「日本における超高速衝突実験の現状と将来展望」
2011 年12 月12-13 日，神戸大学惑星科学研究センター

名古屋工業大学の二段式軽ガス銃 および これまでの研究

名古屋工業大学　機械工学科
西田政弘

国立大学法人
名古屋工業大学

２段式軽ガスガン（横置き型）

1996年　東北大学　高山先生から　名工大　田中皓一先生へ
（同型が九州工業大学　赤星先生へ）

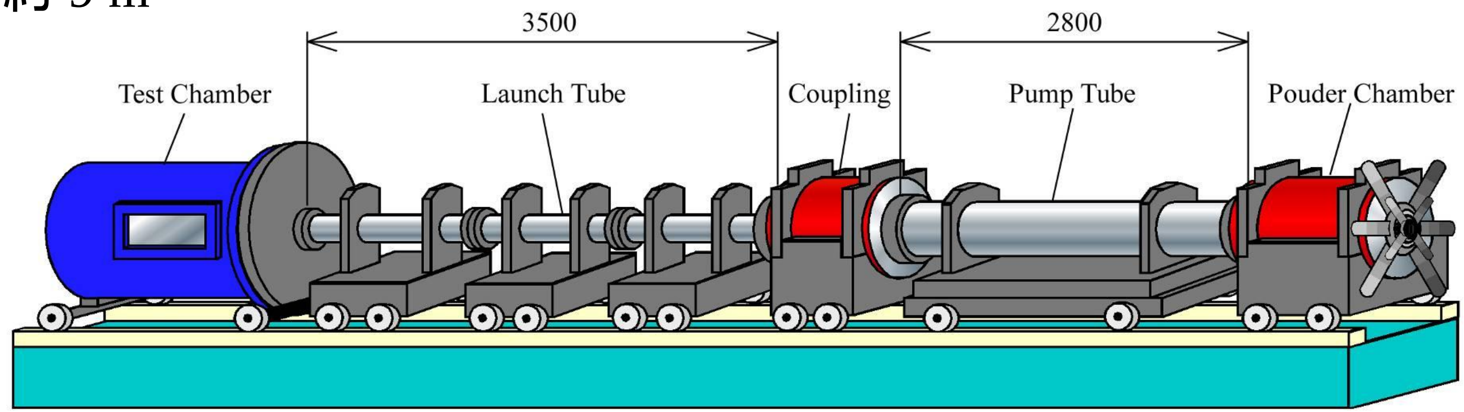
1997年　西田が名工大へ異動

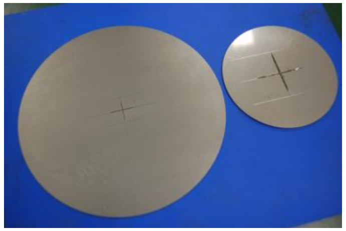
2009年　田中皓一先生のご退職 （現在:中部大）

現在　　運転スタッフ: 常勤２名＋学生2-３名
定常発射頻度:　最大で，一日 ３発

全長:　約 9 m

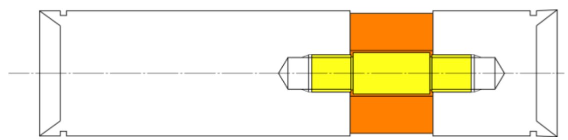
ヘリウム: He, 0.4 MPa

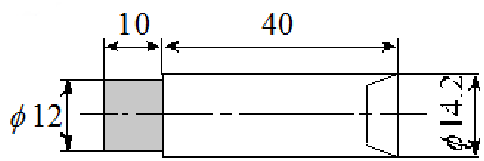




隔壁（ダイヤフラム）
ステンレス製

圧縮管の内径: 60.63 mm
ピストン





加速管の内径:14 mm
（発射管）

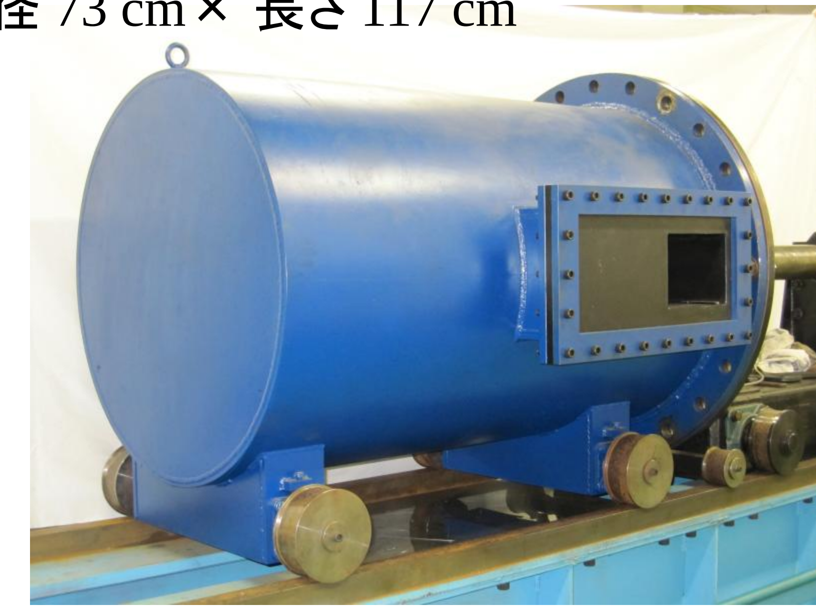
- 試料＋　φ 14 mmのサボ
- アルミ φ 14 mm (2009~)
- サボ分離を試行中
  （飛翔体サイズの小径化）

↓

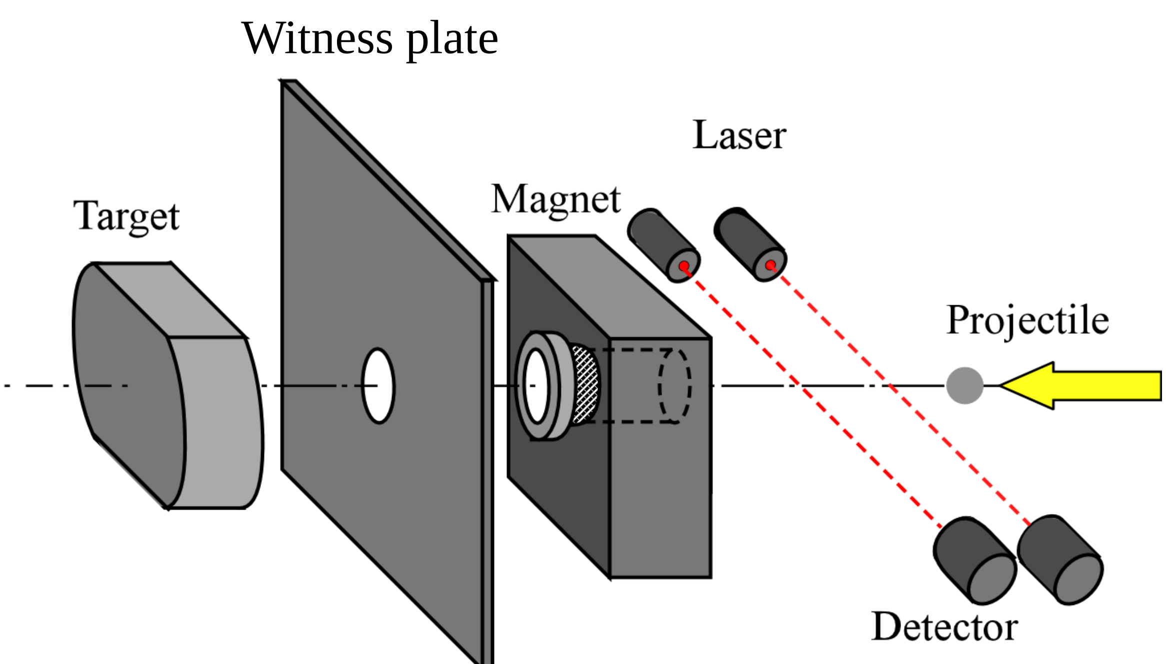
これまでの主な研究：
厚板のクレーター形成

チェンバー:
直径 73 cm × 長さ 117 cm

チェンバーの内側



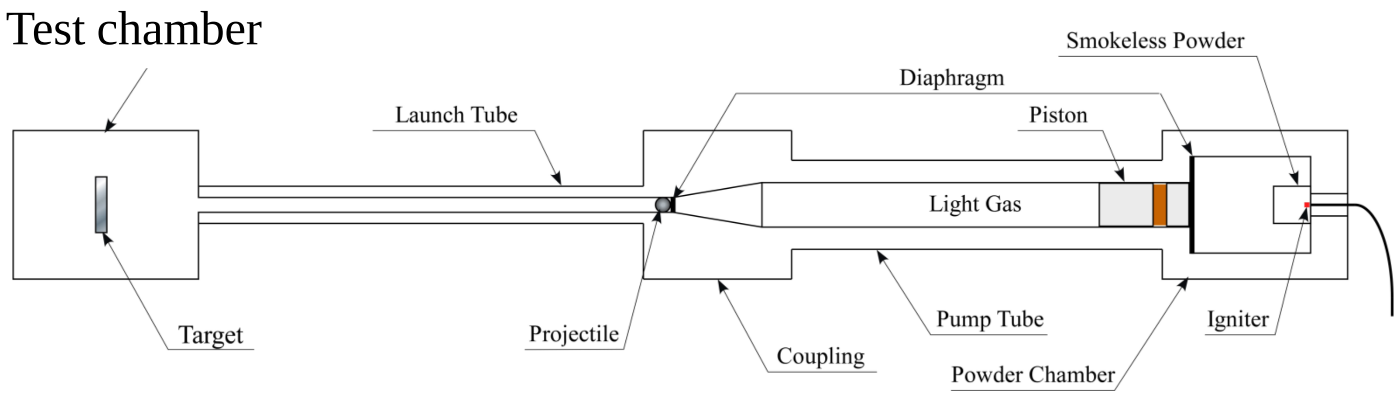
チェンバーの外観



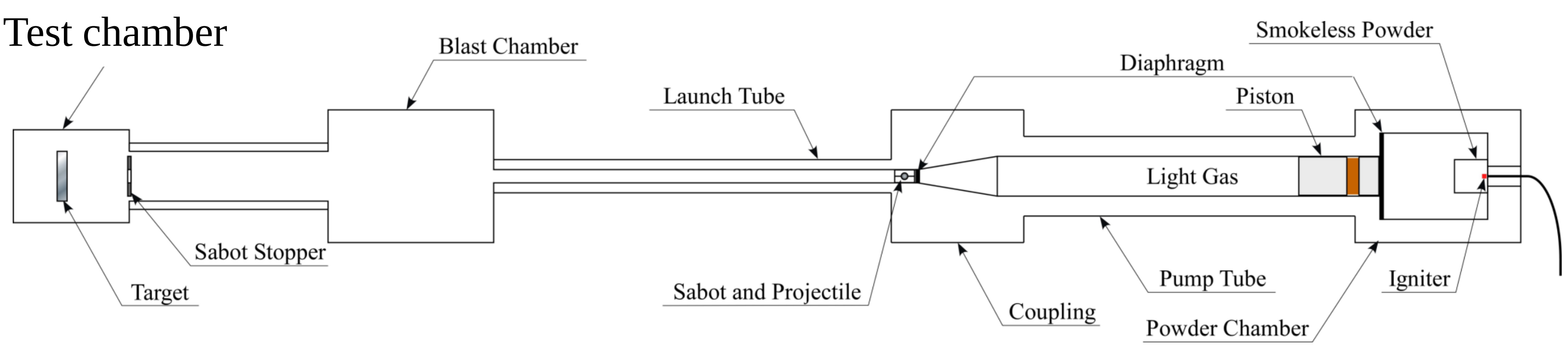
衝突速度: 0.8 ～ 4.0 km/s

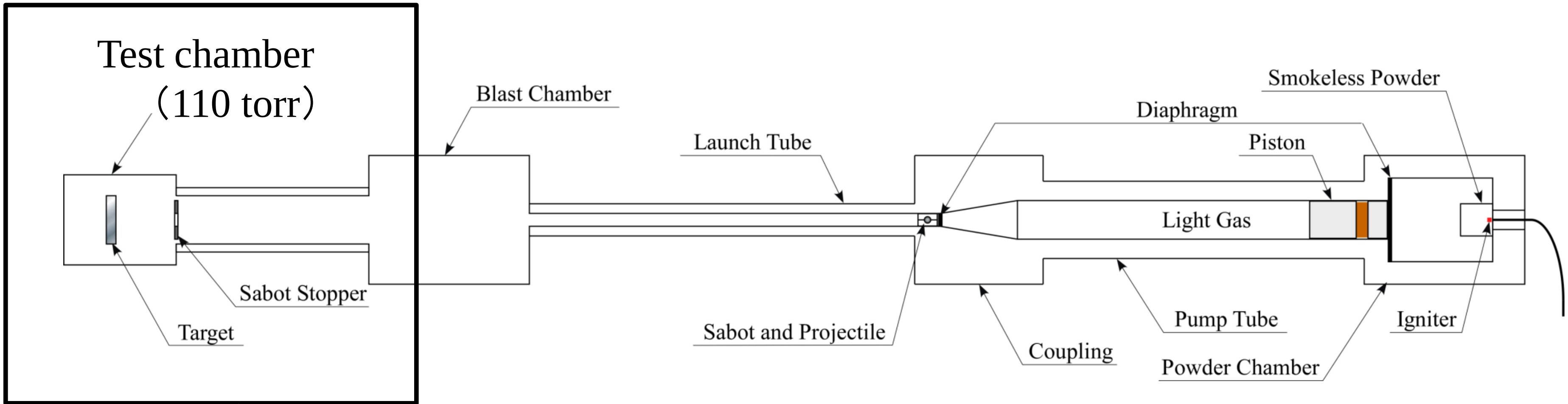
- レーザー式
- 電磁誘導式
- ピンコンタクト式

改良前



サボ分離のために改良



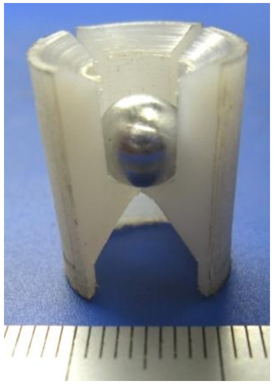


改良後のチェンバー（写真）

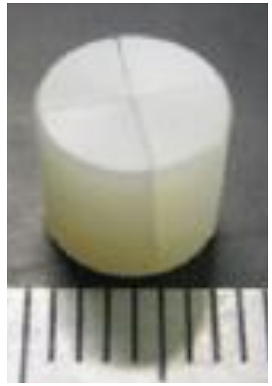
サボ

スリット式

名古屋工業大学



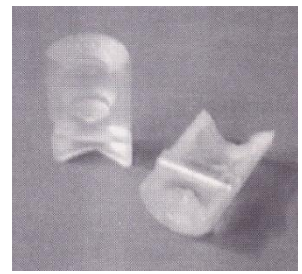
JAXA



分割式

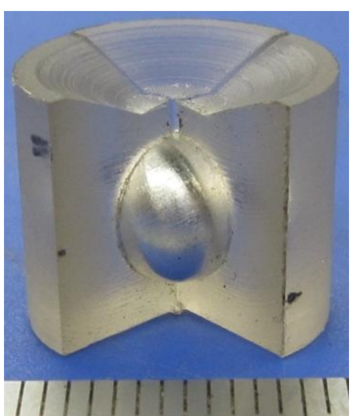
東北大学

九州工業大学

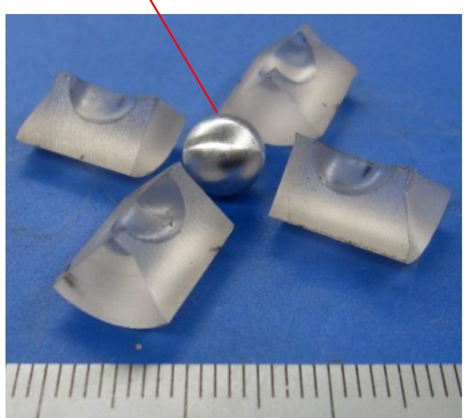


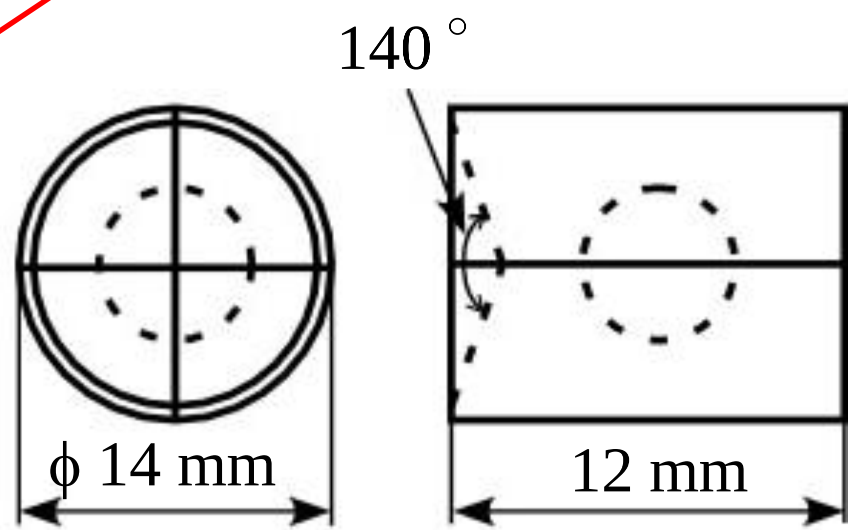
EMI
(Ernst Mach Institute)

サボの改良（現在のサボ）



φ = 7 mm



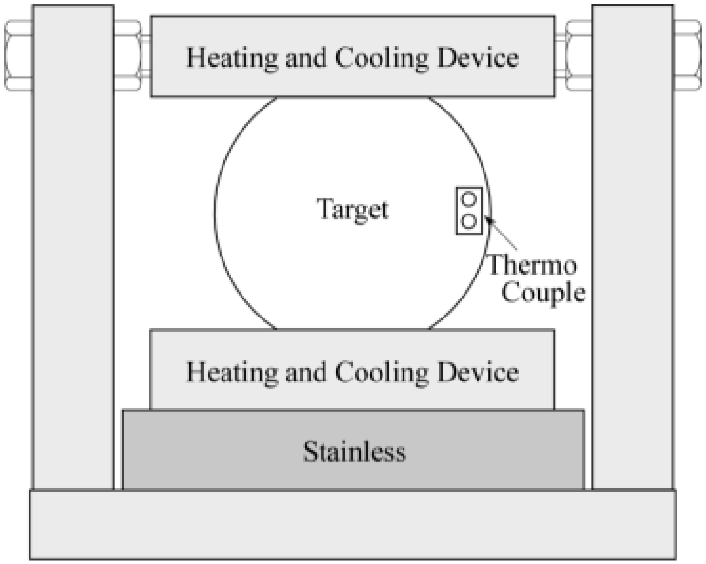


・計測機器　：　オシロスコープ２台
（岩通　WaveRunner DS-4264MとDS-4264ML)

回転鏡式高速度カメラ（株式会社 サンピコ　TS-4D）

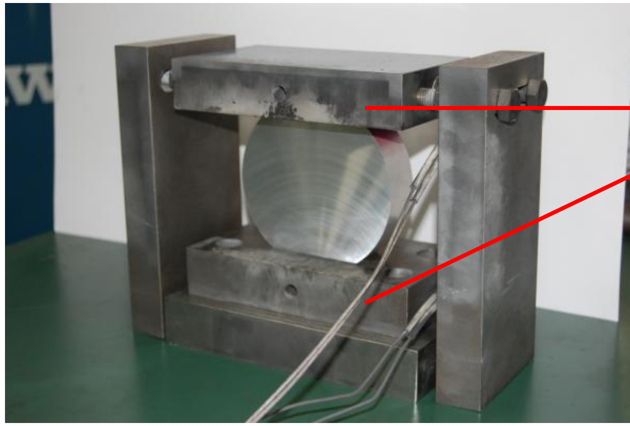
圧力センサー（Dynasen Model Ck2-50）

・標的（ターゲット）の温度
－150℃ ～ ＋200℃



標的（ターゲット）温度の影響

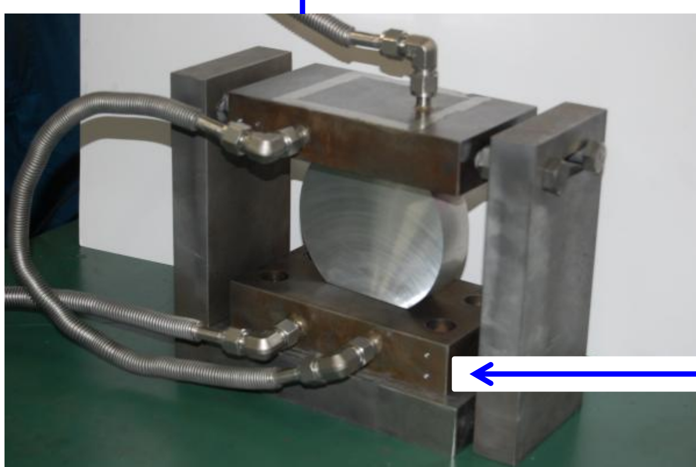
加熱装置
（＋200℃）



カートリッジヒーター
｜
変圧器

冷却装置
（－150℃）

液体窒素
↑



液体窒素
↓

チェンバーの外側

名工大でのガスガンを用いた研究成果

飛翔体　標的

1. K.Tanaka et al., IAC54, (2003).　Steel → 低温
   (Science and Technology 109 (2004) pp. 319-334)　Steel

2. K.Tanaka et al., HVIS-2005, (2005).　Steel → 低温
   (Int. J. Impact Eng. 33, (2006) pp. 788-798.)　Al

3. K.Tanaka et al., HVIS-2007, (2007).　Al → Al
   (Int. J. Impact Eng. 35, (2008) pp. 1821-1826.)　NaCl

4. M. Nishida et al., J. Space Eng, 2-1, (2009) pp. 51-60.　Steel → 薄板＋Al

5. M. Nishida et al., HVIS-2010, (2010)　SiO_2 → Al

6. Nishida et al., Int. J. Impact Engng. (2012), Thermec 2011　Al → 高温，低温
   ターゲット温度がクレータ形状および　Al
   エジェクタに与える影響

エジェクタに与える影響

↓

Important factors

- Temperature (Nishida et al., Int. J. Impact Engng. 2012)
  (Proc Thermec 2011)
- Impact velocity (Nishida et al., Proc. ICHSIP-29, 2011)

- Impact angle
  (日本機械学会 M&M2011材料力学カンファレンス2011)
  (第48回日本航空宇宙学会関西・中部支部合同秋期大会2011)

- Material properties of projectiles (Nishida et al., 6th ISEM 2011)

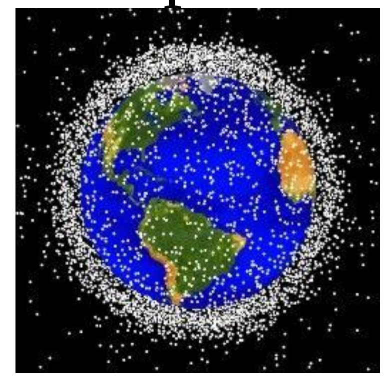
- Material properties of targets
  (第54回宇宙科学技術連合講演会2010)
  (高速度イメージングとフォトニクスに関する総合シンポジウム2011)

ターゲット温度がクレータおよび エジェクタに与える影響

(Nishida et al., Int. J. Impact Engng. 2012, Proc Thermec 2011)

Background

Image of space debris



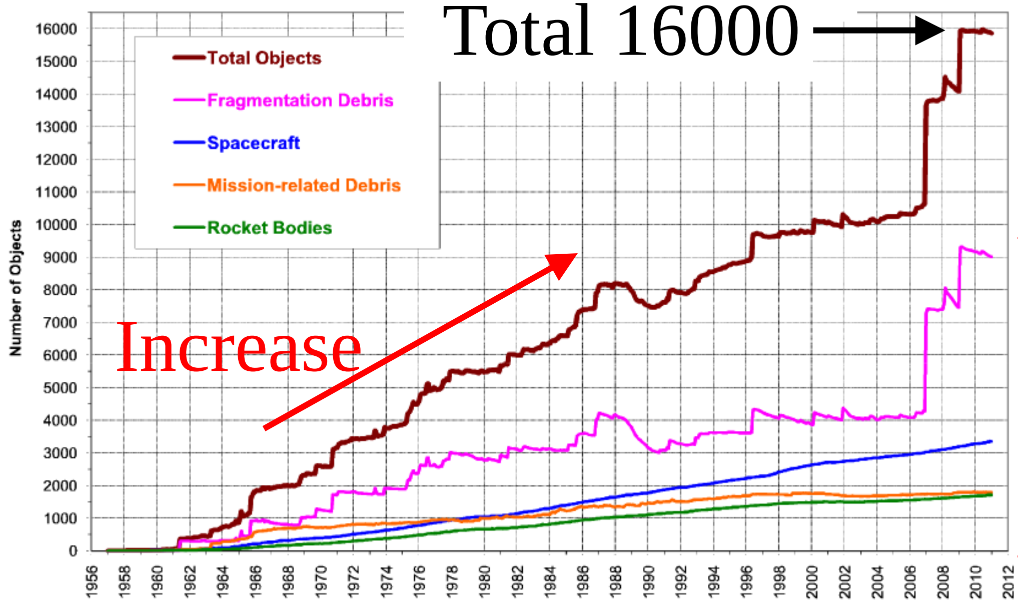
Low Earth orbit (LEO)

NASA Orbital Debris Program Office

http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html#leo

Number of cataloged objects

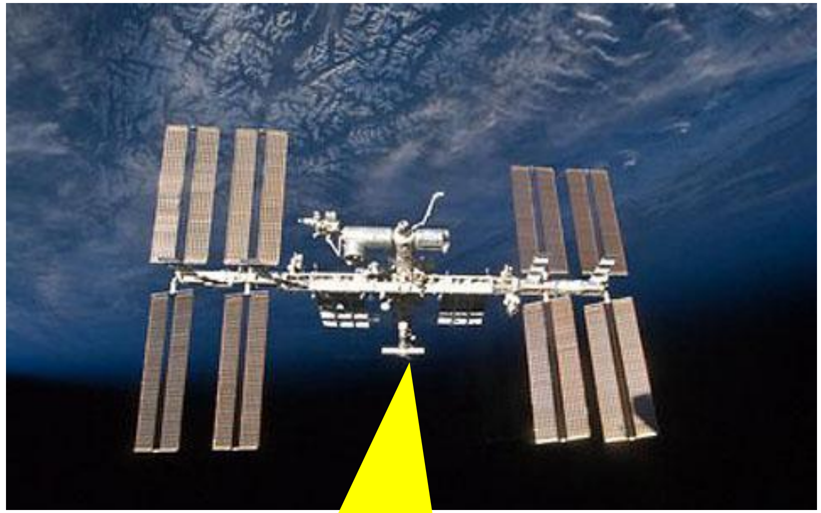
Total 16000



Debris Quarterly News, vol. 15, Issue 1, 2011

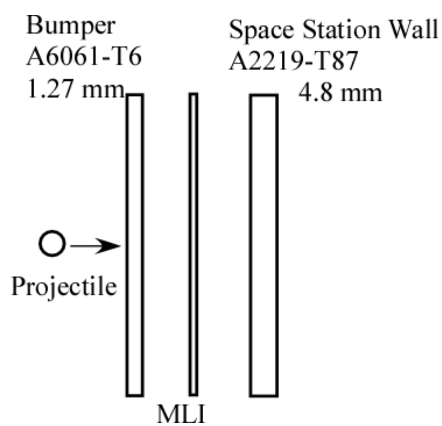
Space debris
over 100 mm = 11,000

International Space Station



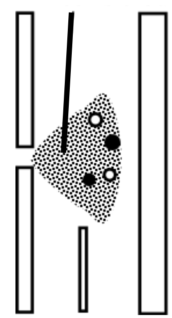
NASA
http://spaceflight.nasa.gov/gallery/images/shuttle/sts-127/html/s127e011212.html

Bumper shields



Whipple bumper

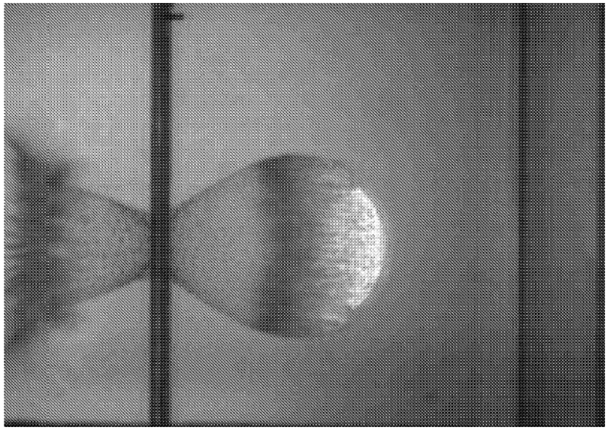
Debris cloud



Thin-plate perforation

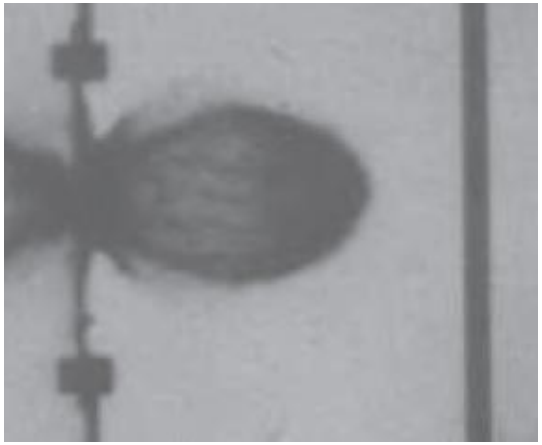
Debris Cloud & Ejecta Study

6mmアルミ球→アルミ板1.2mm，6.7km/s



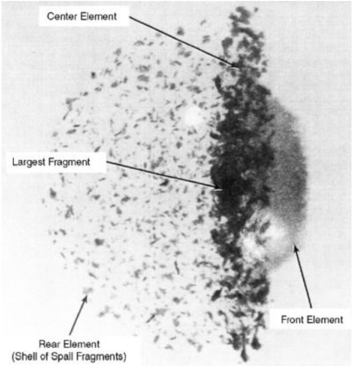
K. Thoma, et al.: Proc 3rd European Conf on Space Debris, 2001, p. 555-567.

7.9 mmアルミ球→CFRP[0º/45º]$_6$，1.7km/s



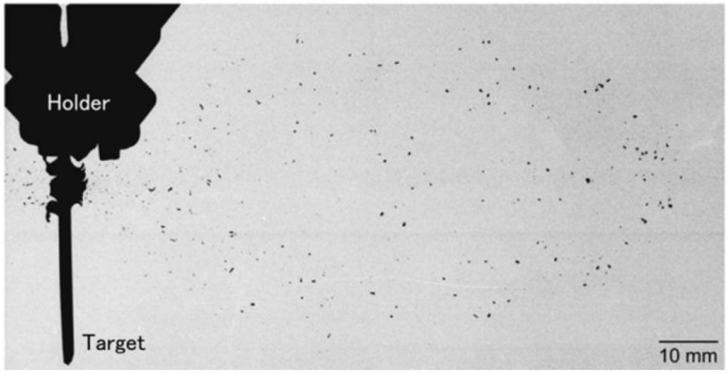
久保田他，実験力学, 2010, p. 110-115.

12.7mmアルミ-球→アルミ板0.59mm, 6.26km/s



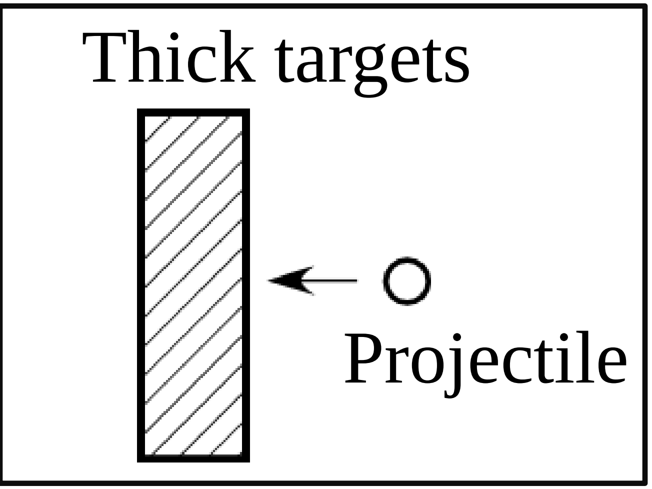
A.J. Piekutowski: Int. J. Impact Engineering, 1997, p. 639-650.

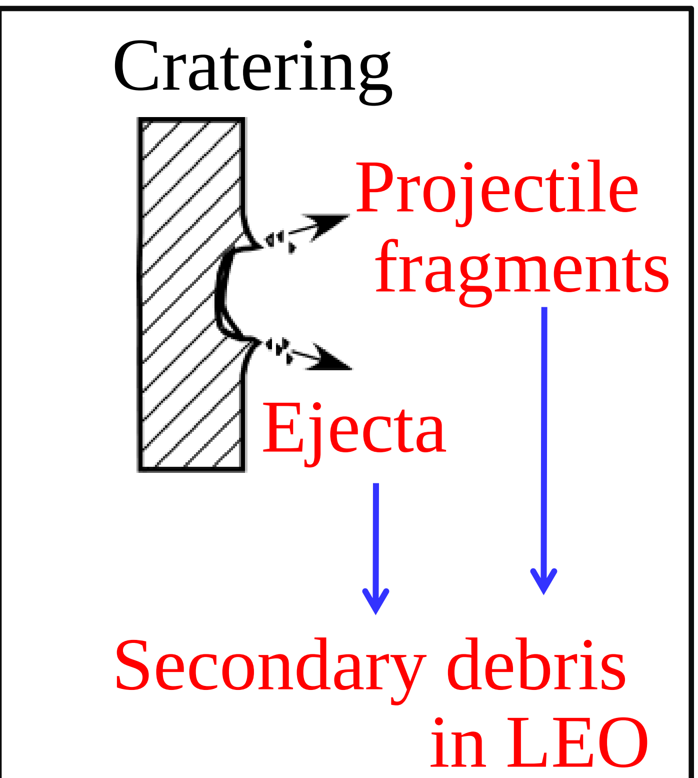
1.01アルミ球→ SiC-fiber/アルミ 複合材料, 4.31km/s



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

Penetration of Thick Targets (1 of 2)

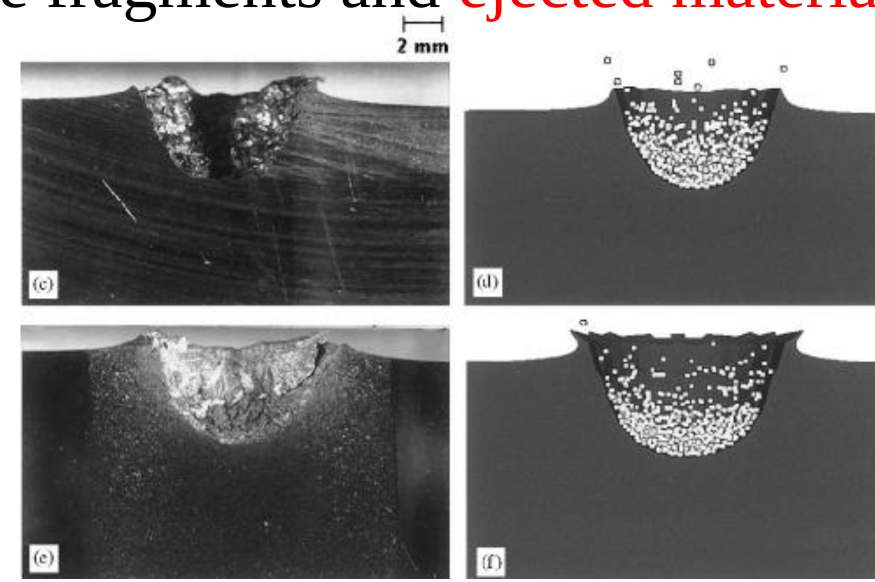




Composition of ejecta

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

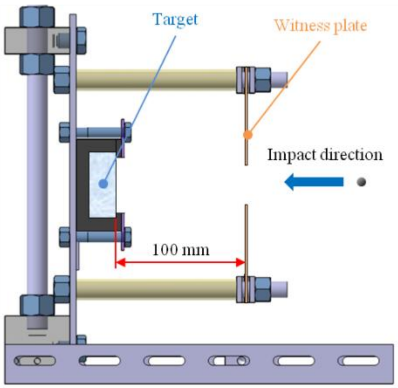
Projectile fragments and ejected materials

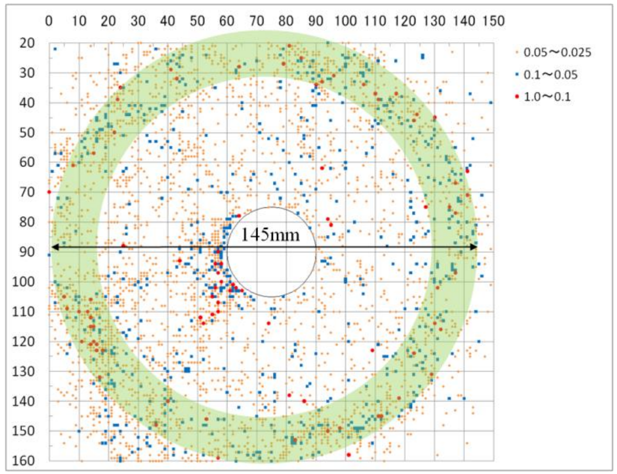


Murr, Int. J Impact Eng., (2006), pp. 1981-1999.

Penetration of Thick Targets (2 of 2)

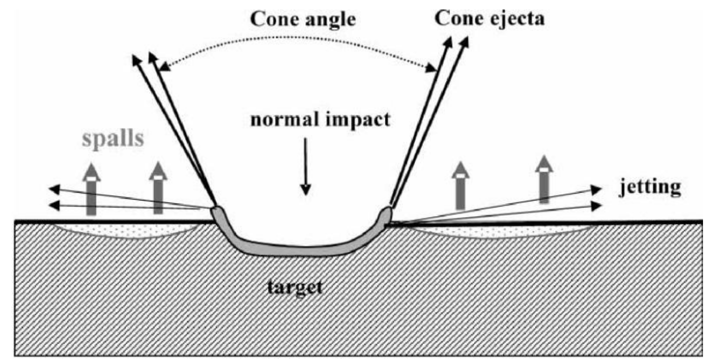
Distribution chart of impact craters





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

- Impact velocity (Nishida et al., Proc. ICHSIP-29, 2011)
- Impact angle (Nishida et al., DYMAT, 2012)
- Material properties of projectiles (Nishida et al., 6th ISEM 2011)
- Material properties of targets
- Temperature (Nishida et al., Int. J. Impact Engng. 2012, Thermec 2011)

Objectives of Our Research

To investigate effects of temperature on crater size & ejecta

Long Term Goal of Our Research

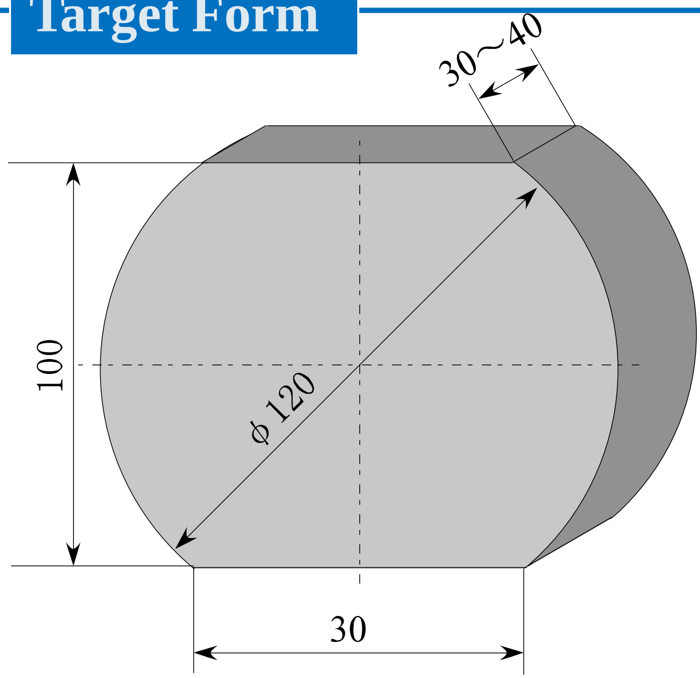
- Understanding ejecta composition and mechanisms of ejecta when projectiles strike thick targets at very high velocities
- Obtaining basic data for new orbital debris models

Test Chamber

Projectile

A2017-T4 , Spherical
Size : ϕ 14.2 mm
Mass : 4.17 g

Target Form



Aluminum alloy 6061-T6

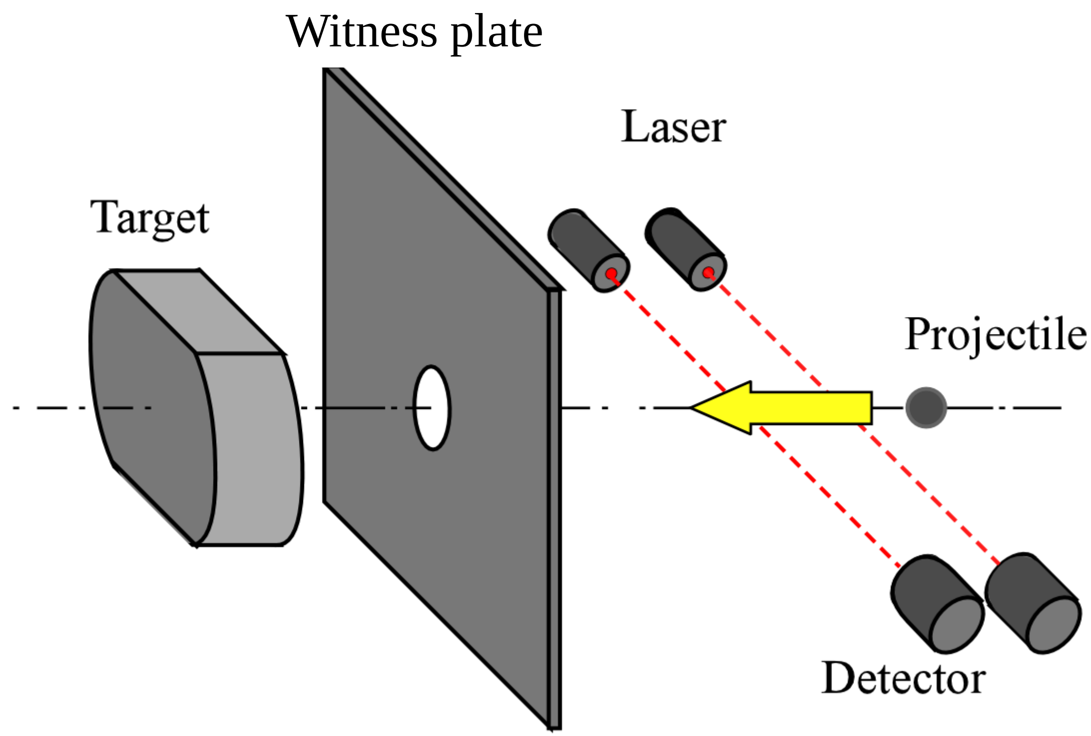
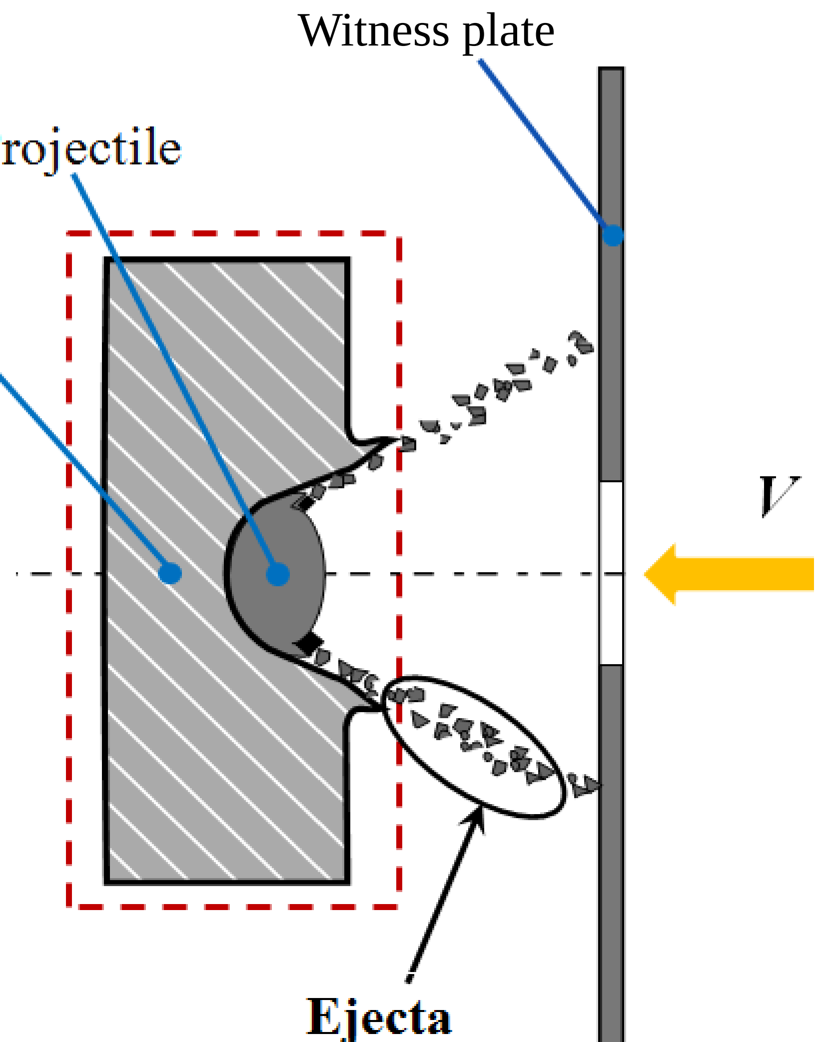


Table 1 Material properties of aluminum alloy 6061-T6

Temperature [°C]	+205	+25	-196
Elastic modulus [GPa]	77	70	63
Tensile strength [MPa]	130	310	415
Yield stress [MPa]	105	275	325
Elongation at break [%]	28	17	22
Temperature [°C]	+200	+25	-150
Vickers hardness	100	110	128

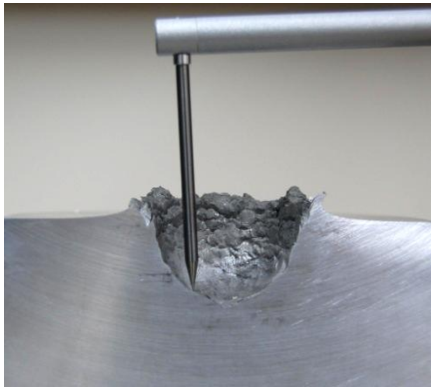
Composition Crater & Ejecta

After the impact
(2.59 km/s Room Temperature)

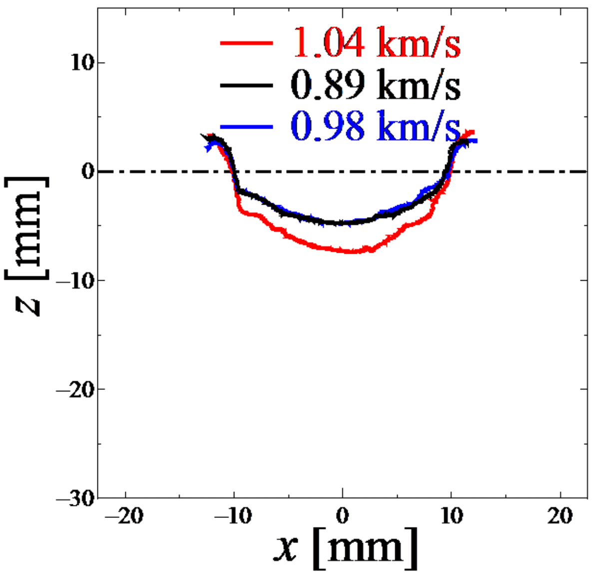


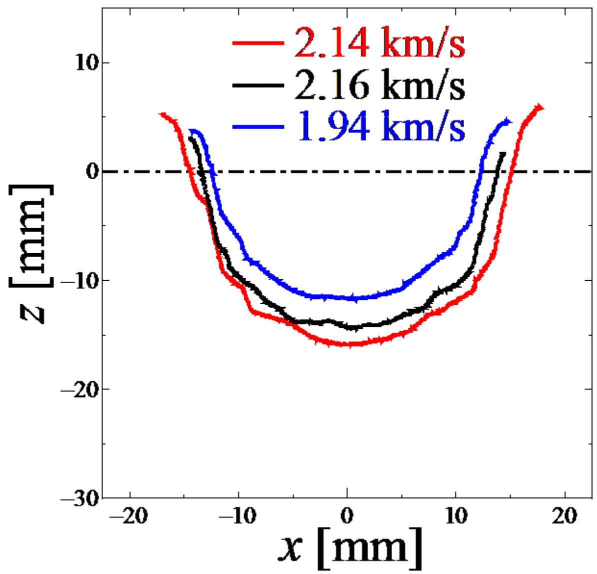
Crater Shape

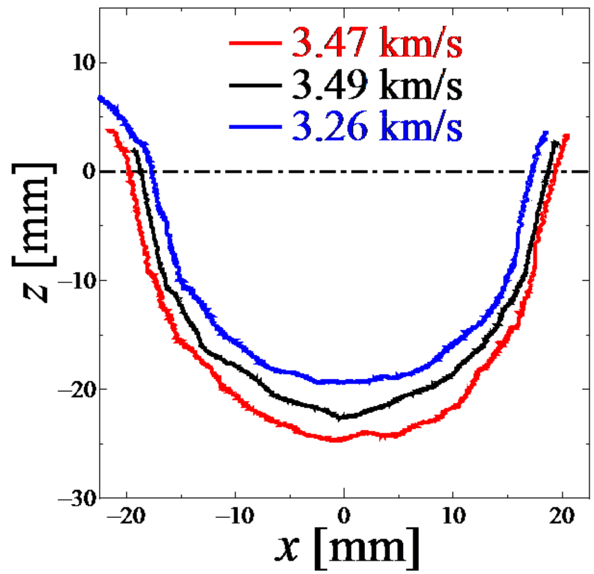
High Temp.
Room Temp.
Low Temp.



Outline measurement device

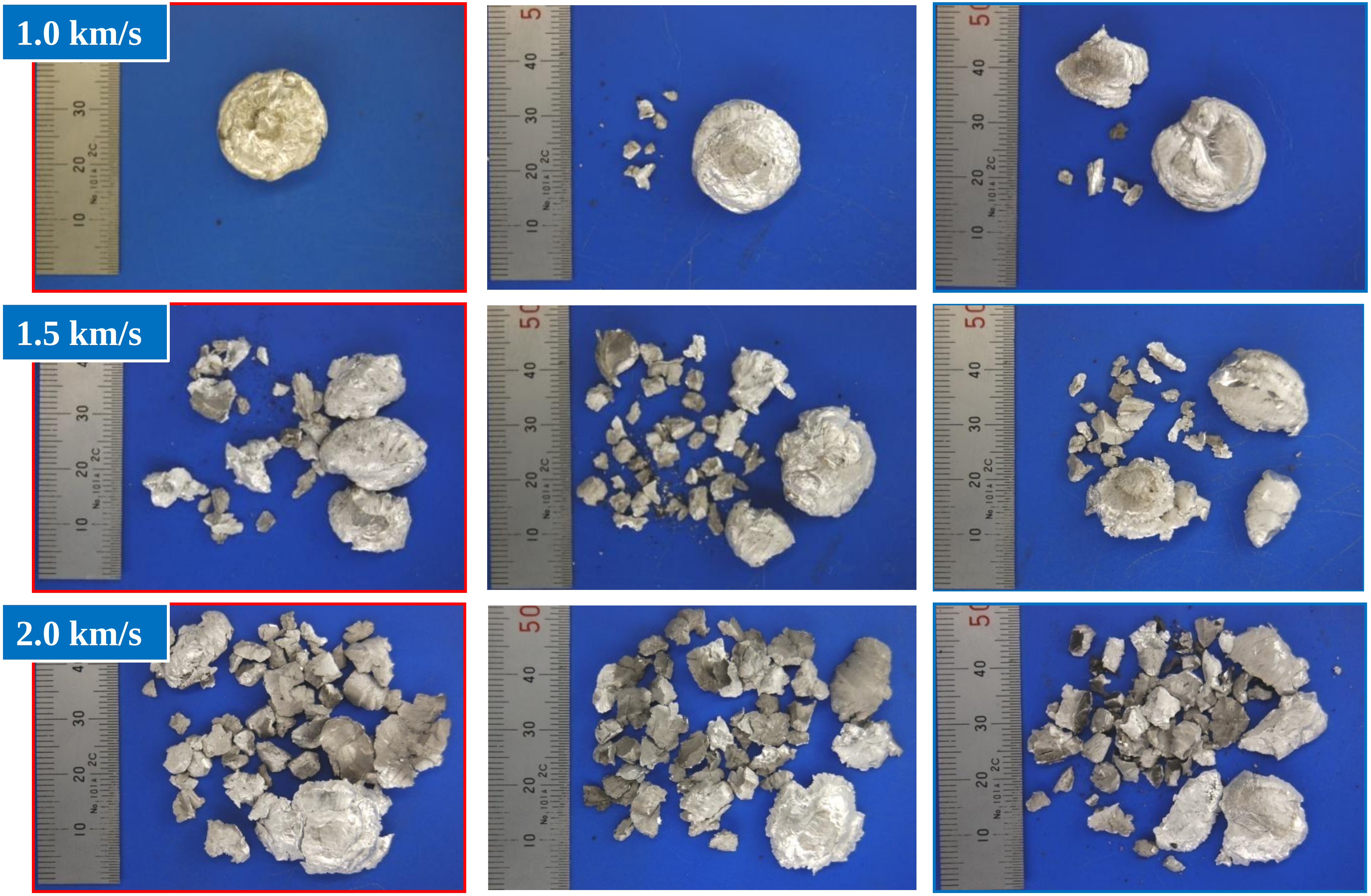




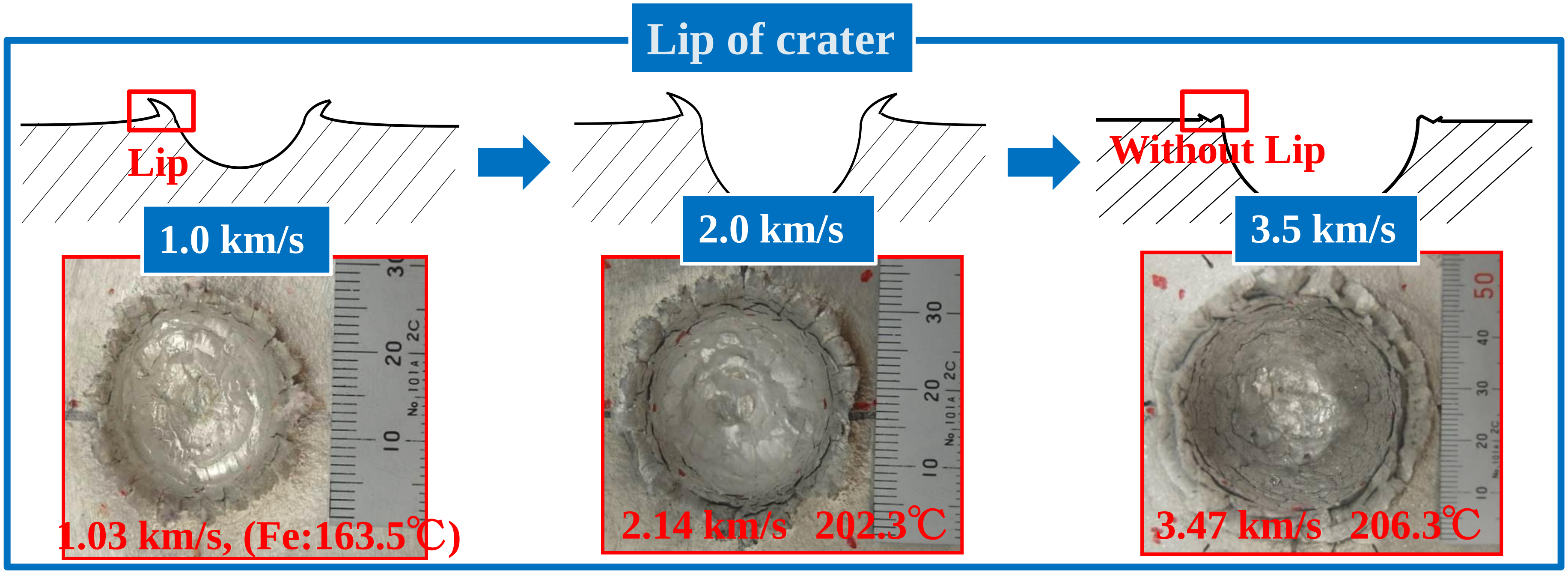


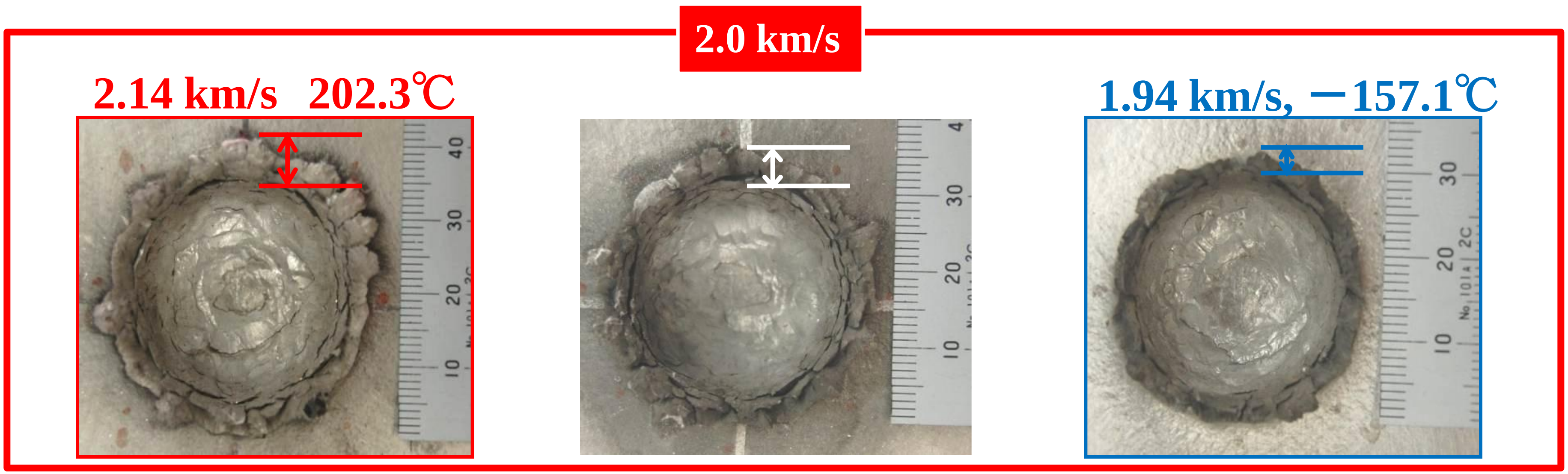
Projectile Fragmentation

High Temp. | Room Temp. | Low Temp.



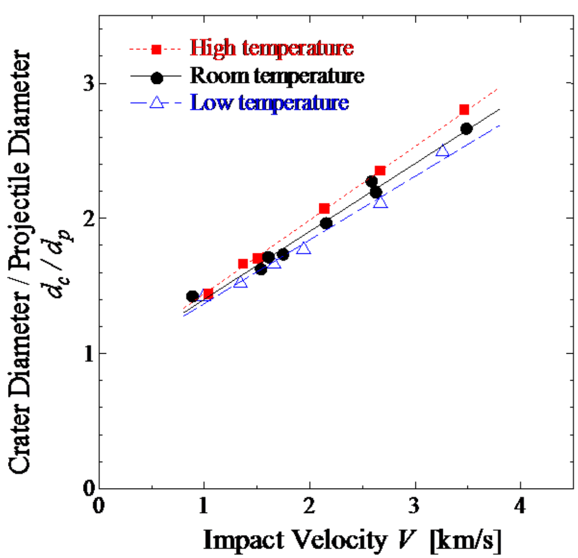
Lip Formation





Crater Shape

Crater diameter



High Temp.

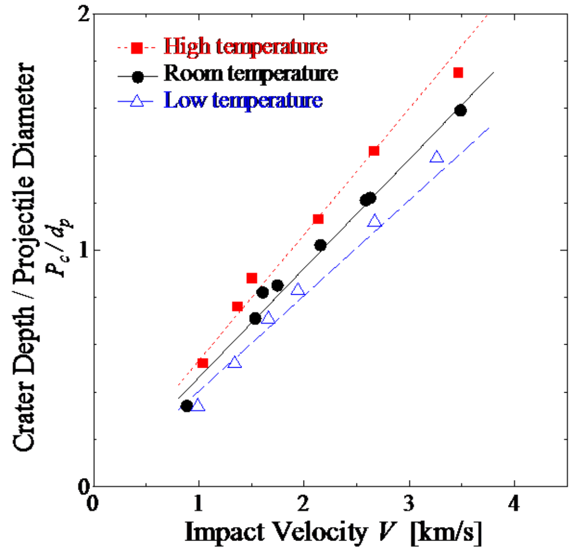
6%↑

Room Temp.

4%↓

Low Temp.

Crater depth



High Temp.

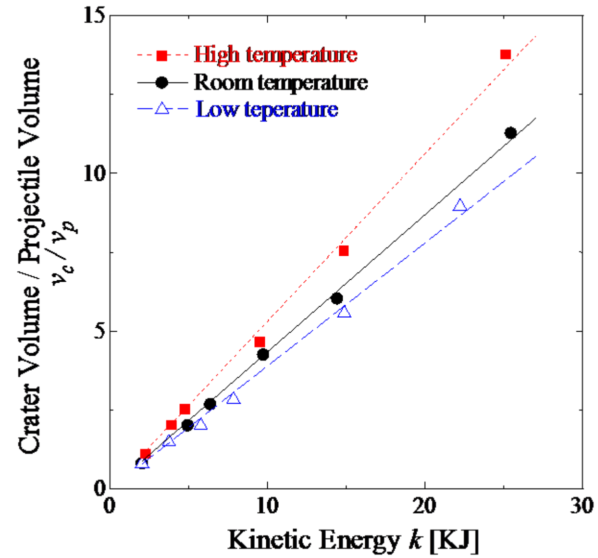
15%↑

Room Temp.

13%↓

Low Temp.

Crater volume



High Temp.

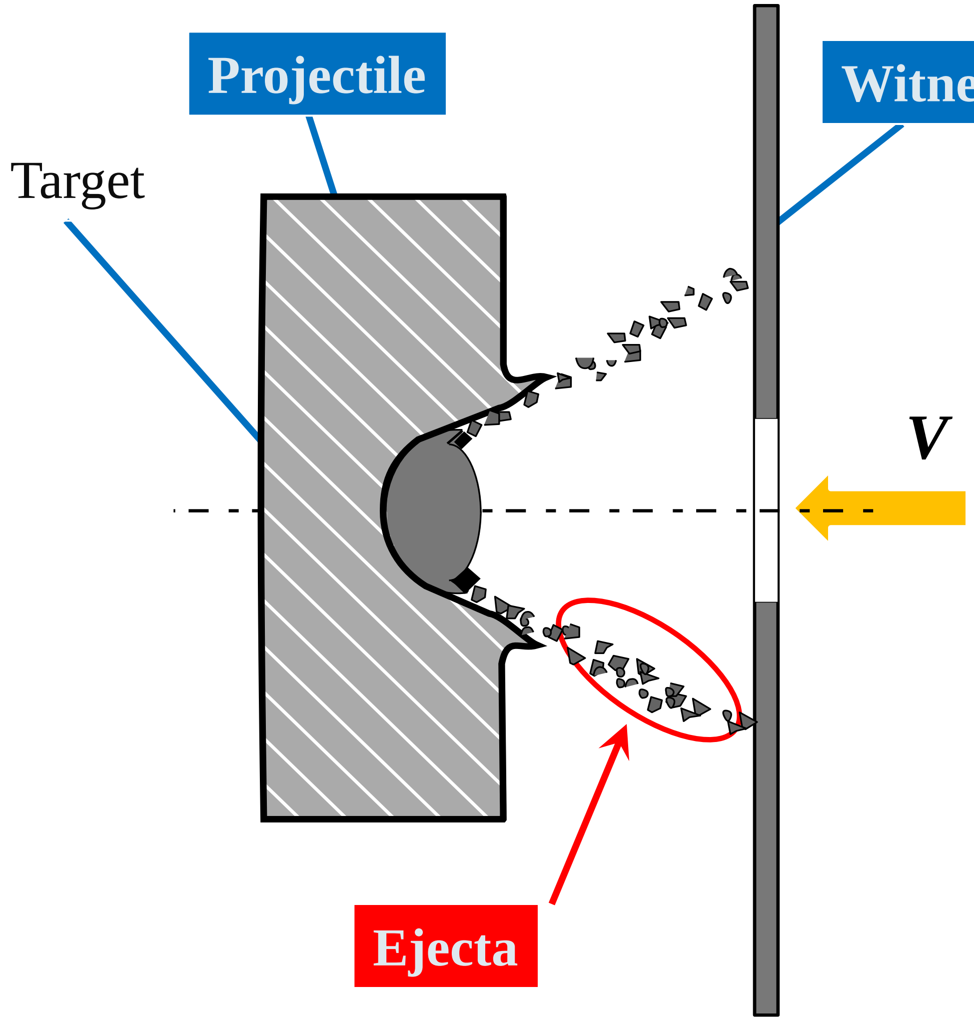
22%↑

Room Temp.

10%↓

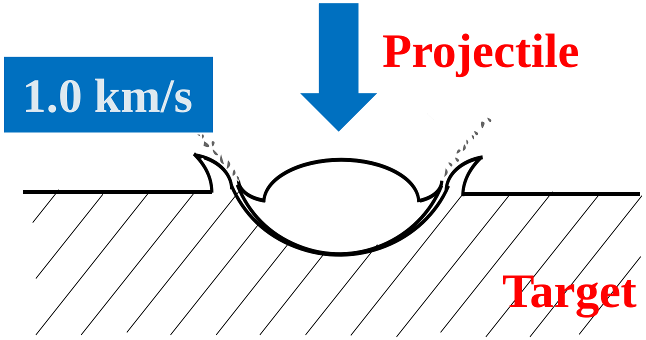
Low Temp.

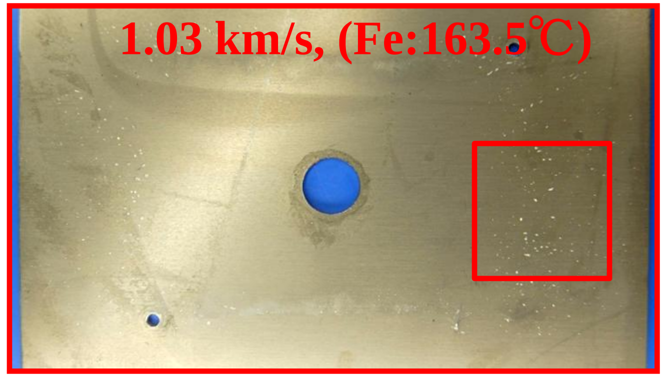
Ejecta & Witness Plate

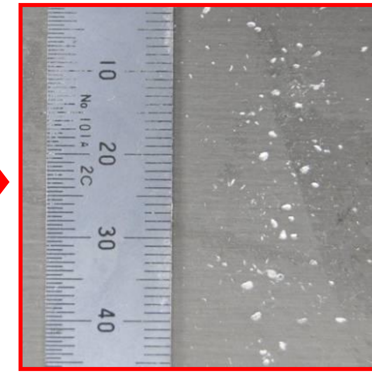


Composition of Ejecta (1/2)

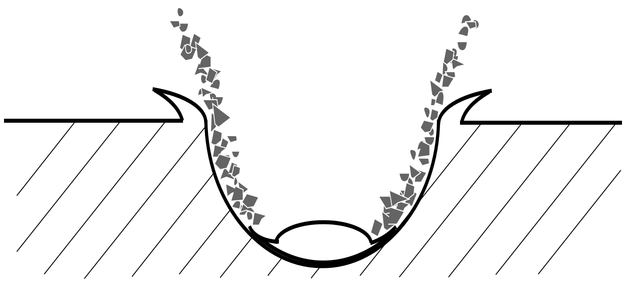
1.0 km/s

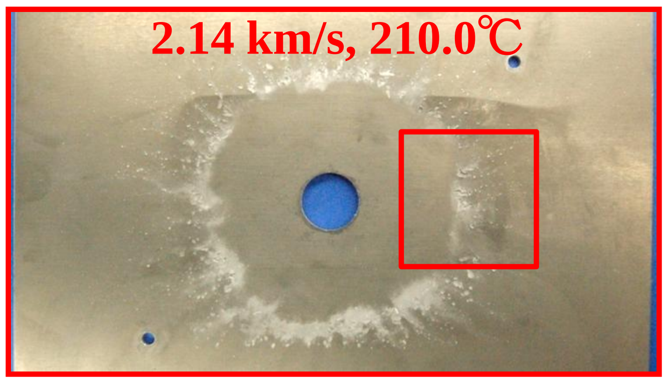


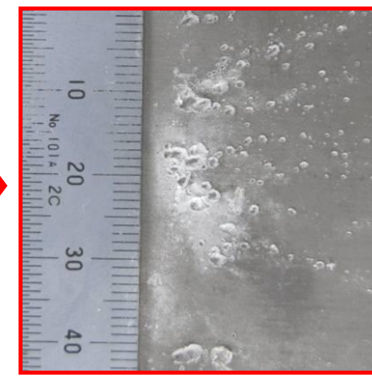




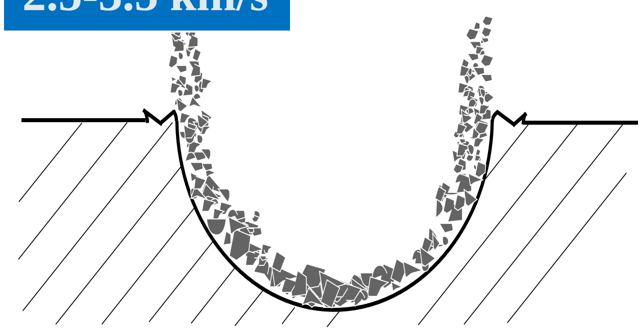
1.5-2.0 km/s

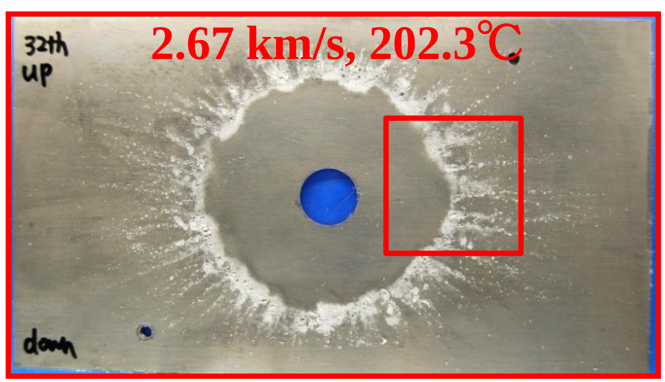


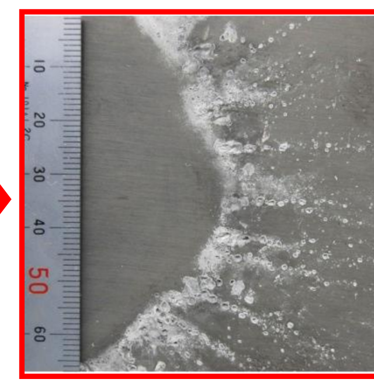




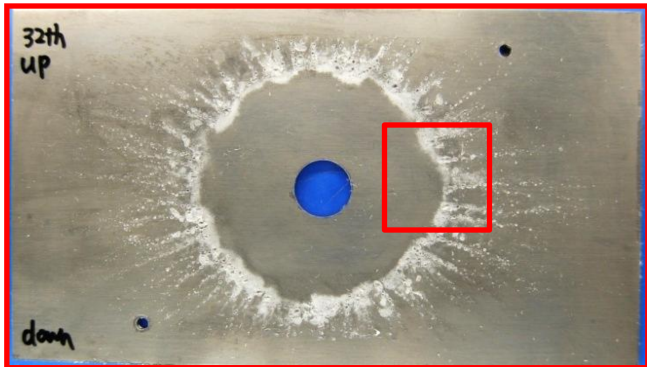
2.5-3.5 km/s





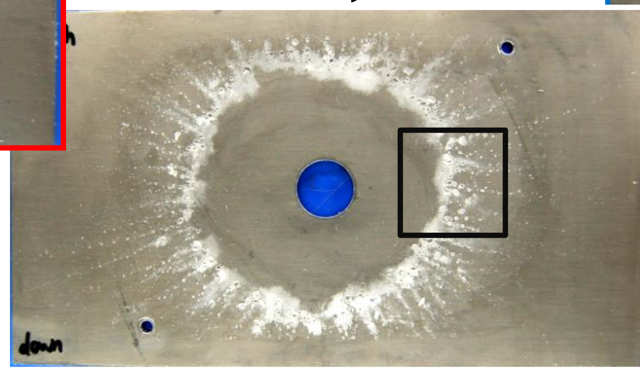


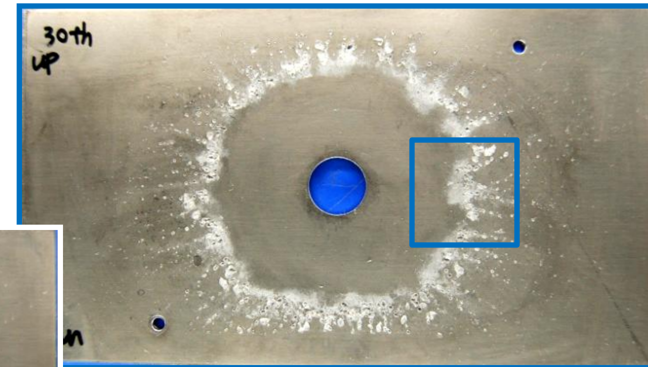
Composition of Ejecta (2/2)



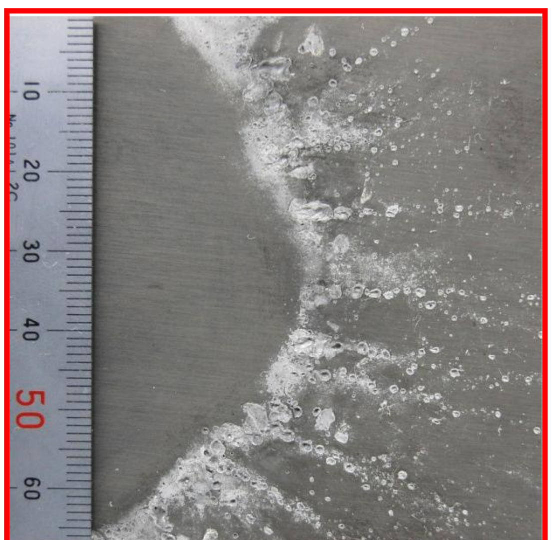
2.67 km/s, 197.0 ℃

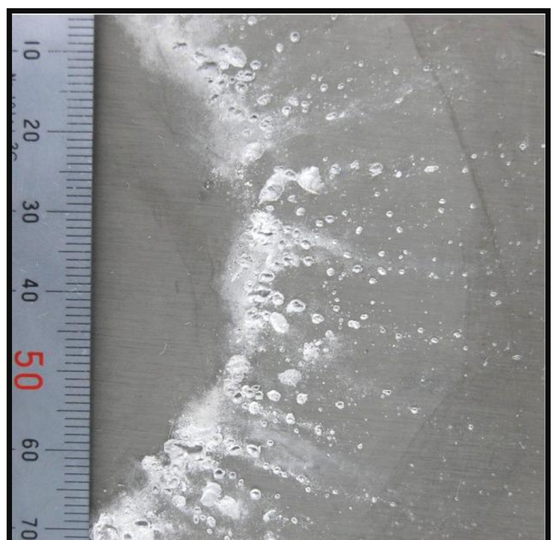
2.63 km/s, 16.0 ℃

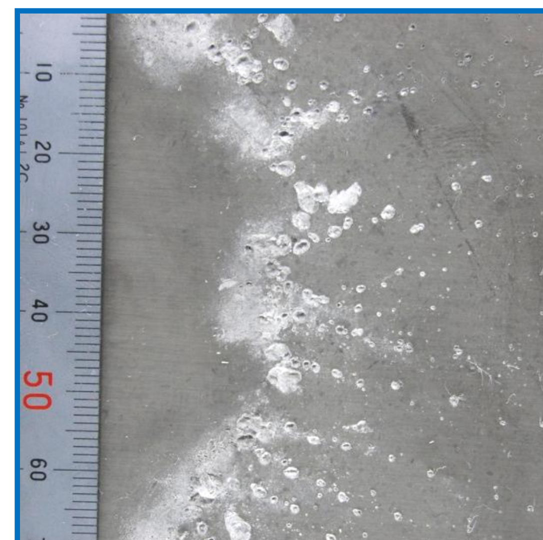




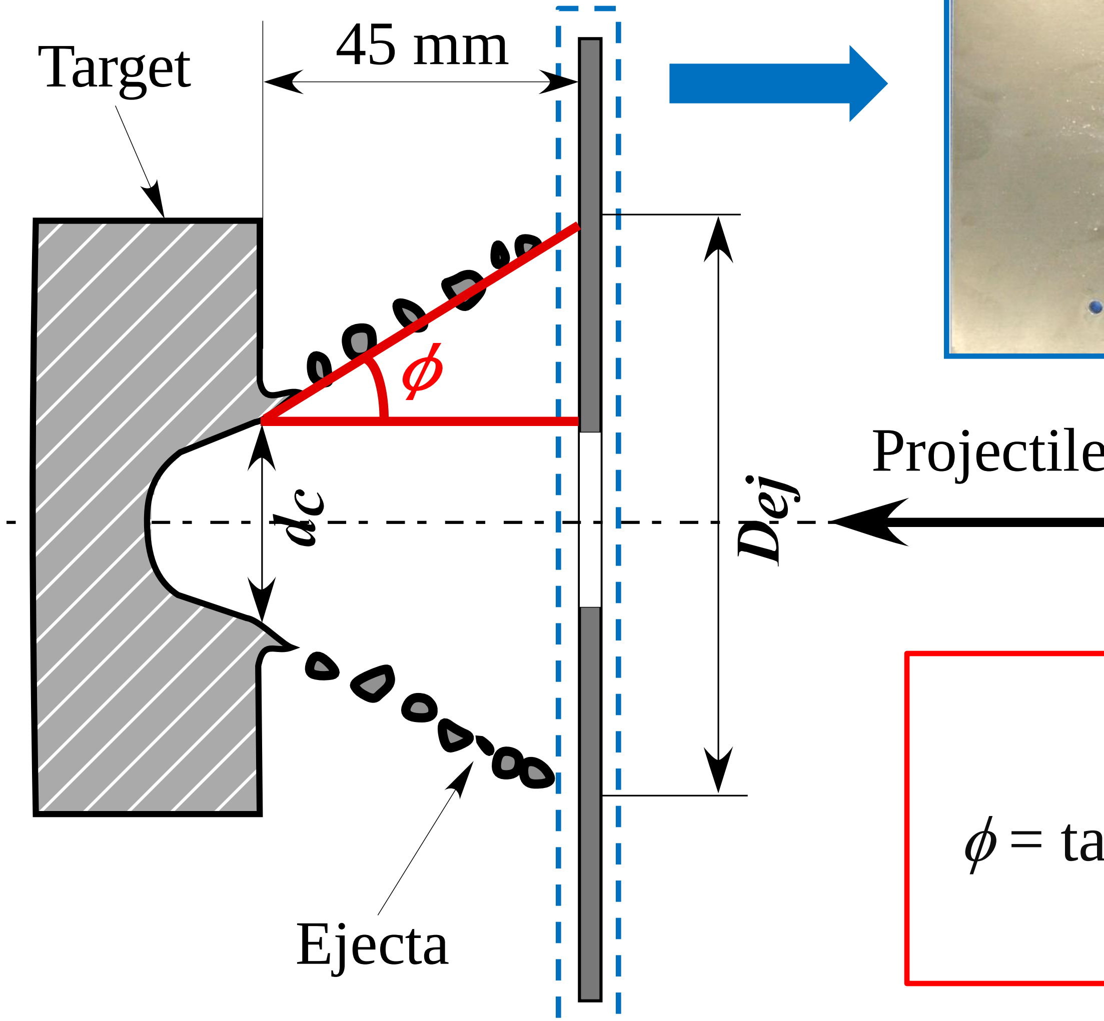
2.67 km/s, -157.3 ℃

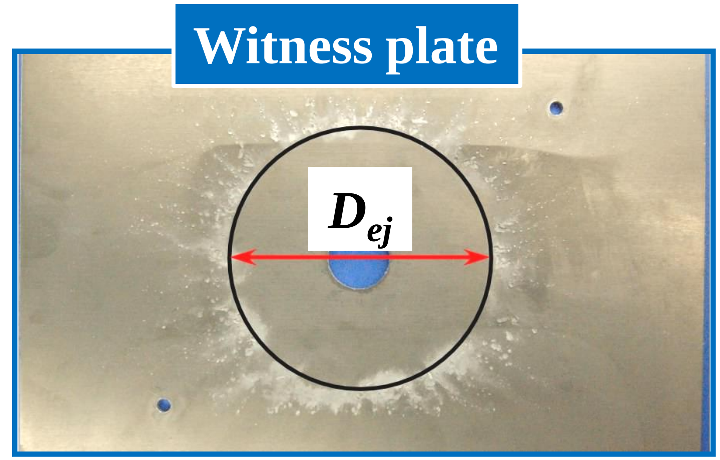






Witness Plate

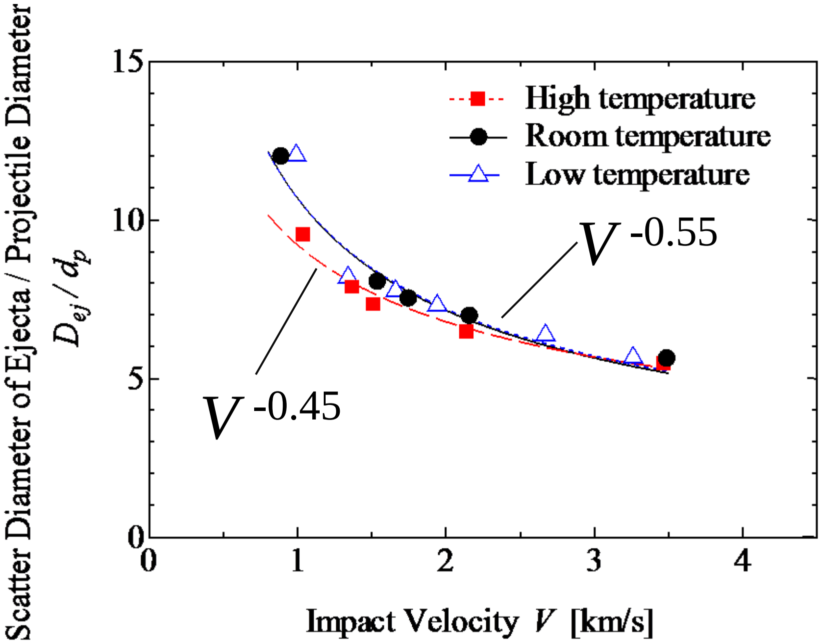


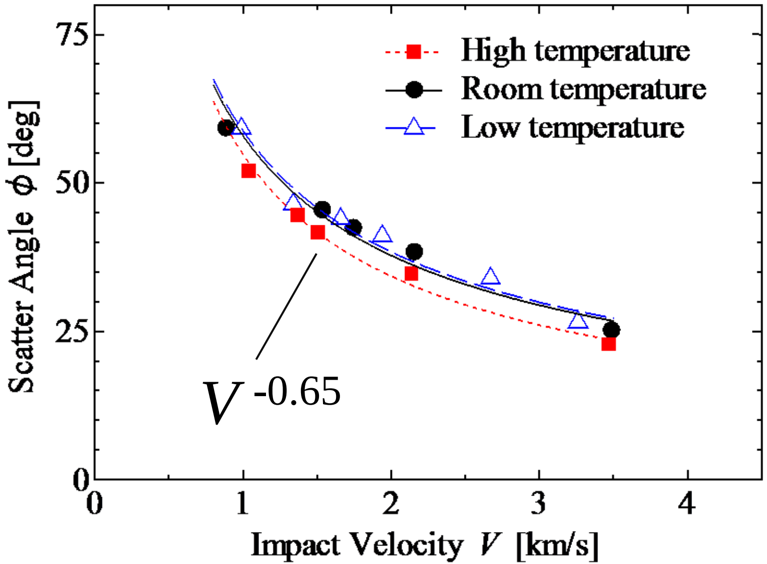


Scatter Angle

$$\phi = \tan^{-1}\left(\frac{D_{ej}/2 - d_c/2}{45}\right)$$

Scatter Angle vs Impact Velocity



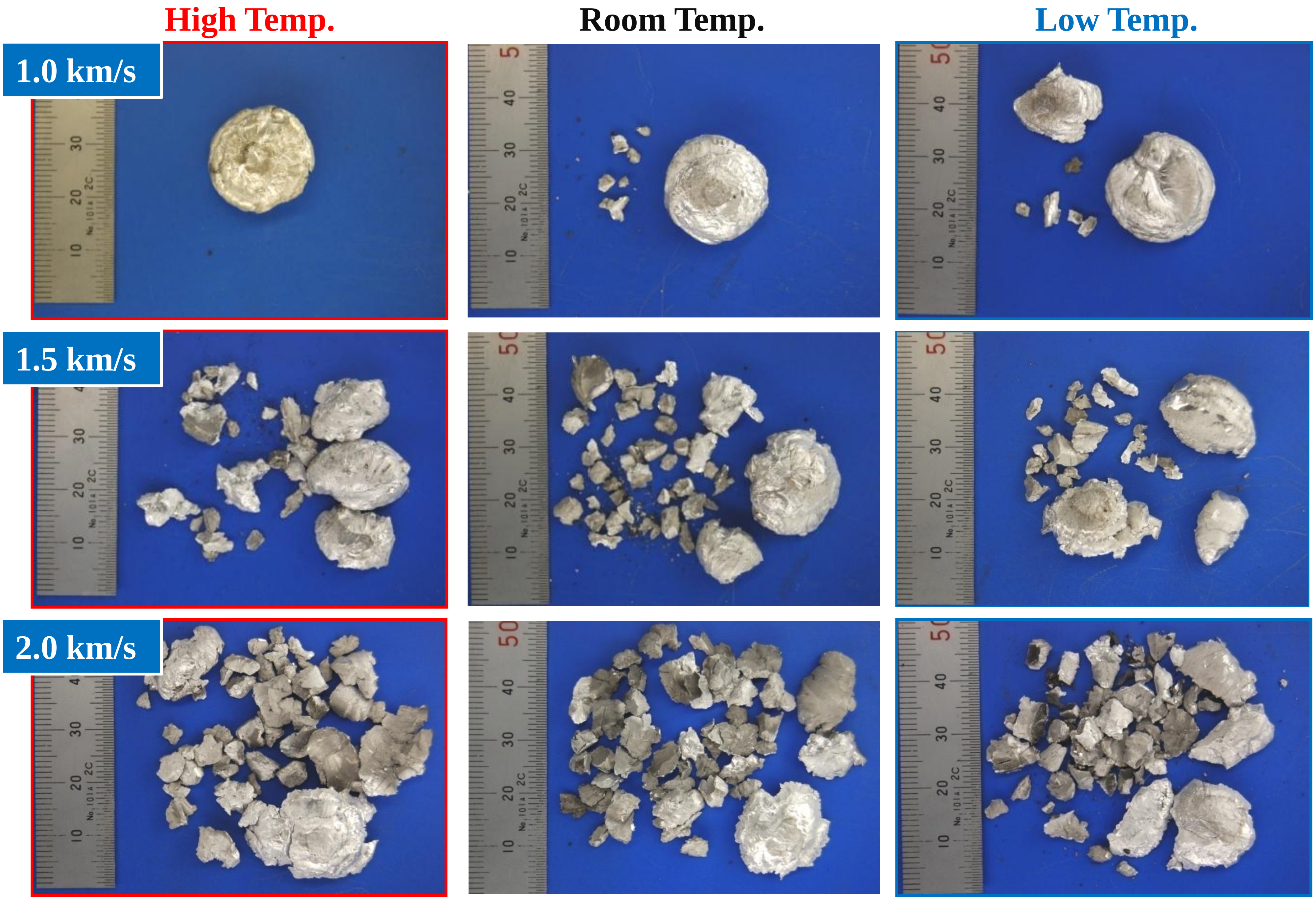


Low Temp.

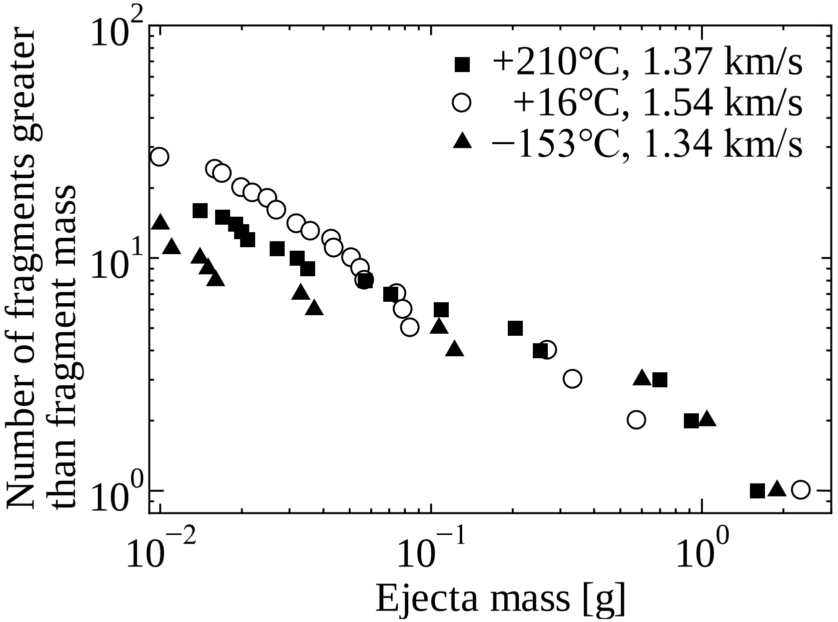
9.2 %↓

High Temp.

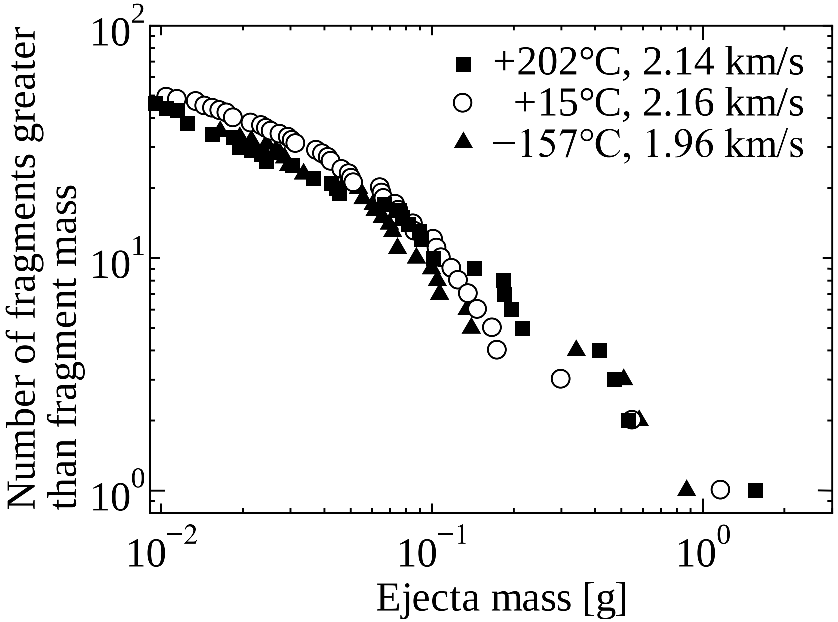
Projectile Fragmentation



Mass Distribution

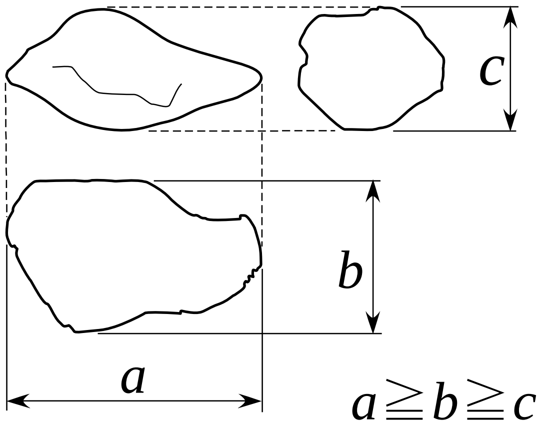


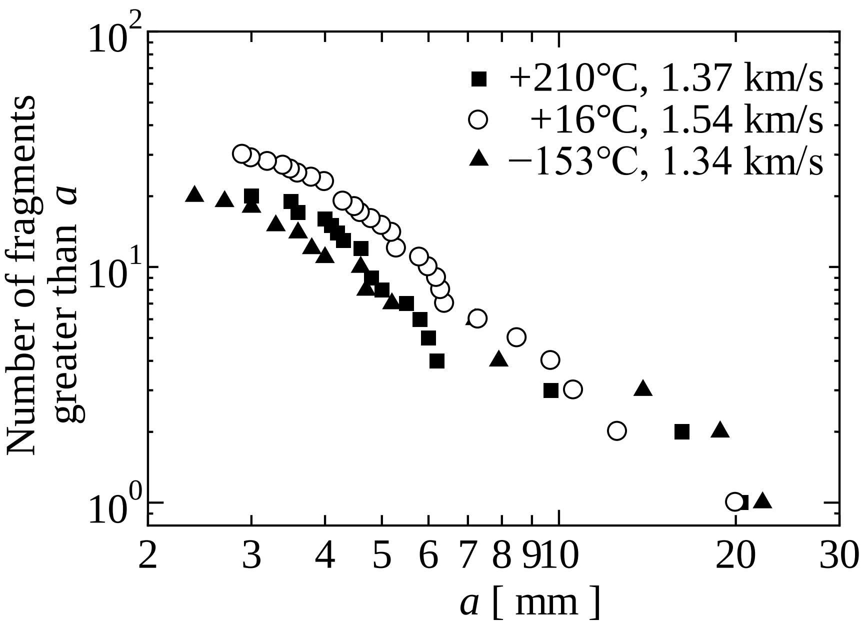
(a) 1.5 km/s



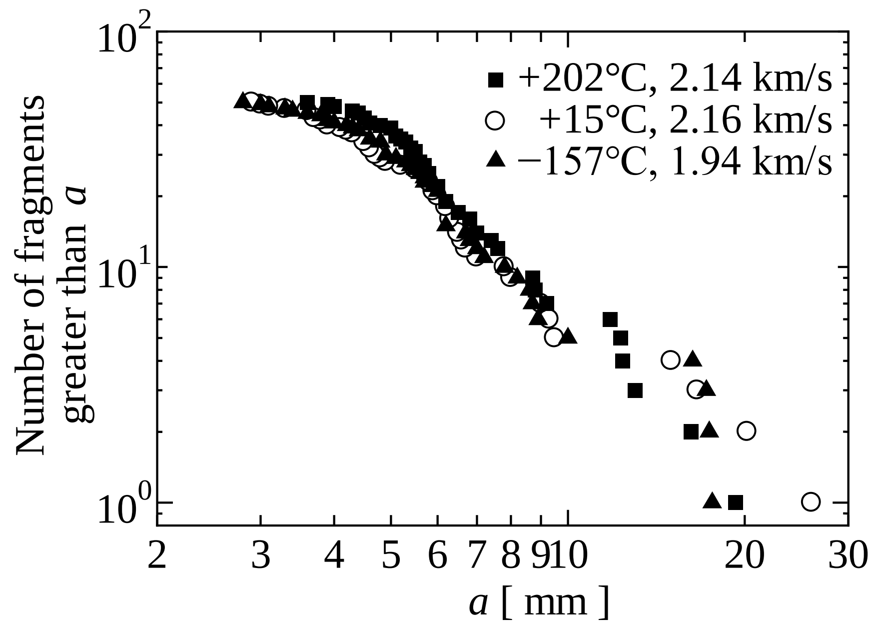
(b) 2 km/s

Size Distribution, *a*



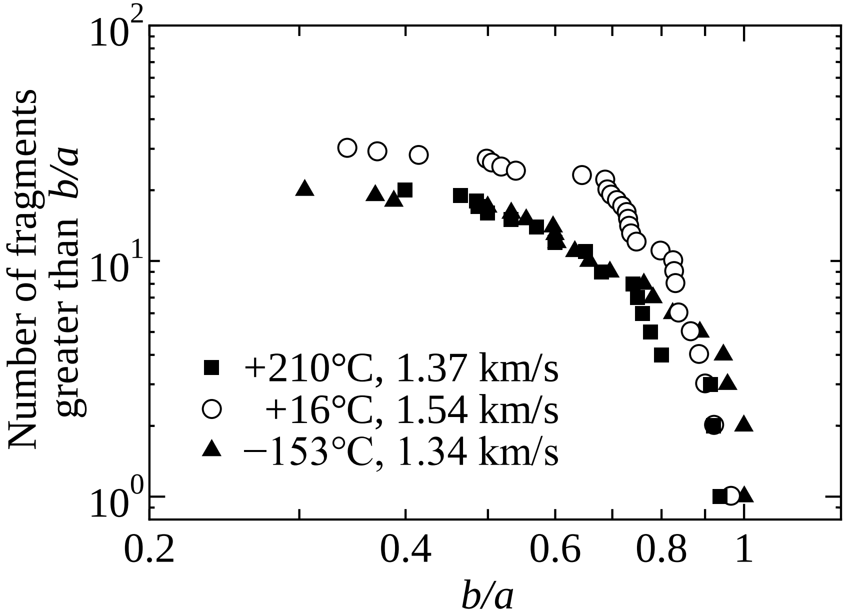


(a) 1.5 km/s

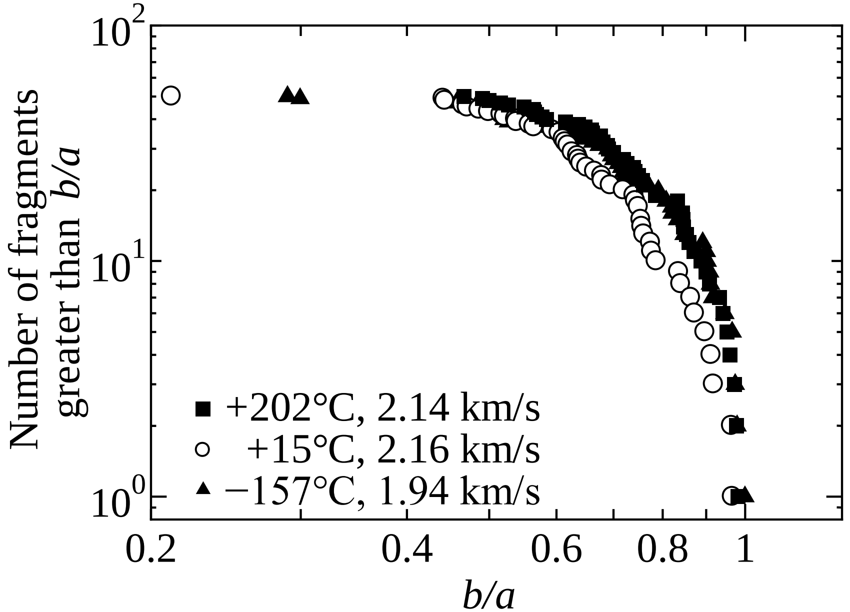


(b) 2 km/s

Axial Ratio of Ejecta Fragments, *b/a*

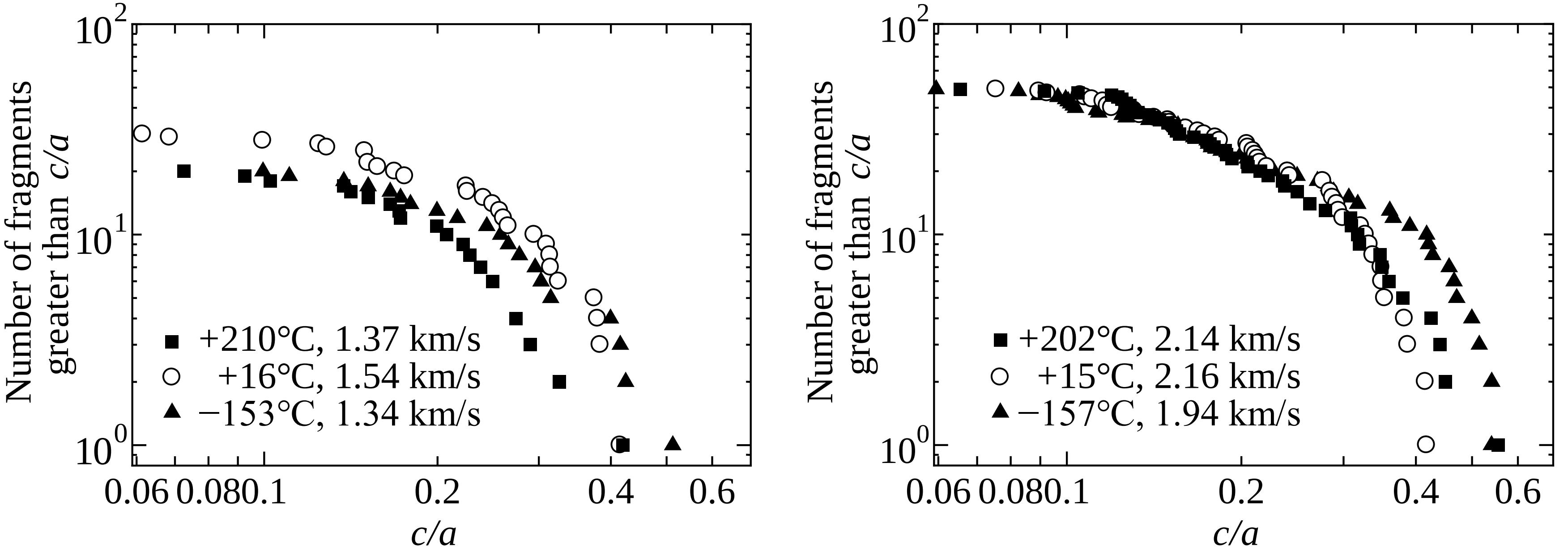


(a) 1.5 km/s



(b) 2 km/s

Axial Ratio of Ejecta Fragments, *c/a*



(a) 1.5 km/s

(b) 2 km/s

Table 1 Material properties of aluminum alloy 6061-T6

Temperature [°C]	+205	+25	-196
Elastic modulus [GPa]	77	70	63
Tensile strength [MPa]	130	310	415
Yield stress [MPa]	105	275	325
Elongation at break [%]	28	17	22
Temperature [°C]	+200	+25	-150
Vickers hardness	100	110	128

Conclusions

1. Crater Formation

Temperature	High [%]	Room	Low [%]
Crater diameter	8.4 ↑	1	6.4 ↓
Crater depth	15.5 ↑	1	12.5 ↓
Crater volume	22.3 ↑	1	10.3 ↓

2. Scatter of Ejecta

Scatter Angle : High Temp. > Room Temp. = Low Temp.

Inspective Plate : Influence of Temperature did not appear

3. Projectile Fragmentaion

Range From 1.0-1.5 km/s

Fragment Size : High Temp. = Room Temp. = Low Temp.

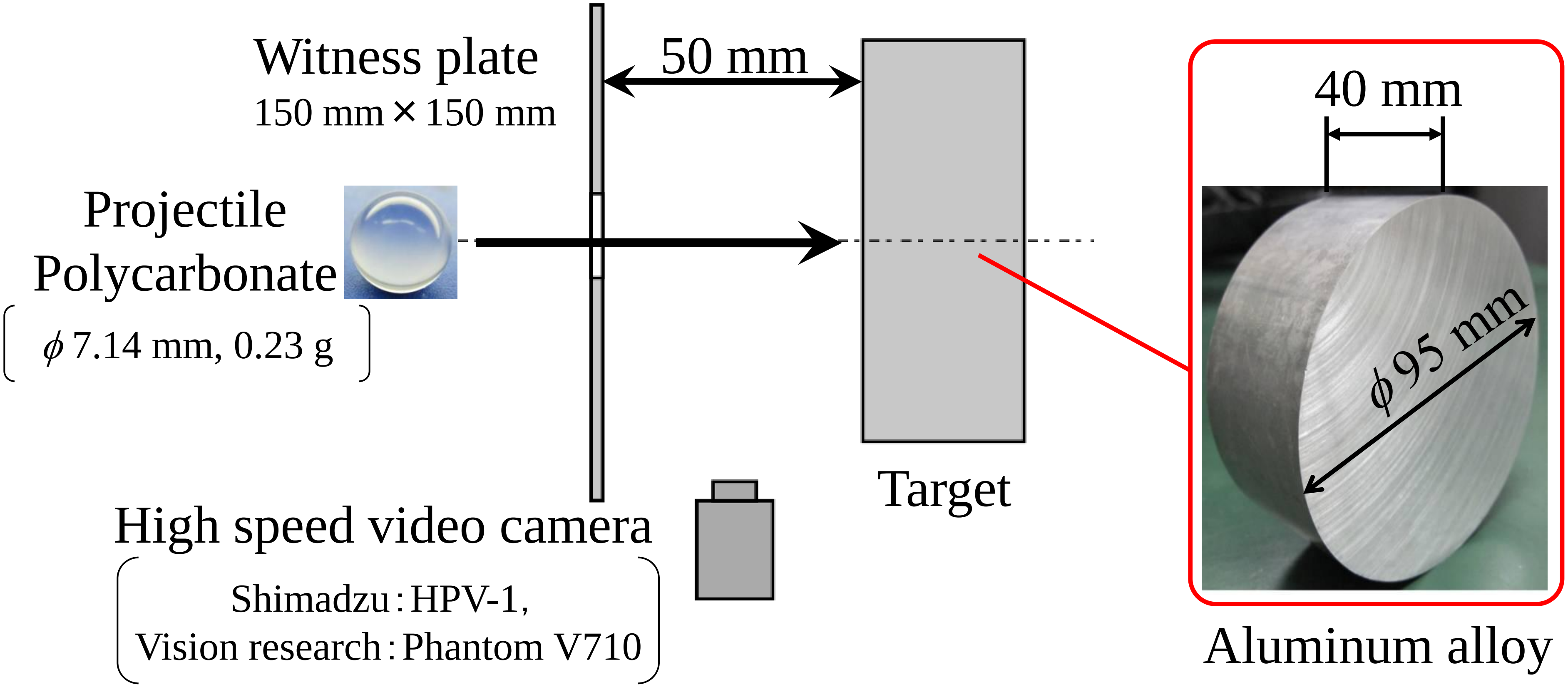
Range From 2.0-2.5 km/s

Fragment Size : High Temp. = Room Temp. > Low Temp.

ターゲットの材質がクレータ形成および エジェクタ構成に与える影響

(第54回宇宙科学技術連合講演会2010)
(高速度イメージングとフォトニクスに関する総合シンポジウム2011)

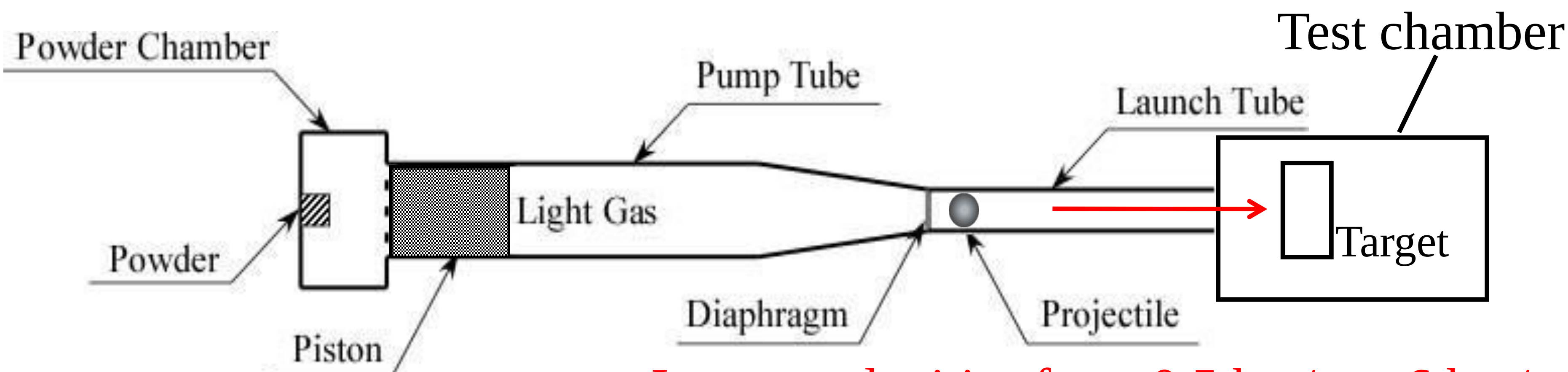
Experimental Setup



	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)

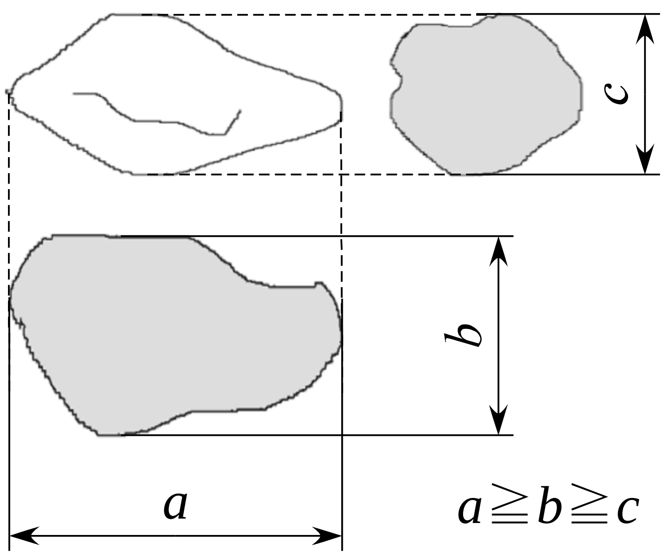


Impact velocities from 0.5 km/s to 6 km/s

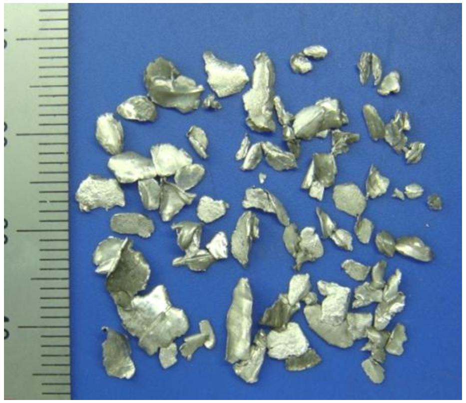
Definition of Ejecta

Measure weight distribution & size distribution of ejecta collected from chambers after experiments.

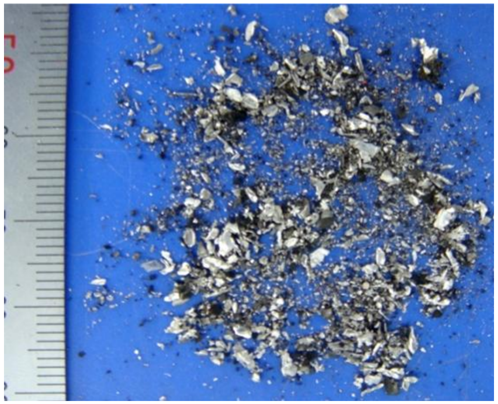
Fragment three dimentions



Ejecta mass ≧ 1 mg
Target origin



Over 1 mg



Under 1 mg

Summary

- アルミニウム合金の合金種および熱処理によってクレータのリップ形状は異なった．回収されたエジェクタの外観は，それに対応した．

- エジェクタの質量，最大長さ，縦横比は，ターゲットの硬さ（降伏応力）および破断伸びに従い，変化した．

  - NASAの破砕モデル
  - Grady－Kipp動的破砕モデル

Important factors

- Temperature (Nishida et al., Int. J. Impact Engng. 2012)
  (Proc Thermec 2011)
- Impact velocity (Nishida et al., Proc. ICHSIP-29, 2011)

- Impact angle
  (日本機械学会 M&M2011材料力学カンファレンス2011)
  (第48回日本航空宇宙学会関西・中部支部合同秋期大会2011)

- Material properties of projectiles (Nishida et al., 6th ISEM 2011)

- Material properties of targets
  (第54回宇宙科学技術連合講演会2010)
  (高速度イメージングとフォトニクスに関する総合シンポジウム2011)

Acknowledgments

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