超高分子量ポリエチレン繊維複合材によるアルミ合金製デブリバンパーからのイジェクタの低減

Reduction in Ejecta from Aluminum Alloy Debris Bumpers using Ultra-high Molecular Weight Polyethylene Fiber Composites

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高強度繊維である超高分子量ポリエチレン繊維の複合材は、防御材料として有望である。この材料を用いて、アルミ合金製デブリバンパーからのイジェクタの低減しつつ、バンパーとしての性能は同等もしくは向上するようなデブリバンパーを目指して、研究している。その結果を報告する。

Ultra-high molecular weight polyethylene fiber composites of high strength fibers are promising materials for defense materials. Our group is trying to reduce ejecta from aluminum alloy debris shielding and to keep or improve bumper performance. We would like to report some results using ultra-high molecular weight polyethylene fiber composites.
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Improvements to Bumpers

8.33 mm al sphere $\rightarrow$ **double-layer foam**
6.9 km/s


2.82 mm al sphere $\rightarrow$ **Metallic glass-stuffed**
7.06 km/s


$\varnothing$20 mm, 2 mm Al plate $\rightarrow$ **Mullite bumper**
3.08 km/s


4 mm al (AlCu4Mg1) $\rightarrow$ **Hybrid metal foams**
6.5 km/s

Andreas Klavzar *et al.*, Procedia Engineering, 103 (2015)

Thick Plate Penetration

Composition of ejecta


Projectile fragments and ejected materials

Earlier Studies of Our Group

Experimental Setup

- **Projectile**
  - Aluminum alloy (2017-T4)
  - 1.6, 3.2, & 7.0-mm diameter

- **Witness plate**
  - 150 mm x 150 mm
  - 2 mm in thickness (C1100P-1/4H)

- **Target**
  - Aluminum alloy (6061-T6)
  - 95-mm diameter
  - 30-mm thickness

- **High-speed video camera**
  - Shimadzu Corporation, HPV-X
Image of Scattering Ejecta

Projectile: Aluminum alloy (2017-T4)  
3.2-mm diameter  
Impact velocity 4.14 km/s

Definition of Ejecta Size

Length > 0.5 mm

Projected area

Ejecta length (Maximum length)

Width

$\phi$7mm, 2.92 km/s

Thickness

Impact velocity 4.14 km/s
**Today’s Presentation Contents**

1. Hypervelocity impacts of aluminum alloy spheres on aluminum alloy targets

2. Length distribution of ejecta collected from test chamber

3. Scaling law for ejecta length

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**Normalization on Horizontal Axis**

- **Velocity 6.6 km/s**
  - φ 3.2 mm, 6.62 km/s
  - φ 1.6 mm, 6.75 km/s

- **Velocity 4 km/s**
  - φ 3.2 mm, 4.14 km/s
  - φ 1.6 mm, 4.06 km/s

- **Velocity 3 km/s**
  - φ 3.2 mm, 3.01 km/s
  - φ 7.0 mm, 2.92 km/s
  - φ 1.6 mm, 3.09 km/s

- **Velocity 2 km/s**
  - φ 7.0 mm, 1.91 km/s
  - φ 1.6 mm, 1.85 km/s

Ejecta length on horizontal axis divided by projectile diameter $D^{1.0}$ → Good agreement

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Normalization of Vertical Axis & Horizontal Axis

\[ N / V^{1.5} = 151.6 \exp(-10.6 \frac{a}{D}) + 18.0 \exp(-3.24 \frac{a}{D}) \]

The Number of Ejecta on Front Side

Effects of projectile diameter

Al sphere → CFRP plates
(Front side of target)

Reduction of ejecta

Projects for Reduction of Ejecta

Project: High strength fiber composites / Al (Mg)

Light metal plates (Al alloy, Mg alloy, Mg-Li alloy)

High strength fiber composites (Dyneema composites) 0.3 mm

Earliest Studies of Debris Shielding (1/2)

PBI coating/CFRP

Polybenzimidazole (PBI):
Atomic Oxygen Protective Coating

SiC coating/Al

Sarath Kumar Sathish Kumar, et al., Polybenzimidazole (PBI) film coating for improved hypervelocity impact energy absorption for space applications, Composite Structures 188 (2018) 72–77

Earlier Studies of Debris Shielding (2/2)

Ti-Al nylon impedance-graded materials

![Diagram of Ti-Al nylon impedance-graded materials](image1)


Kevlar/CFRP

![Diagram of Kevlar/CFRP](image2)

Emile Haddad, et al., Mitigating the effect of space small debris on COPV in space with fiber sensors and self repairing materials, Proc. ECSSMET (2018)

Project 3  High strength fiber composites / Al (Mg)
Earlier Studies of Dyneema Composites


Experimental Setup

Projectile
A2017-T4

Witness plate (Front side)

Target

Witness plate (Rear side)

Pressure wall
A2024-T3, 3 mm
Results of projectile diameter 1.0 mm and impact velocity 6 km/s
Penetration Holes

FRP 0.3 mm + Al 0.8 mm (shot 36) (Projectile φ1.0 mm, 6.00 km/s)  
Al 1.0 mm (shot 18) (Projectile φ 1.0 mm 6.24 km/s)

Penetration hole areas

<table>
<thead>
<tr>
<th>FRP / Al</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.81 mm² / 7.59 mm²</td>
<td>7.64 mm²</td>
</tr>
</tbody>
</table>

Witness Plates on Impact Side (1/2)

ISO 11227: Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact

FRP 0.3 mm + Al 0.8 mm (shot 36)  
Al 1.0 mm (shot 18)

(Projectile φ1.0 mm, 6.00 km/s)  
(Projectile φ 1.0 mm 6.24 km/s)
**Witness Plates on Impact Side (2/2)**

ISO 11227: Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact

FRP 0.3 mm + Al 0.8 mm (shot 36)  
Al 1.0 mm (shot 18)

**Pressure Wall**

FRP 0.3 mm + Al 0.8 mm (shot 36)  
Al 1.0 mm (shot 18)

(Projectile φ 1.0 mm, 6.00 km/s)  
(Projectile φ 1.0 mm 6.24 km/s)
Summary

Areal density of FRP/Al was – 5.9% of Al plates.

1. Penetration holes → No tendency
2. Witness plates on impact side → Low ejection velocity
3. The number of ejecta collected from test chamber → The same
4. Pressure walls → Less damage
5. Ballistic Limit Curve → Slightly improved

Unclear points （困っている点）

1. Welding of aluminum alloys?
2. Adhesive of FRP/Al?

Thank you for your kind attention

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