-H	A6061-O	A6061-T6



6.01 km/s	6.16 km/s	6.24 km/s	6.01 km/s

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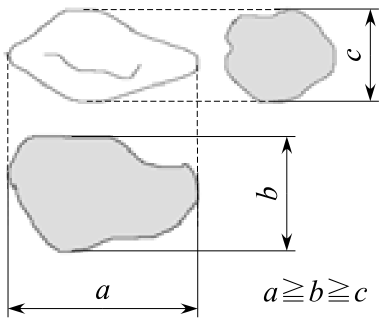
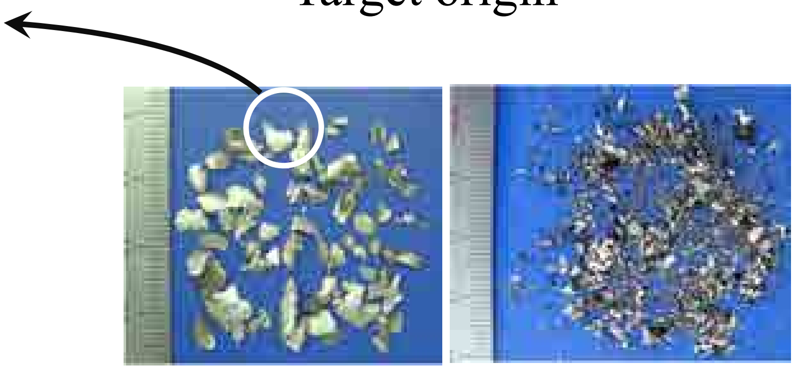
Definition of Ejecta

Measurement of mass distribution & size distribution of ejecta collected from chambers after experiments.



Condition
- Ejecta mass; > 1 mg
- Target origin



> 1 mg   < 1 mg

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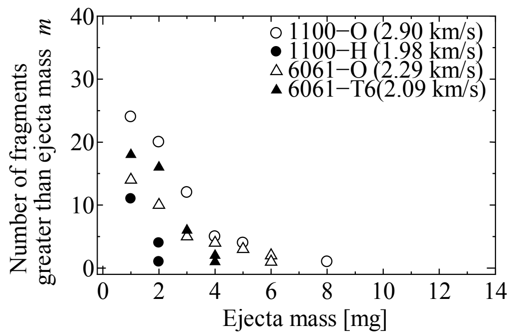
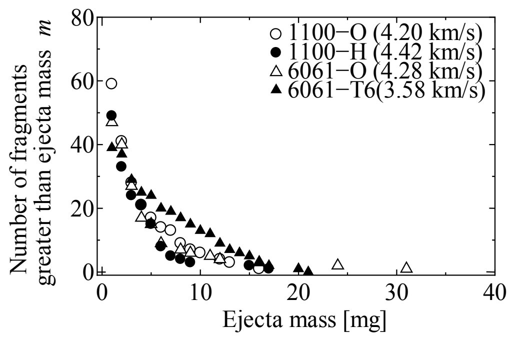
Distribution of Ejecta Mass

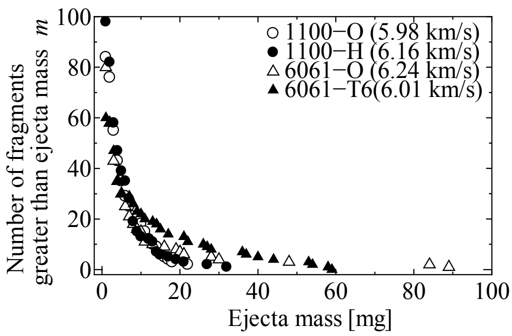
Impact velocity : 2 km/s



1100 < 6061



Impact velocity : 4 km/s



Impact velocity : 6 km/s

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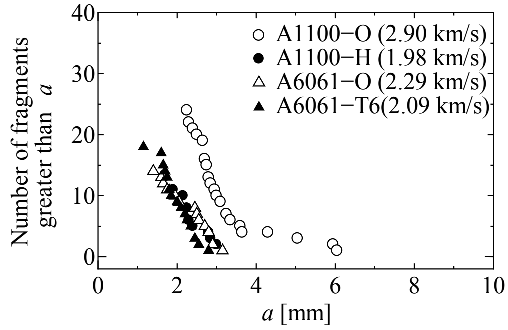
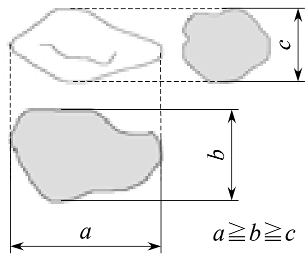
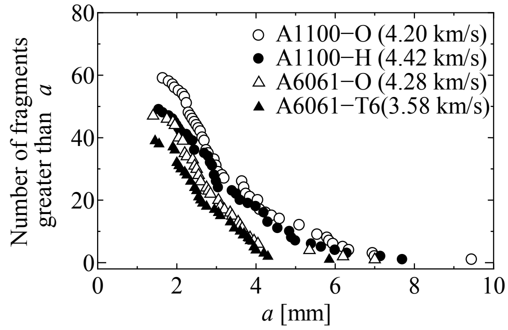
Ejecta Length *a*

Impact velocity : 2 km/s

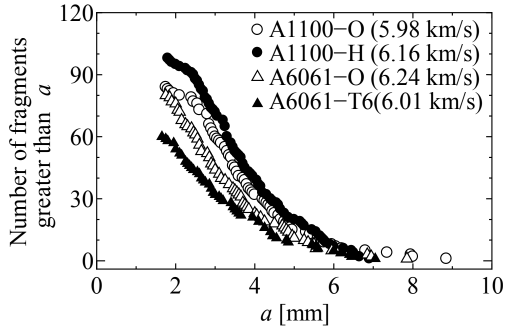




1100 > 6061



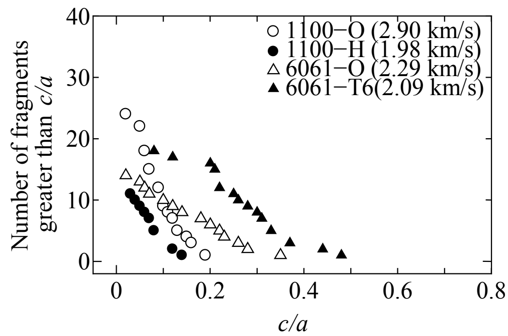
Impact velocity : 4 km/s

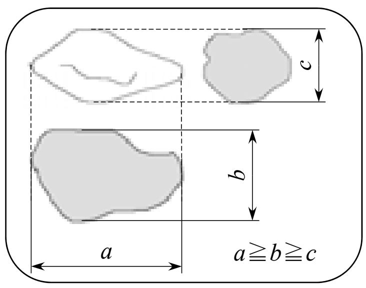


Impact velocity : 6 km/s

Ejecta Thickness, *c/a*

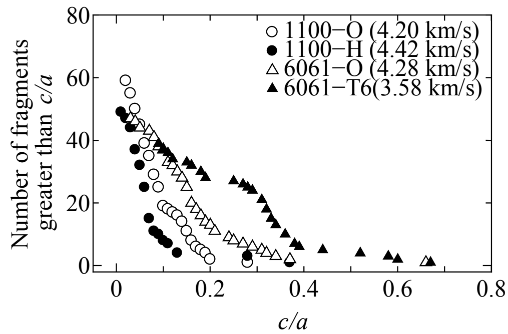
Impact velocity : 2 km/s



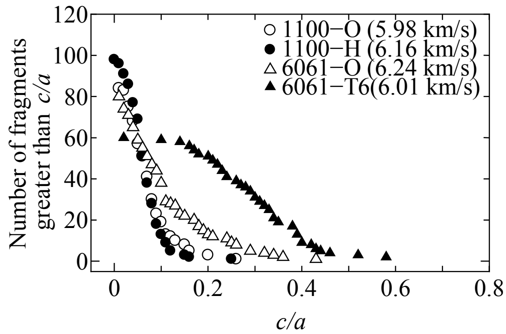


1100 Thinner

6061 Ticker

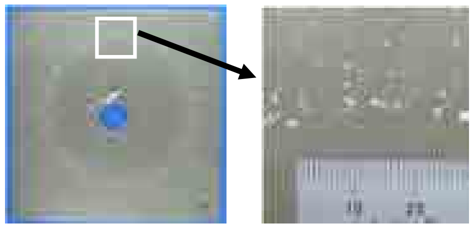


Impact velocity : 4 km/s

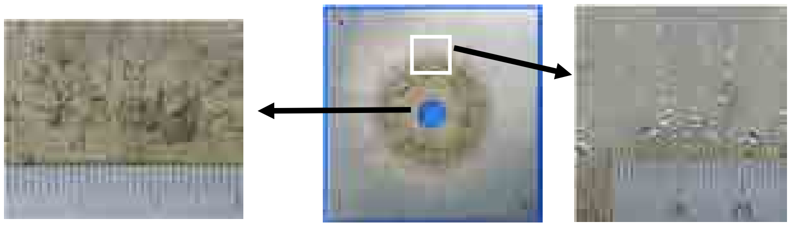


Impact velocity : 6 km/s

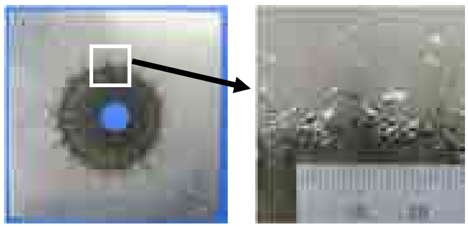
Witness Plates (Aluminum Alloy 1100-O Target)



Impact velocity : 2.90 km/s



Impact velocity : 4.20 km/s



Impact velocity : 5.98 km/s

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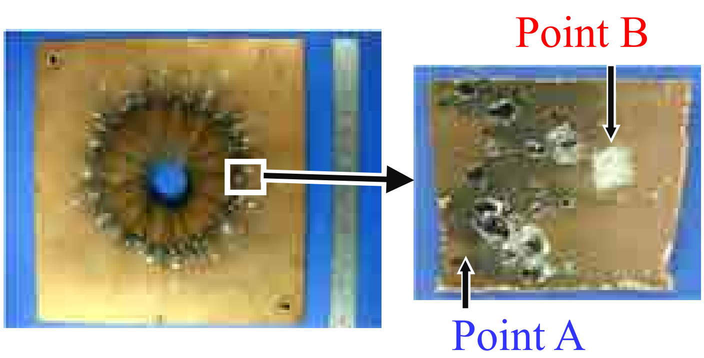
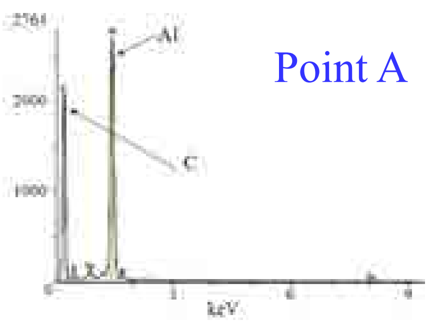
Energy Dispersive X-ray Spectroscopy





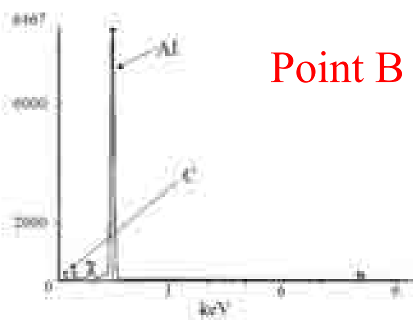


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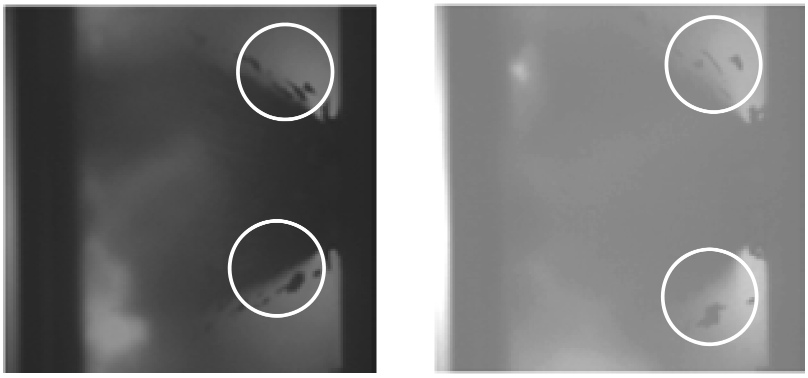
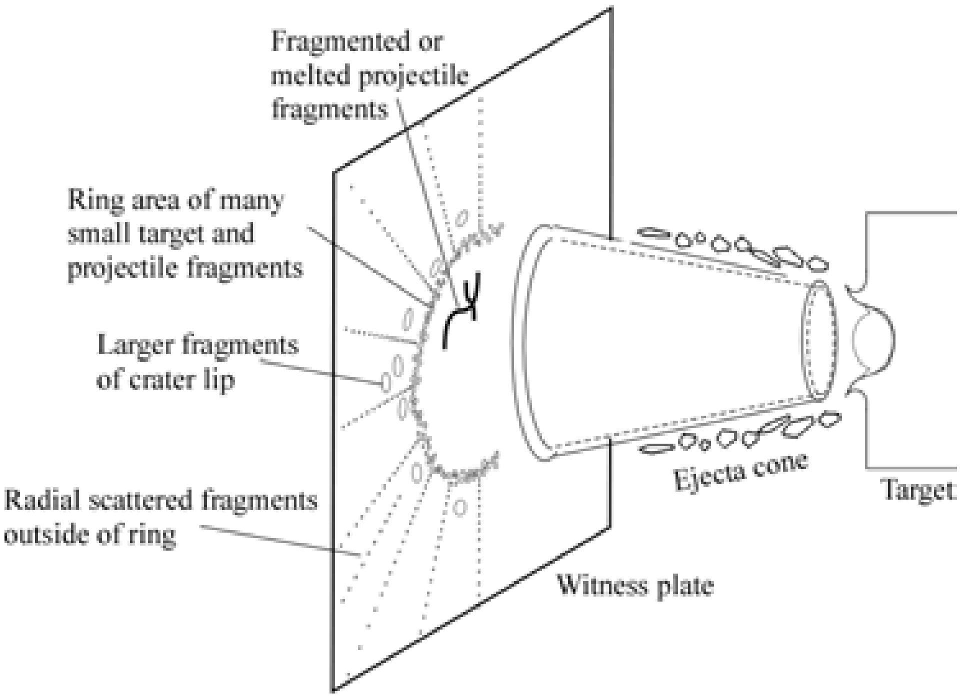
Image of High-speed Video Camera

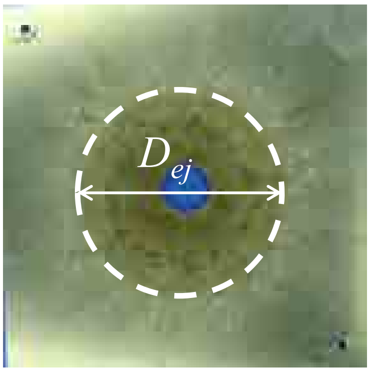


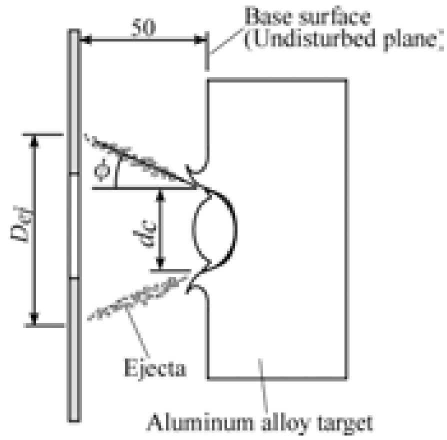
(a) 40 μs after impact (b) 64 μs after impact

Schematic Diagram of Ejecta Composition

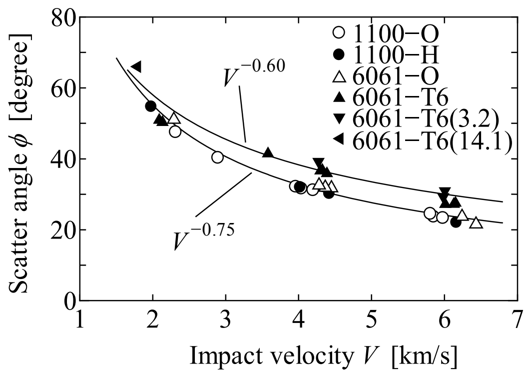


Scatter Angle of Ejecta





$$\phi = \tan^{-1}\left(\frac{D_{ej} - d_c}{2} \times \frac{1}{50}\right)$$



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Similarity Rule

Nishida, et. al, Int. J. Impact Engineering, Vol. 54, (2013), pp. 161-176.

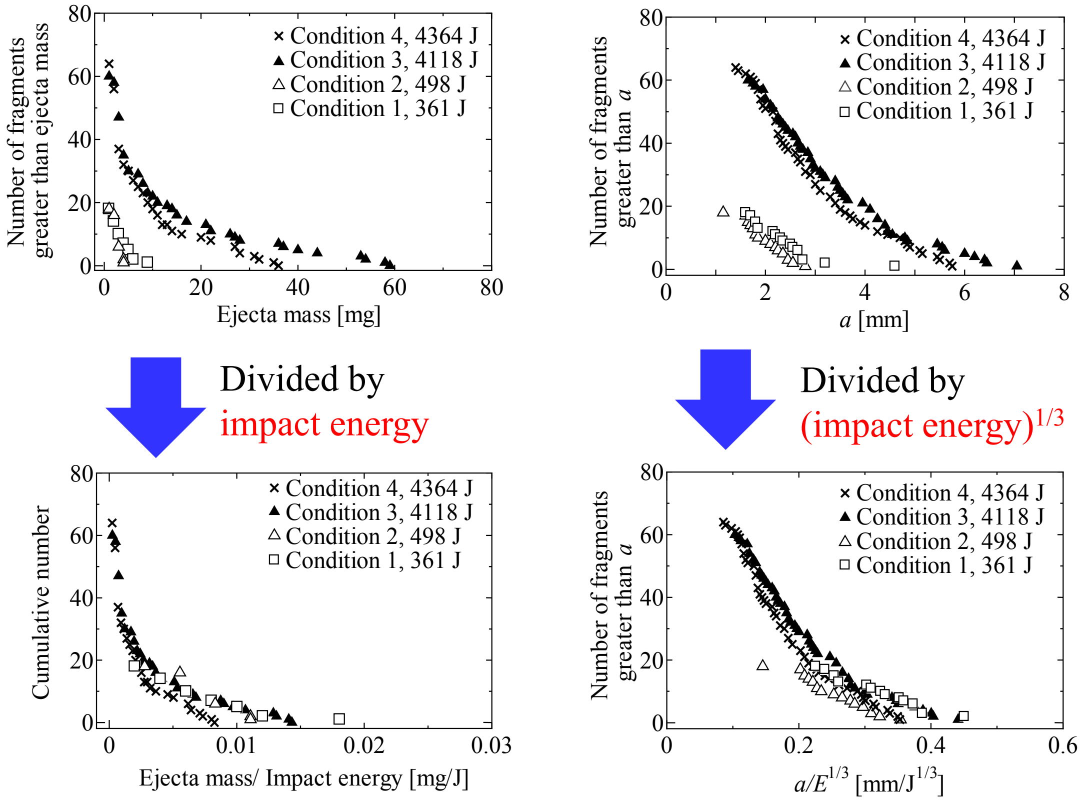
Two-Stage Light Gas-Gun

(Nagoya Institute of Technology)

Experimental Condition

Condition	Projectile diameter	Projectile mass	Impact velocity	Impact energy
1	3.20 mm	0.02 g	6.01 km/s	361 J
2	7.14 mm	0.23 g	2.09 km/s	498 J
3	7.14 mm	0.23 g	6.01 km/s	4118 J
4	14.3 mm	1.82 g	2.19 km/s	4364 J

Ejecta Mass & Ejecta Length



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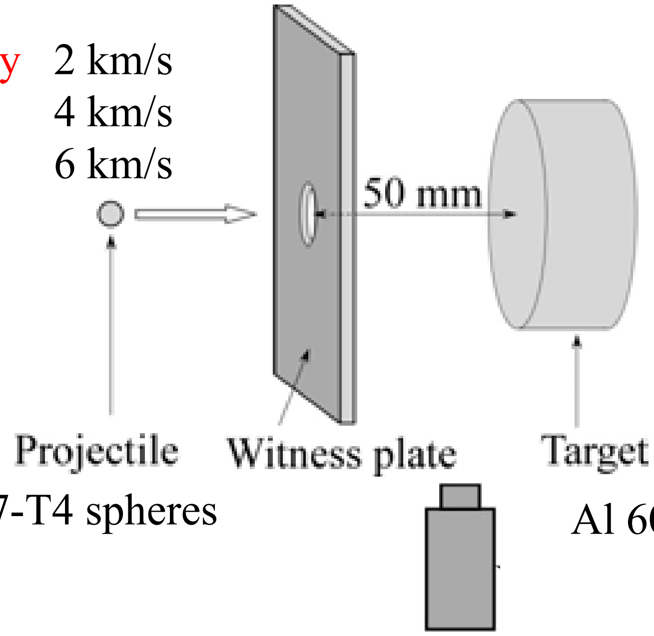
Formulation of Size Distribution (Fragmentation model)

Nishida, et. al, Int. J. Impact Engineering, Vol. 54, (2013), pp. 161-176.

Experimental Setup

Impact velocity 2 km/s
4 km/s
6 km/s

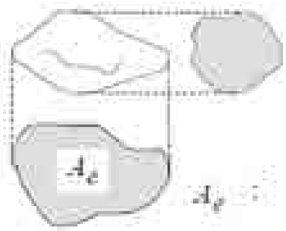


3.2 mm Al 2017-T4 spheres

Al 6061-T6 targets

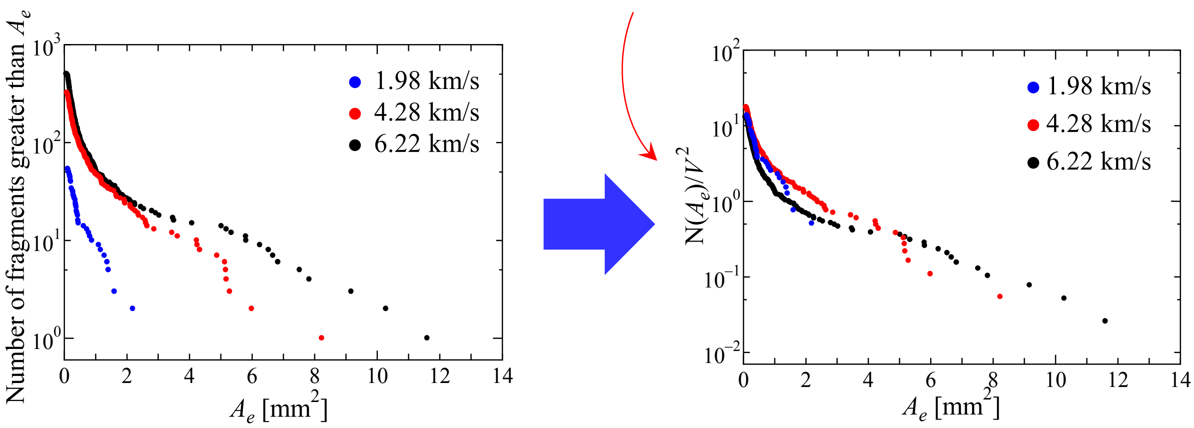
High-speed video camera

Distribution of Projected Area



Projected area of ejecta

Divided by square of impact velocity



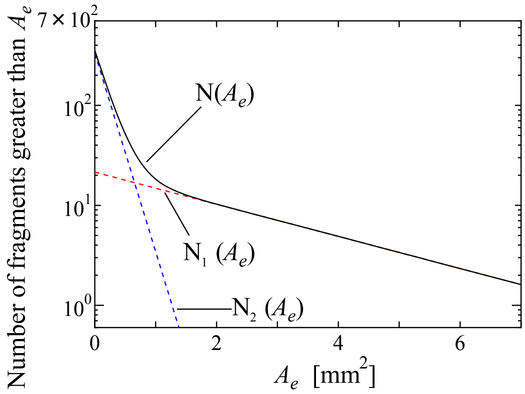
Good agreement

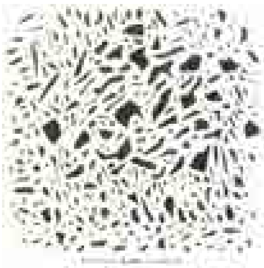
Fragmentation Model

Bi-liner form

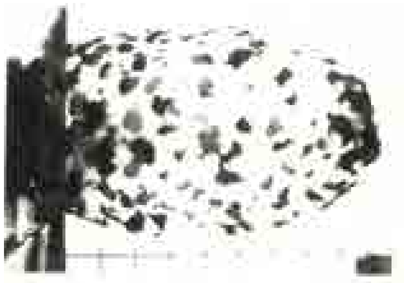
Cumulative number
$N(A_e) = a_1 \exp(a_2 A_e) + a_3 \exp(a_4 A_e)$

Bi-liner exponential description





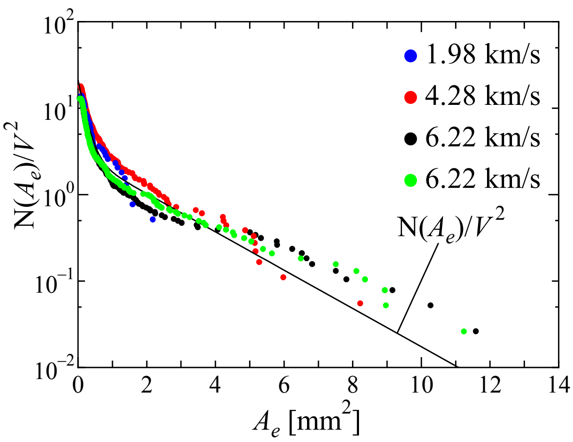
Dynamic fracture of thin plate



Hypervelocity impact of lead (1.5 km/s)

D.E.Grady, M.E.Kipp: APPLIED PHYSICS LETTERS, (2006) 88
D.Grady, Shock Wave and High Pressure Phenomena,(2006) 7-32

Projected Area Distribution of Ejecta Fragments



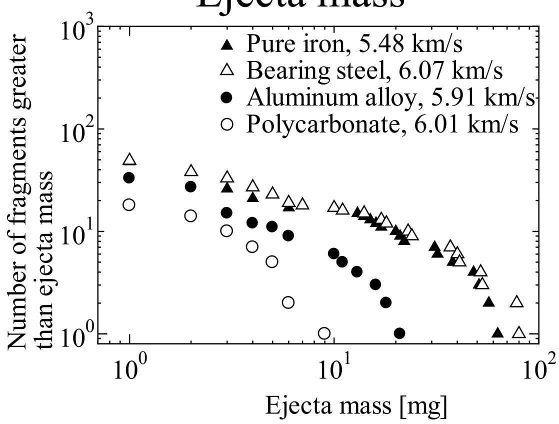
Bi-liner exponential description

$$\frac{N(Ae)}{V^2} = 18.48\exp(-5.07Ae) + 2.85\exp(-0.51Ae)$$

Effects of Projectile's Materials & Impact Angle of Projectiles

Effects of projectile's materials

Ejecta mass

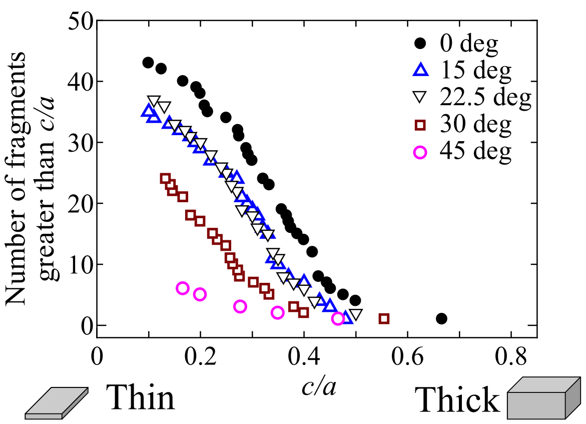


3.2 mm projectiles impacting on aluminum alloy 6061-T6 target (Impact velocity of 6 km/s)

Nishida et al., J. JSEM, 2012

Effects of impact angle

c/a



14.4 mm polycarbonate spheres impacting on aluminum alloy 6061-T6 target (Impact velocity of 1.8 km/s)

Nishida et al., Proc. DYMAT, 2012

Summary

1. Ejecta mass and ejecta size distributions were examined in detail.
   - Material properties of targets
   - Impact velocity of projectiles
   - Material properties of projectiles
   - Impact angle of projectiles
2. Ejecta composition was proposed.
3. Scatter angle of ejecta depended on impact velocity.
4. Experimental formula of fragment size distribution were created.
5. Similarity rule was discussed for predicting ejecta size resulting from hypervelocity impacts of small projectile (<1mm).

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Thank you for your kind attention

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JSPS 日本学術振興会 Japan Society for the Promotion of Science

NITTO 日東工業株式会社