Structural Analysis of Commonly Used Materials for Slow Heating Ovens (per AOP-4382) and Their Effects on the Projection of Hazardous Debris

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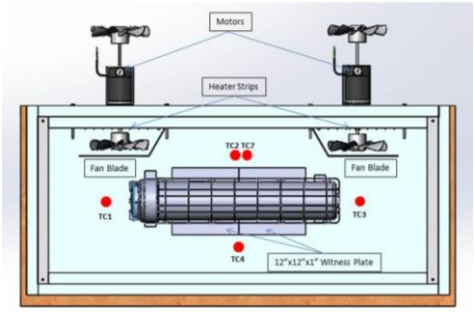
Background & Objectives

- The presence of an oven can suppress or alter evidence and prevent clear evaluation of munition reaction
  - Fragment projection, propulsive behavior, blast pressure
- Requirements do not specify any particular oven construction
  - Test facilities tend to select materials convenient for their construction based on heat transfer, cost, and protection
- A lighter oven construction should be used to minimize the effects on reaction
  - Modeling and experiments currently being conducted to evaluate various oven materials
  - Currently examining fragment projection

STANAG 4382 and Typical Setups

- Per STANAG 4382 Ed (2) 2003
  - "The oven should be constructed so as to provide the least possible confinement for any reactions that occur, and it should have a window to permit video coverage"
  - "The presence of the oven will affect the blast pressure, so the oven should be as light as possible"



Oven volume must be spacious enough to provide room for thermocouple placement and clearance between item and oven wall, be sturdy enough to withstand test, while not inhibit munition response.

Foam & Ductboard

Plywood & double-pane glass

Silica impregnated fiberboard

Oven Material Comparison

- Silica based fiberboard (Super Firetemp L)
  - Density: 20 pcf
  - Compressive Strength: 450 psi
  - 2” Thick (Areal density 3.33 lbm/ft^2)

- Foam (Thermax) / Ductboard
  - Density: 2-3 pcf
  - Compressive Strength: 25 psi
  - 2” Thick (Areal density 0.3-0.5 lbm/ft^2)

Note – If necessary, non-inhibitive materials (e.g. vinyl tarps / tents) should be used to protect oven / equipment from weather (e.g. rain). Wood, sand, sheet metal, etc. are too inhibitive.

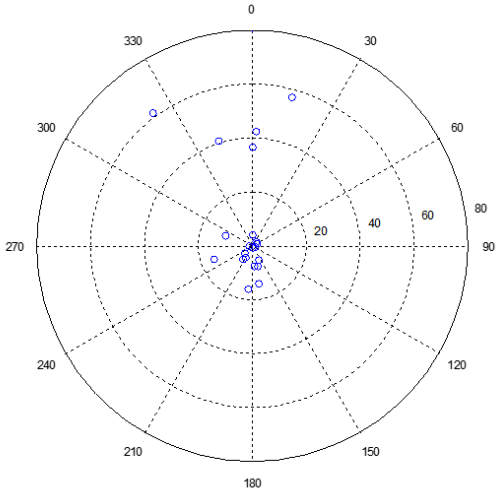
- Current modeling/testing focus
  - Comparison of these materials
  - Characterization of their ballistic limits and residual velocities for various masses and impact obliquities

- Future modeling/testing focus
  - Munition response pressure effects comparison of these materials

SCO w/ Super Firetemp L

- Large, heavy pieces of the oven thrown significantly farther than any debris from the item
- Oven materials may have reduced munition fragment projection

RT16170 launcher			
number	item	dist (ft-in)	angle
1	ring	4	0
2	door handle	36-6	0
3	oven	42-6	2
4	oven	41	342
5	oven	61-6	323
6	oven	57	15
7	launcher tube	2	45
8	ring	10-6	290
9	case	15	250
10	oven	16	185
11	launcher	7-9	175
12	rail	5	210
13	rail	6	215
14	case	4	225
15	rail	5-8	155
16	bumper	0-10	270
17	plastic	1-4	110
18	case?	2	65
19	metal?	0-8	180
20	oven motor	14-6	170
21	shield, oven heaters	8	165



SCO w/ Foam & Duct Board

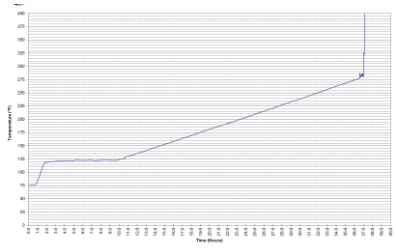
- Foam & Duct board provide:
  - Easy construction of box, window opening & camera support
  - Inner and outer boxes provide strength & stability
  - Terrific thermal insulation
  - Uninhibited fragment projection

Heater / Motor equipment can be protected below oven. Does not need to be in, or hang on, oven walls.

If oven is designed correctly, additional supports (e.g. steel/iron supports, etc.) are not necessary. If used, test might be considered a not test.

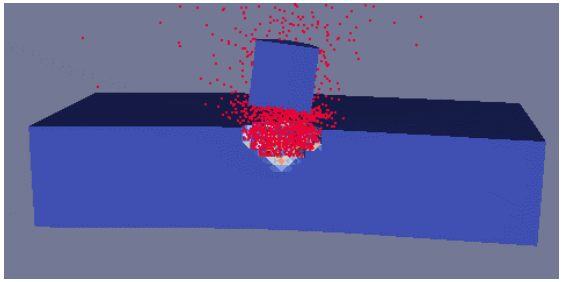
- Compromised ovens from time elapsed reactions?
  - Example of **holes in oven from primers** (pre main event)
    - **6F/hr was still achieved**
    - **Fragment analysis valid**
  - If significant damage is done to oven

and **if TYPE IV reaction outcome is obvious**, then **technical justification** can be made for **heavier oven material** to allow test to complete and evaluate results based on other evidence (e.g. witness plates, munition case, etc.)

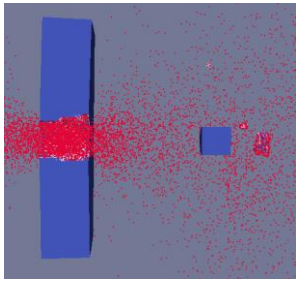


Preliminary Modeling Methodology & Results

- Preliminary analysis performed for a 60g aluminum fragment with a KE of 20J (~25 m/s) with zero obliquity against both materials
- Analysis performed using EPIC
  - Continuum Lagrangian code, can use tetrahedral elements and conversion to smooth particle hydrodynamics (SPH) particles based on excessive grid distortion
  - Linear stress strain response assumed up to the compressive strength, at which point failure assumed to occur
  - Shear and bulk modulus backed out from modulus of elasticity and estimated Poisson's ratio, provides strength and Equation of State (EOS) approximation appropriate for low speed impacts
  - Equivalent plastic strain to failure set to a very small value



Silica Based Fiber Board (Super Firetemp L)
- **density 20pcf**
- **450 psi compressive strength**
- **– no perforation, bounces off**



Thermax/Ductboard,
- **density 2-3 pcf**
- **25 psi compressive strength**
- **– 12% velocity reduction**

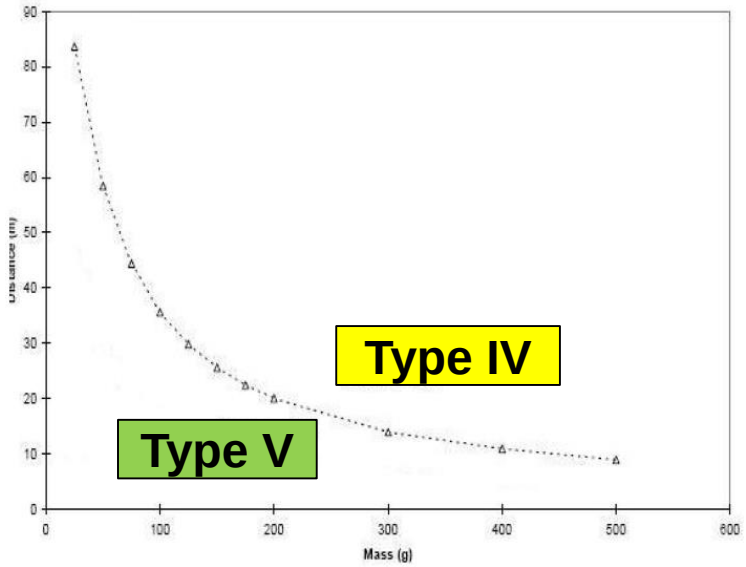
Experimental Setup

- Experimental verification of models should always be performed to the extent practical
- An air gun has been constructed consisting of a metal tube and a projectile with a plastic sabot
- Various fragment sizes will be launched at candidate oven wall materials at various speeds and obliquities of interest
- Ballistic limit and residual velocity will be obtained for candidate wall materials

Test Matrix for Mass 1 (M1)			
Material	Energy		
	20J	50J	79J
Firetemp	$\Delta V_{M1\_Firetmp}$	$\Delta V_{M1\_Firetmp}$	$\Delta V_{M1\_Firetmp}$
Plywood	$\Delta V_{M1\_Plywood}$	$\Delta V_{M1\_Plywood}$	$\Delta V_{M1\_Plywood}$
Foam & Duct Board	$\Delta V_{M1\_Foam\&Duct}$	$\Delta V_{M1\_Foam\&Duct}$	$\Delta V_{M1\_Foam\&Duct}$

Fragment Projection Curve

Mass	Projection distance (m)	
(g)	20 J	8 J
25	83.6	46.8
50	58.4	28.7
75	44.4	20.6
100	35.6	16.2
125	29.8	13.3
150	25.6	11.4
175	22.43	10
200	20	8.8
300	13.9	6.3
400	10.9	4.9
500	8.9	4.1



- The 20J projection curve used to distinguish between TYPE IV (deflagration) and TYPE V (burn)
  - Corresponds to the maximum distance a chunky steel fragment could travel having been launched at 20J, easily calculated with a simple exterior ballistics code

- Using the residual velocity data, it will be possible to reformulate the 20J projection curve to account for the velocity losses of fragments through the oven walls
  - Modeling predictions can also be made

Conclusions and Path Forward

- Determination of reaction type can be suppressed by oven walls
  - Some oven construction currently based solely on **insulation** and test facility concerns, not taking into account external reaction evidence.
    - Heavy **equipment support** (heaters/motors), weather (**rain**), etc.

Conclusions and Path Forward

- Oven materials should be selected to meet all the requirements per STANAG 4382
  - For engineering testing (unofficial)
    - If test results (e.g. **vent design functionality**) other than fragment projection, pressure, etc. are of interest, oven construction may not be as important.
    - When **TYPE IV of TYPE V reactions** are expected, and munition response evidence like **fragment projection is of interest**, **lighter materials should be used**.
    - When TYPE III, II, or I reactions are expected, medium weight materials may not inhibit fragment projection as much, however…
  - For qualification testing (official), **lighter materials must be used** unless TYPE I reaction is guaranteed to occur.
  - In general, for consistency & ease of comparison, **same material should always be used** when evaluating munition response based on evidence such as **fragment projection.**

Conclusions and Path Forward

- Modeling predictions made using EPIC
  - Foam / Ductboard allows fragments to pass through fairly uninhibited, providing ease of fragment projection evaluation.
  - Silica Impregnated Fiberboard (Super Firetemp L) extremely inhibits fragments projection within the TYPE IV fragment regime.
- Experimental data is being gathered to quantify the interference of candidate oven materials with fragment projection.
- 20J projection curve may be modified for SCO testing using this data.

Questions?