2006 Insensitive Munitions & Energetic Materials Technology Symposium

Development of Ceramic Ball Armor for Insensitive Munitions Applications

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Background

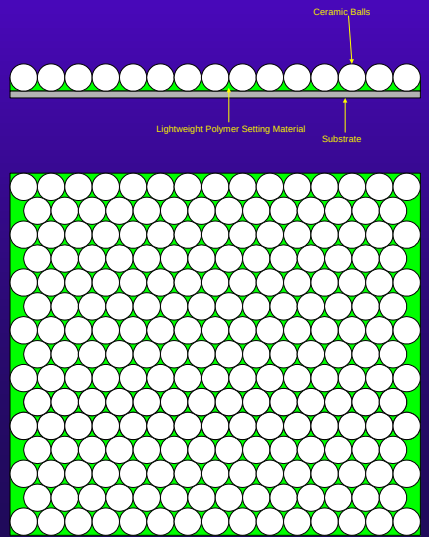
- Recent requirements to protect high explosive materials from sympathetic detonation have been identified.
- MIL-STD-2105C specifies a performance level that Insensitive Munition (IM) performance must achieve.
- This performance requires that an explosive payload cannot sympathetically detonate from the impact of a single 287-gn conical steel fragment impacting at 8300 +/- 300 ft/sec.

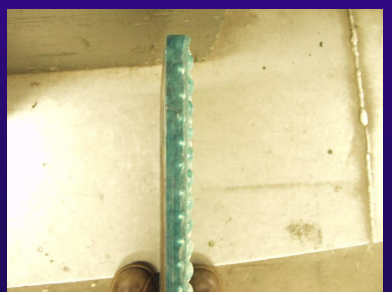
Goal

- Develop an armor solution that prevents sympathetic detonation
- Find a solution that minimizes cost and weight while meeting the MIL-STD-2105C performance requirements
- Develop a solution that can be engineered to most geometric configurations

Solution

- Ceramic ball armor
- Solution consists of a front layer of ceramic balls backed by a layer of 3/16” HHS
- Ceramic balls are adhered to HHS substrate using high tensile strength polymer





Why Ceramic Ball Armor

- Ceramic balls (Al_2O_3) mass produced as grinding media (low cost high availability)
- Ceramic balls extremely hard (very high compressive strength)
- Minimal damage area as compared to tiles
- Balls enable IM configuration to most geometric shapes
- 3/16” HHS and polymer low cost and readily available
- Proven performance in past lightweight vehicle armor development

Engineering Variables

- Performance can be increased/decreased through the following variables:
  - Ceramic ball chemistry
    - Increased performance with SiC, Boron Nitride
      - Cost increase by factor of 10 or more
      - No weight penalty (some weight loss)
  - Ceramic ball purity
    - 90%, 95%, and 99.5%
      - Cost increase up to factor of 5
      - Slight weight cost (minimal)
  - Ceramic ball diameter
    - Ball diameter can be increased from 1/8” up to 3”
      - Weight increases with diameter
      - Cost increase
  - Polymer tensile strength
      - Slight cost and weight increase
  - Substrate material property/thickness

Objective

1. Verify performance variation of selected variables using V-50 ballistic performance techniques
   - Vary ceramic ball diameter and substrate
   - Vary ceramic ball chemical purity
   - Quantify performance variation
2. Investigate exit velocity from STANAG fragment impacting at ~7500 ft/sec
3. Perform MIL-STD-2105C test against high explosive payload (30mm HEI-T)

V-50 Ballistic Test

V-50 Ballistic Test

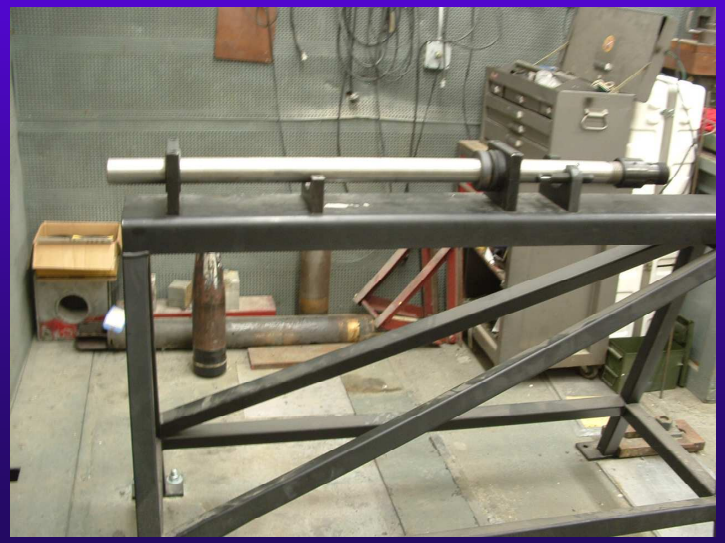
- 14 different armor panels were investigated

Target #	Substrate	Armor
1.	.202” HHS	1” 99.5 % Al_2O_3 Balls
2.	.202” HHS	3/4” 99.5 % Al_2O_3 Balls
3.	.202” HHS	1/2” 99.5 % Al_2O_3 Balls
4.	.202” HHS	3/8” 99.5 % Al_2O_3 Balls
5.	.202” HHS	1” 90 % Al_2O_3 Balls
6.	.202” HHS	3/4” 90 % Al_2O_3 Balls
7.	.202” HHS	5/8” 90 % Al_2O_3 Balls
8.	.202” HHS	1/2” 90 % Al_2O_3 Balls
9.	.250” A-36	1” 99.5 % Al_2O_3 Balls
10.	.250” A-36	3/4” 99.5 % Al_2O_3 Balls
11.	.250” A-36	1/2” 99.5 % Al_2O_3 Balls
12.	.375” Al 6061	1” 99.5 % Al_2O_3 Balls
13.	.375” Al 6061	3/4” 99.5 % Al_2O_3 Balls
14.	.375” Al 6061	1/2” 99.5 % Al_2O_3 Balls

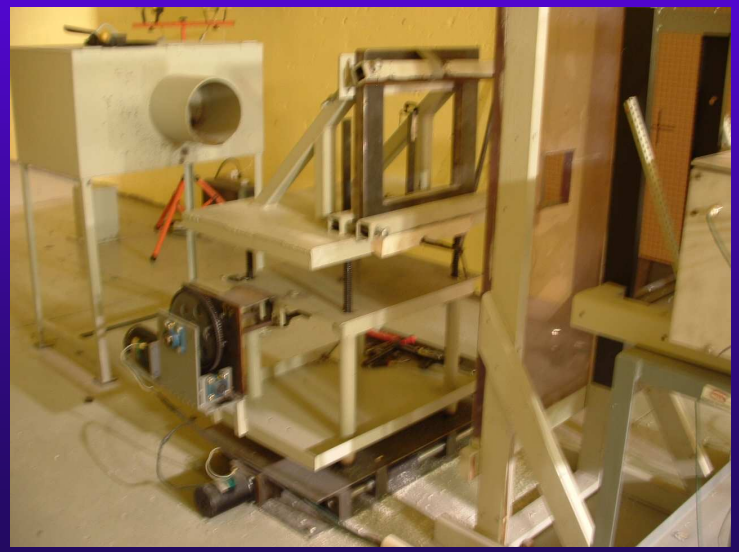
V-0/V-50 Ballistic Test Facility

Control Room

Laser and Ohler Velocimeters

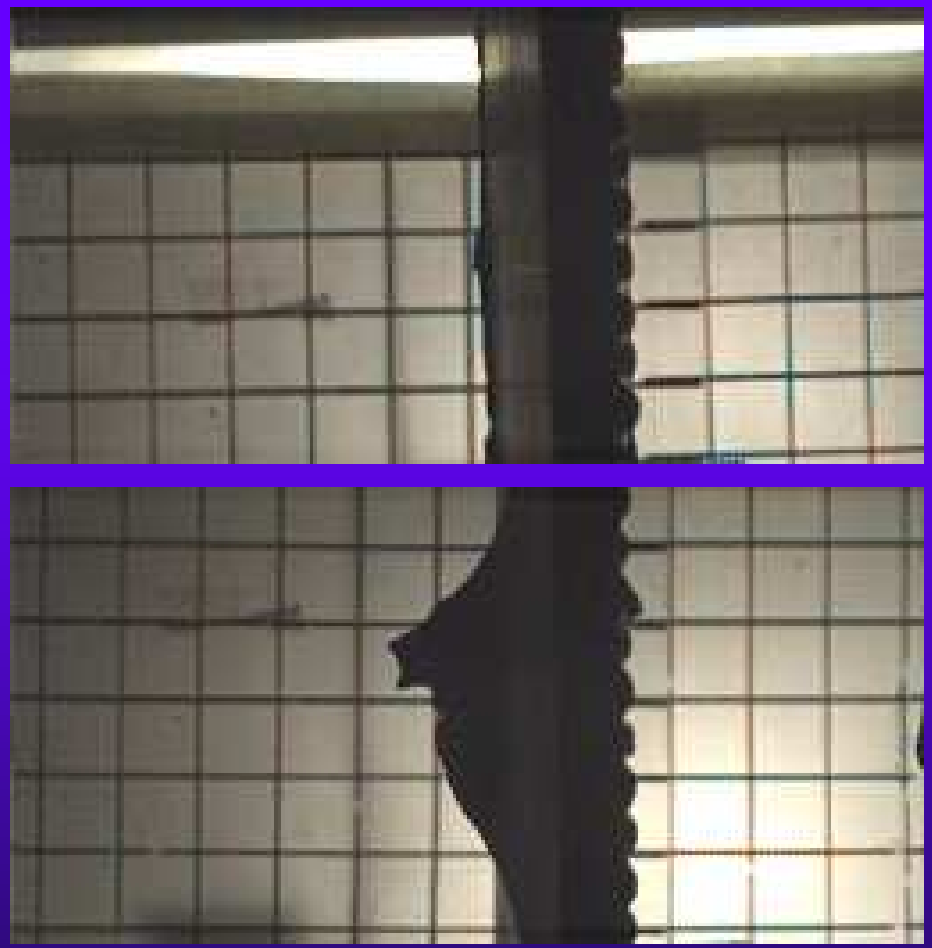


Universal Gun System



Computer Controlled Armor Holder

V-50 Ballistic Test



Partial Penetration

Complete Penetration

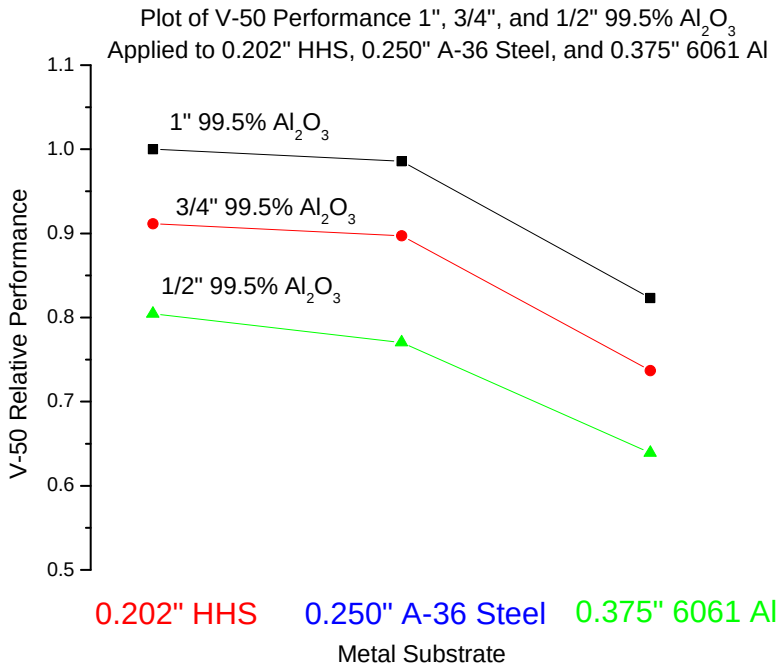
A V-50 performance test consists of varying the impact velocity of a selected projectile where the difference in velocity between a complete and partial penetration is < 50 ft/s

V-50 Ballistic Test

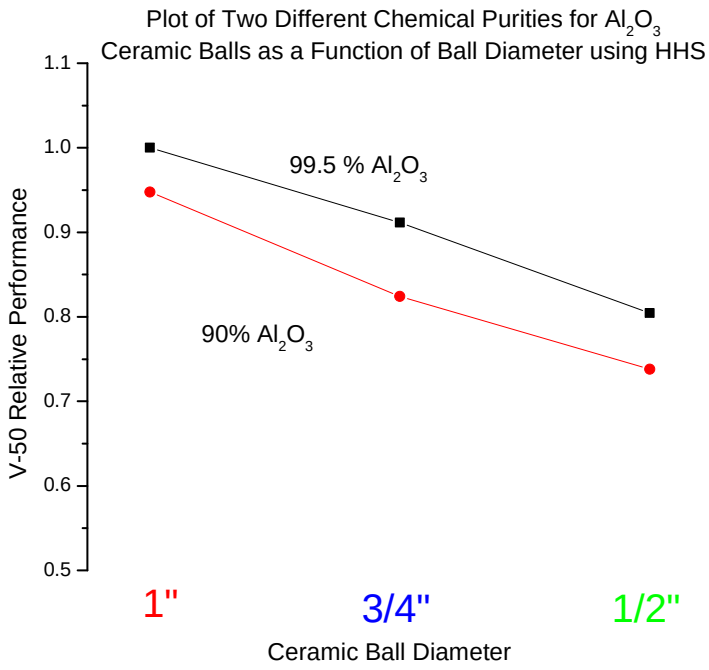
Substrate	Armor	V-50 Relative Performance Scoring (1 highest 14 lowest)
.202” HHS	1” 99.5 % Al_2O_3 Balls	1
.250” A-36	1” 99.5 % Al_2O_3 Balls	2
.202” HHS	1” 90 % Al_2O_3 Balls	3
.202” HHS	3/4” 99.5 % Al_2O_3 Balls	4
.250” A-36	3/4” 99.5 % Al_2O_3 Balls	5
.202” HHS	3/4” 90 % Al_2O_3 Balls	6
.375” Al 6061	1” 99.5 % Al_2O_3 Balls	7
.202” HHS	1/2” 99.5 % Al_2O_3 Balls	8
.202” HHS	5/8” 90 % Al_2O_3 Balls	9
.250” A-36	1/2” 99.5 % Al_2O_3 Balls	10
.202” HHS	1/2” 90 % Al_2O_3 Balls	11
.375” Al 6061	3/4” 99.5 % Al_2O_3 Balls	12
.202” HHS	3/8” 99.5 % Al_2O_3 Balls	13
.375” Al 6061	1/2” 99.5 % Al_2O_3 Balls	14

V-50 Ballistic Test

Substrate Performance



Ceramic Ball Diameter Performance



V-50 Ballistic Test Conclusions

- The following conclusions can be made based on testing performed

1. Ceramic balls
   - Increased diameter = increased performance
   - Increased purity = increased performance
2. Substrate
   - 3/16” HHS best performer
   - ¼” A-36 second best performer
   - 3/8” 6061 Al third performer

Exit Velocity Impact Tests

Exit Velocity Impact Tests

- STANAG fragments will impact ceramic ball panels at ~7500 ft/sec
- Exit velocities for each impact will be recorded
- Tests performed at NSWC Indian Head using single stage powder gun

Target #	Substrate	Impact Vel (ft/sec)	Armor
1.	.202” HHS	7500 ft/sec	1/2” 90 % Al_2O_3 Balls
2.	.202” HHS	7500 ft/sec	5/8” 90 % Al_2O_3 Balls

Results - Exit Velocity Impact Tests

- All ceramic ball panels reduced the exit velocity of the incident projectile by over 50%
- All that is required is to reduce the exit velocity below threshold velocity that would enable sympathetic detonation

Armor	Test #	Incident Velocity (ft/sec)	Exit Velocity (ft/sec)	% Reduction of Init Vel (ft/sec)
1/2” 90 % Al_2O_3 Balls/.202” HHS	1	7535	3448	54.2
1/2” 90 % Al_2O_3 Balls/.202” HHS	2	7554	3036	60
5/8” 90 % Al_2O_3 Balls/.202” HHS	3	7561	2507	67

MIL-STD-2105C 30mm HEI-T Tests

MIL-STD-2105C 30mm HEI-T

- A total of 7 different IM armor configurations were tested
- STANAG fragment launched from 60mm powder gun

Test #	Substrate	Impact Vel (ft/sec)	Explosive Payload
1.	Foamcrete	8300 +/- 300 ft/sec	30mm (HEI-T)
2.	1/2-in Ceramic Balls + HHS .202	8300 +/- 300 ft/sec	30mm (HEI-T)
3.	Kevlar Type 1 (light green)	8300 +/- 300 ft/sec	30mm (HEI-T)
4.	Kevlar Type 2 (Spectra)	8300 +/- 300 ft/sec	30mm (HEI-T)
5.	Pultruded Glass/Polyester Tubes	8300 +/- 300 ft/sec	30mm (HEI-T)
6.	Filament Wound Glass/Epoxy Tubes	8300 +/- 300 ft/sec	30mm (HEI-T)
7.	0.202” HHS With Polymer Spray	8300 +/- 300 ft/sec	30mm (HEI-T)

Submitted IM Armor Solutions

Foamcrete Solution

Reaction: High Order Detonation

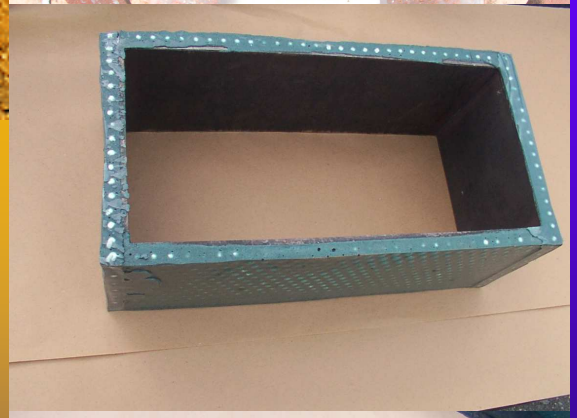
Glass Epoxy Tube Solution

Reaction: High Order Detonation

Kevlar Solution

Reaction: High Order Detonation

Submitted IM Armor Solutions



½” Ceramic Ball Solution

Reaction: Type 4
Deflagration/Burning

MIL-STD-2105C 30mm HEI-T Field Tests

Foamcrete Solution

High Order Detonation

Ceramic Ball Solution

Type 4 Deflagration/Burn

MIL-STD-2105C 30mm HEI-T Field Test Conclusions

- From the 7 IM armor solutions tested only the ceramic ball armor solution was successful in preventing high order detonation.

Conclusions

- Ceramic ball armor can be engineered to meet various performance requirements
- Performance increases with ceramic ball diameter, and ceramic ball purity
- Additional performance enhancement can be performed through substrate selection
- ½ and 5/8” ceramic balls w/ 3/16” HHS substrate have demonstrated performance to reduce impact velocity of incident STANAG at incident velocities of 7500 ft/sec by over 50%
- Within the MIL-STD-2105C 30mm HEI-T Field Tests, only the ceramic ball armor was able to prevent detonation from the STANAG fragment impact