Investigation of Commercially Available Inerts as Gun Propellant Coating Materials – Feasibility Study

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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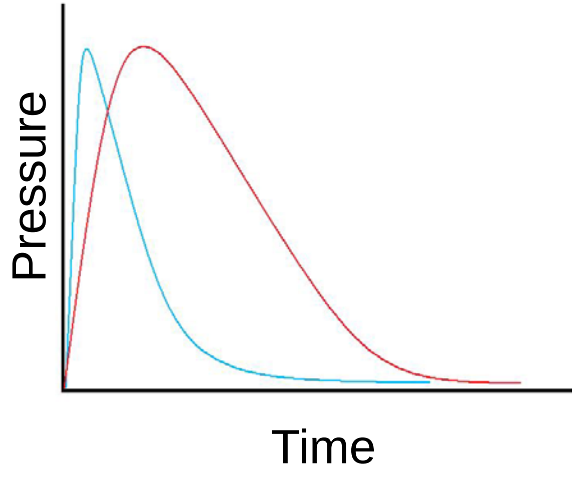
OUTLINE

- Background
  - Goal/Objectives
  - Deterred vs coated propellants
  - Coating material attribute consideration
  - Material selection
- Approach
  - Material selection and Processing methods
- Results
  - Processing Study:
    - Aerosol spray (single grain)
    - Jury-rigged device & Dipping (up to ~30g)
    - Rotary pan coater (up to ~10 lbs)
  - Characterization Results – IR, Optical Analysis, CB, etc
- Summary and Conclusions

Background: Goals/Objectives of Coating

- Increase performance w/o increasing P_{max}:
  - Slowed/inhibited burning
- Inhibit/reduce migration
  - Prevents plasticizer migration and degradation of performance resulting from migration
- To improve IM characteristics
  - Coat with less energetic materials (Impact, spall threats)



Background: Deterred vs Coated Propellants (1)

- Deterred propellants
  - Many of the fielded propellants/igniters for the small cal, med cal, mortars, and artillery systems are deterred
  - Inert ingredient (deterrent) is applied and penetrates into the energetic substrate (base grain) → chemical gradient
  - Progressivity is achieved via chemical means
  - Typical deterrents are: dibutylphthalate (DBP), dinitrotoluene (DNT), ethyl centralite (EC), methyl centralite (MC), paraplex, and vinsol.
  - Examples: M38, M47, WC 806, WC 808, WC 844, WC 864, AFP001, etc.
  - Pros: cost-effective process, performance improvement…
  - Cons: difficult to model (e.g. diffusion, interior ballistics, etc) and migration issue.

Background: Deterred vs Coated Propellants (2)

- Coated propellants
  - None fielded – still experimental
  - Inert and/or less energetic ingredient is applied to energetic substrate (base grain) → homogeneous layer with distinctive thickness
  - Progressivity is achieved via chemical means
  - Several candidates are being considered for coating
  - Pros (in theory): cost-effective process, easier to model, increased performance, reduced/inhibited chemical migration, possible improvement in IM response, and improved ballistic stability.
  - Cons (in theory): may require blending (e.g. coated w/ uncoated grains), possible delamination while aging, etc…

Approach: Considered Attributes of Coating

- Considered Attributes (for both feasibility study and scale-up production)
  - Life cycle cost: Inexpensive
  - Availability: be commercially/readily available
  - Compatibility: Be compatible with gun propellant base grain
  - Processibility: cost, performance, ease of processing (in terms of time, control, etc)
  - Processing methods: spray, adhesion, solvent, surface tension, drying requirement, scalability, etc
  - Ability to work as a chemical barrier: Be able to block migration of chemicals in/out of base grain
  - Workable solvent System
  - No adverse effect on gun erosion
  - No additional contribution to residue after gun firing
  - No harmful product species

Approach: Processing Methods

- Lab Scale:
  - Spray (i.e. aerosol can, hand sprayer)
  - Dipping
  - Individual propellant grain was coated one at a time then about a dozen grains at a time in a jury-rigged device
- Pilot Scale:
  - Rotary pan coater was used to coat ~200 g of propellant grains per batch.
  - Dipping of multiple grains (~dozen per batch) was tried
- Coated propellants were analyzed for weight, thickness, surface finish, etc.
- Processibility was assessed for each method.

Results: Aerosol Spray

- Aerosol sprayer was used for inerts:
  - Individual grains were coated evenly with high quality
  - No sticking
  - Good even coverage throughout the grain surface
  - Even thickness where inspected
  - Appeared to have good adhesion
  - Results were promising for moving forward to increase batch size.

Results: Jury-Rigged Device & Dipping

- Increased batch size (~10g - ~30g):
  - While propellant grains were rotated in a drum, the coating materials were hand sprayed followed by forced air drying
    - The number of sprays (i.e. amount of applied coating per turn) between forced air drying were varied
    - The number of coats per batch were varied
    - The concentration of coating material in carrier solvent was varied
    - The solvent system was optimized initially based on coating material solution viscosity, substrate-solvent interaction, degree of stickiness, etc.
  - Dipping of multiple grains were attempted
    - Grains were sticking and were hard to break apart
    - Base grains were deforming due to the solvent system over-solvating the NC-based substrate
    - This method was dropped

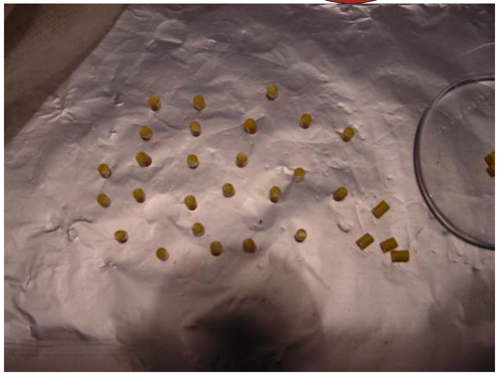
Results: Spray Coating

Quick assessments

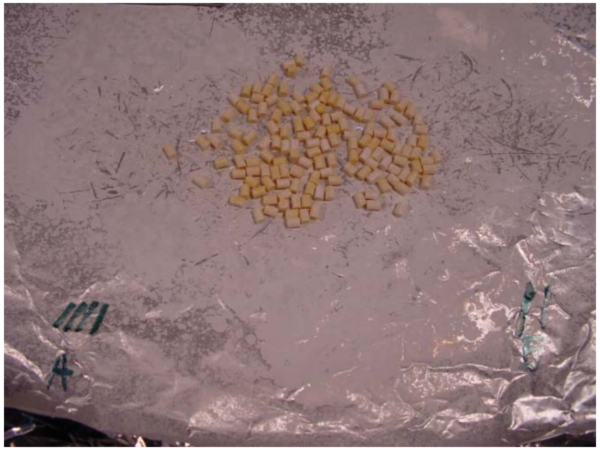
- •Visual inspection
- •IR analysis – samples were coated (coating masked the base grain well)
- •Optical microscope – coating thickness was determined → ~45 microns

Results: Processibility Study

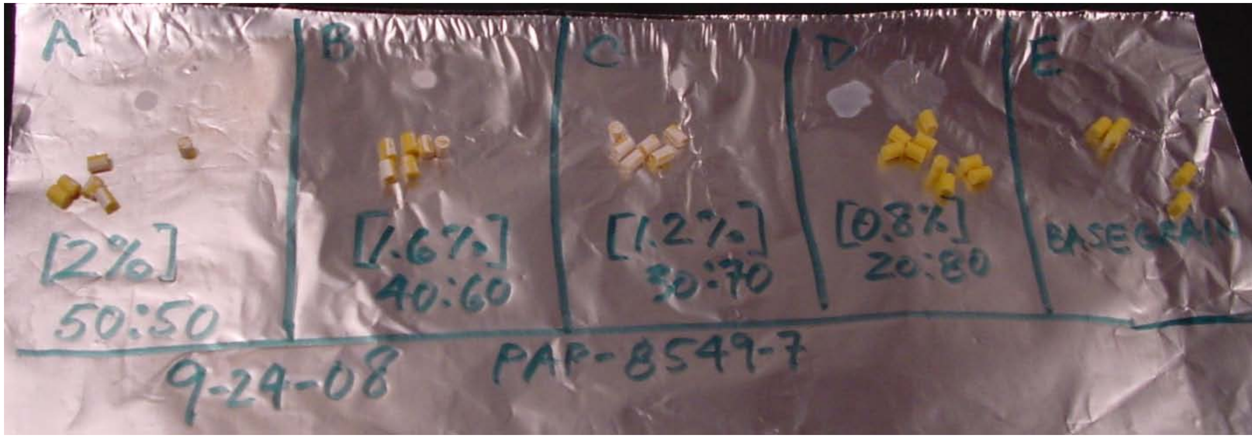
- Proof-of-concept
  - Aerosol spray: one grain at a time; high quality; low throughput
  - Manual spray bottle: several grains at a time; med quality; medium throughput



Aerosol can method (Sep 2008)



Hand Spray Method (Sep 2008)

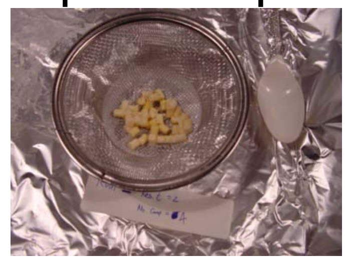


Effects of concentration and co-solvent (acetone:EtOH) system – Hand Spray (Sep 2008)

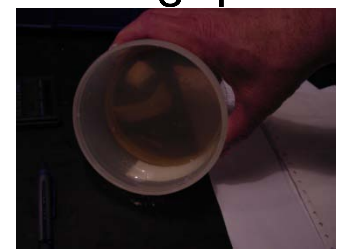
Results: Processibility Study (cont'd)

- Proof-of-concept
  - Dipped coating: clumping was observed; distortion of base grains due to a long exposure to solvent.
  - "Jury-rigged" rotating coater: improved quality; high throughput

Krispy Kreme® Doughnuts – Glazed by Dipping Process

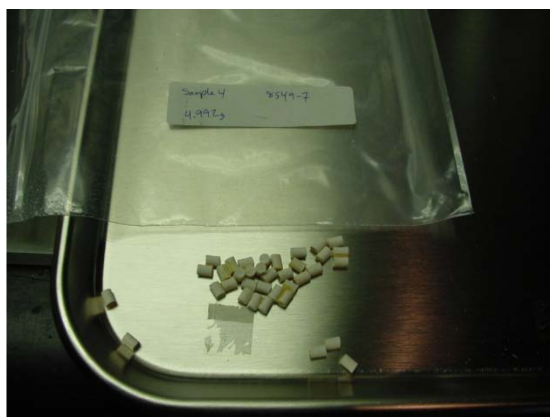


Dipped method (2009)

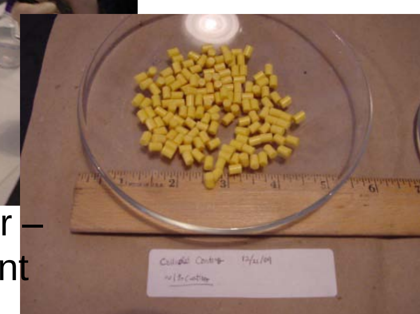


Homemade Coating Stock (2009)

Jury-Rigged rotating coater (Sep 2009)



Tumbler Improved the Quality



Automated Tumbler – Quality improvement (Dec 2009)

Results:
Rotary Pan Coater

Modernized processing

- Sweetie Barrel – Antiquated technology; current industrial process
- Fully Perforated Rotary Pan Coater - achieve predicted concentration gradient and coating thickness; adapted from pharmaceutical industry

Rotary Pan Coater (Vector Coater)

- Fully remote, PLC-controlled
- 3 coating pans (0.5 L, 2.5 L, 8 L)
- Variable spray guns configuration

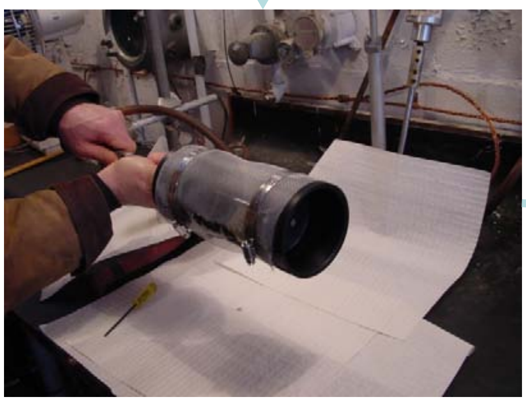
Process Optimization

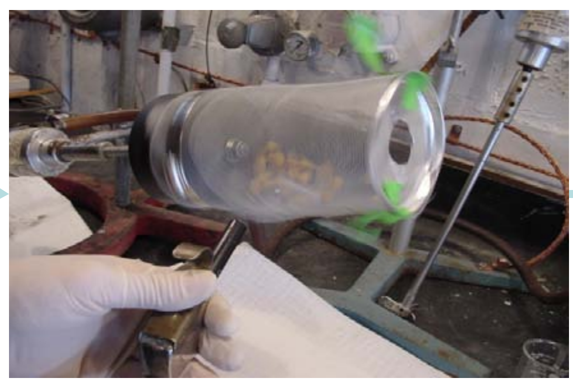
- Pan speed
- Inlet air temperature
- Degree of fill
- Spray gun – atomization
- Mass flow rate (coating)
- Coating solution viscosity and concent.
- Residence time

Results: Evolution of Coating Process

Aerosol Spray (*Source:* Wikipedia)

Make-shift Tumbler + Hand Sprayer + Compressed Air





Make-shift Tumbler (pneumatic motor) + Hand Sprayer + Compressed Air

Rotary Pan Coater

Results: Closed Bomb Test

Closed bomb

- Samples coated with three different inerts were tested:
- These samples were prepared using the make-shift tumbler and rotary pan coater.

Ignitability

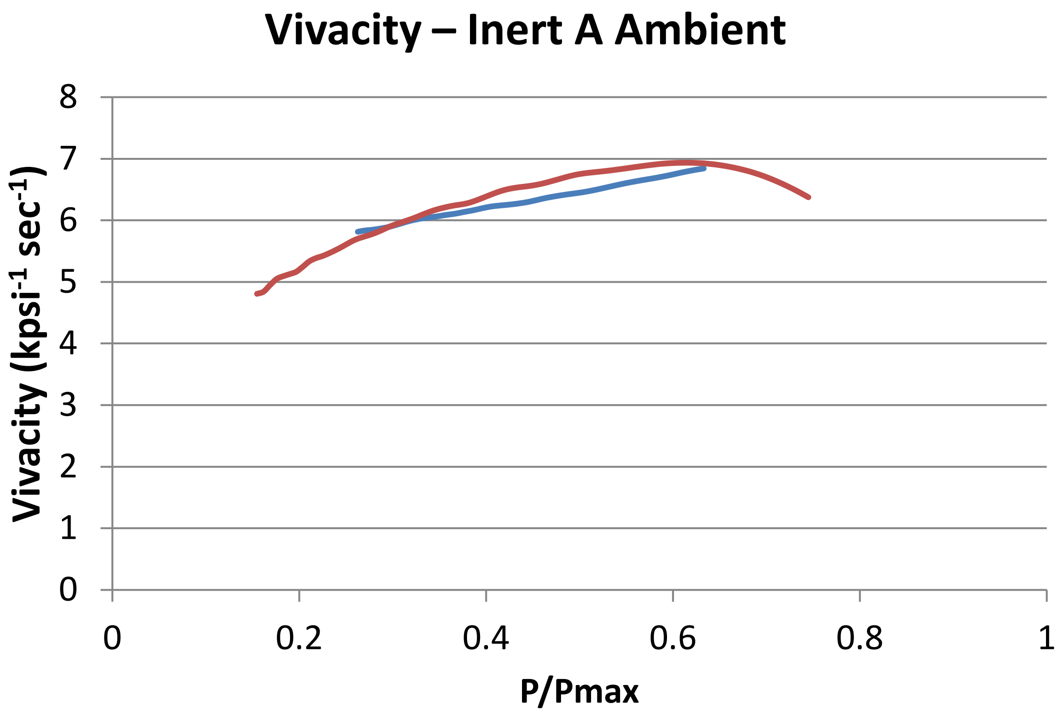
- It was conducted at ARL (results are not shown in this paper)

30mm Ballistic Firing

- To be conducted later in FY12

30mm gun

Results: Closed Bomb Test - Vivacity



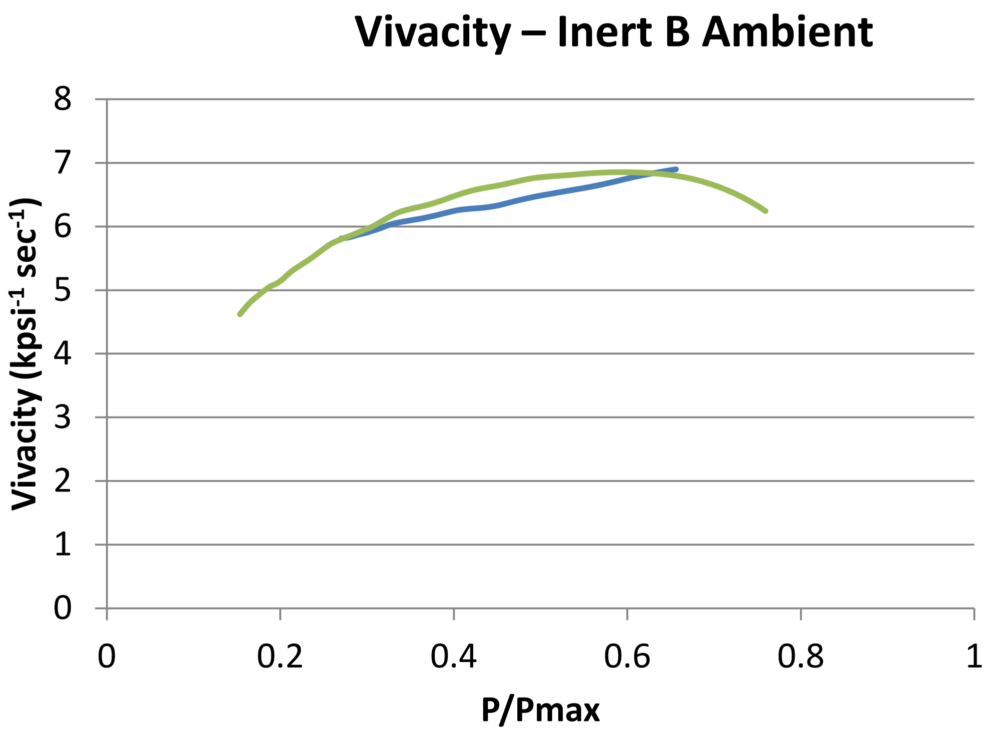
Red = Coated propellant

Blue = Reference (uncoated base grain)

Inert A coated propellant

- 3.69 wt% coated
- Higher slope then baseline until P/Pmax = ~0.4
- Similar slope as baseline b/t 0.4 and 0.6 (P/Pmax)
- Burning starts to be degressive around 0.65 (P/Pmax).
- These samples were prepared using the rotary pan coater.

Results:
Closed Bomb Test – Vivacity



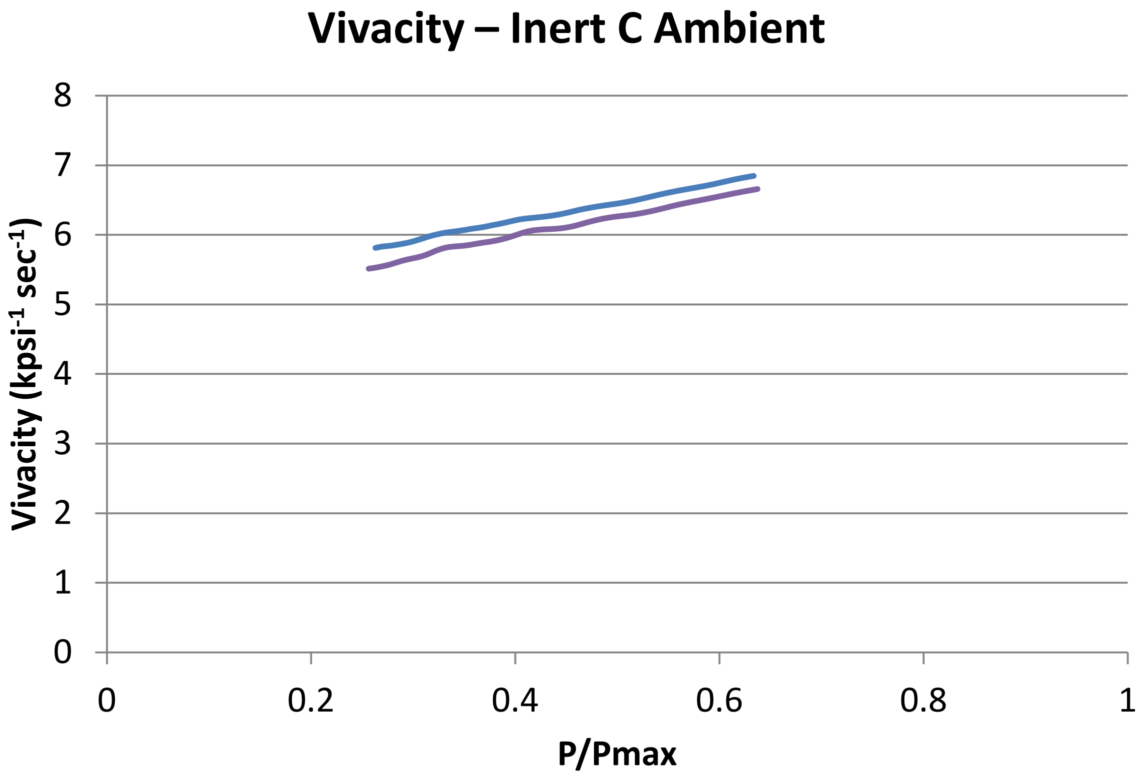
Green = Coated propellant

Blue = Reference (uncoated base grain)

Inert B coated propellant

- 1.16 wt% coated
- Higher slope then baseline until P/Pmax = ~0.4
- Similar slope as baseline b/t 0.3 and 0.6 (P/Pmax)
- Burning starts to be degressive around 0.7 (P/Pmax).
- These samples were prepared using the rotary pan coater.
- Significant ignition delay @ cold temp.

Results:
Closed Bomb Test - Vivacity



Purple = Coated propellant

Blue = Reference (uncoated base grain)

Inert C coated propellant

- 2.31 wt% coated
- The resulting curve parallels the baseline
- It is possible the plasticizer may have migrated into the grain (not confirmed yet)
- Much less ignition delay compared to two preceding inerts

Summary and Conclusions

- Several types of coating materials have been investigated for their processibility and progressivity
  - Three inerts have been downselected for further study
- Several methods of coating have been studied
  - Aerosol, dipping, jury-rigged mini-tumbler, and rotary pan coater
- The implementation of rotary pan coater has been successful in coating granular propellants at a pilot scale
  - Several processing variables were explored
- Coated propellants have been characterized in several ways:
  - Optical imaging, IR spectroscopy, closed bomb, ignitability study, etc
- Initial closed bomb results indicate that the better fundamental understanding of ignition of surface coated propellants is needed
  - Gun firing will follow; relationship between CB and gun firing will be better understood