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Demonstration and Validation for Lead Free Ballistic Modifier for Rocket Propellants

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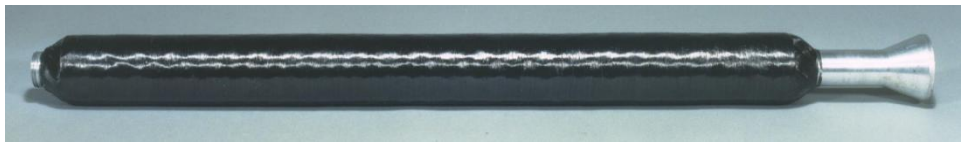
Lead in Military Applications

- **Double-Base (DB) Rocket Propellants: Cast Cure and Extruded**
  - Lead citrate is used in TOW, Hellfire and Chapparal launch motors
  - LC-12-15 in NOSIH-AA-2 propellant for the 2.75 in rocket motor
  - LC-12-6 in M36 propellant for the Javelin launch motor and other applications
- **Percussion Primers**
  - Most percussion primers employ lead styphnate
- **Gun Propellants**
  - Lead carbonate in BS NACO propellant
- **Bullets**
  - Bullet cores traditionally made of lead

Lead widely used in military applications

2.75 Inch Rocket Background

- 1991 – 1993 Extruded Double Base (EDB) Lead-Free Study (Hercules, Inc)
  - Several candidates (RPD-308 and RPD-309) close to NOSIH-AA-2 requirements for strand burn rates (SBR)
- 1996 – 1998 Lead-Free Double Base Propellant Development (ATK and NSWC/IH)
  - Developed a viable candidate (RPD-422) that did not meet aging requirements
- 1998 – 2000 Accelerated Aging of Lead-Free Propellant (ATK and NSWC/IH)
  - Studied RPD-422 to determine cause of aging issues: identified the monobasic cupric salicylate as problematic
- 2001 – 2002 Coated and/or Pre-Reacted Lead-Free Ballistic Modifiers (ATK and NSWC/IH)
  - Attempted to improve RPD-422 aging through coating and pre-reacting modifiers
    - » No improvement



Introduction/Approach

- 2.75 inch rocket propellant NOSIH-AA2 presently contains LC-12-15, a lead containing ballistic modifier
- Lead is undesirable from an environmental and toxicity standpoint
  - Removal of lead from the rocket is imperative
- Our two-pronged approach is to optimize data obtained from past work
  - First prong: Improve aging on past programs
    - Several ATK studies conducted on 2.75 inch rocket programs
      - » Three formulations with excellent SBR data and unacceptable aging properties
  - Second prong: transfer cast-cure technology to extruded double-based
    - AMRDEC has developed lead-free cast cure formulations based on bismuth compounds
      - » Plan to transfer that technology to an extruded double base propellant

Performance Criteria for Lead Free DB Propellants

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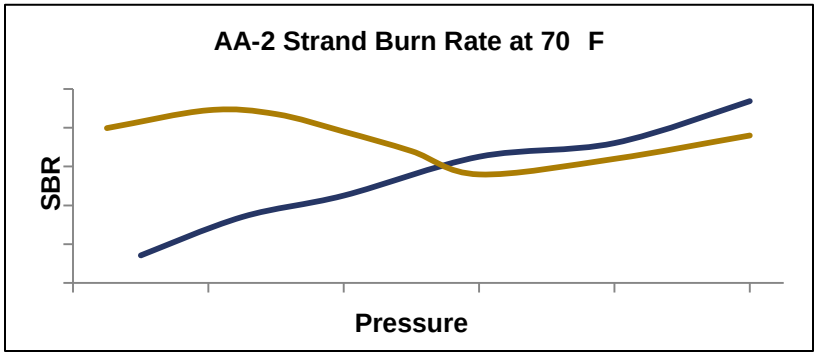
- **Ballistic Performance (Burn Rate)**
  - ✓ Plateau behavior over operating temperature range
  - ✓ Low temperature sensitivity
- **Propellant Aging Properties**
  - ✓ Must perform as well as or better than leaded ballistic modifiers
    - – Needs to retain as much as or more stabilizer upon aging than traditional
    - – Must retain plateau burn rate behavior after accelerated aging
    - – Must retain temperature sensitivity after accelerated aging



Several metrics for success

Status of Present ESTCP-Funded Program

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- **Evaluations Completed to Date**
  - ➢ Formulations developed to improve on earlier studies
    - – AMRDEC's cast-cure results
      - – Based on bismuth compounds
    - – ATK's Copper based formulations that performed well but aged poorly
      - − Attempted to improve aging properties

- **Results**
  - ➢ Attempts to improve aging properties proved unsuccessful
  - ➢ Formulation based on cast cure work showing promise
    - – Exhibits plateau behavior with respect to strand burn rate
    - – Excellent accelerated aging properties

Promising new lead free candidate

First Prong: Optimizing to Improve Aging

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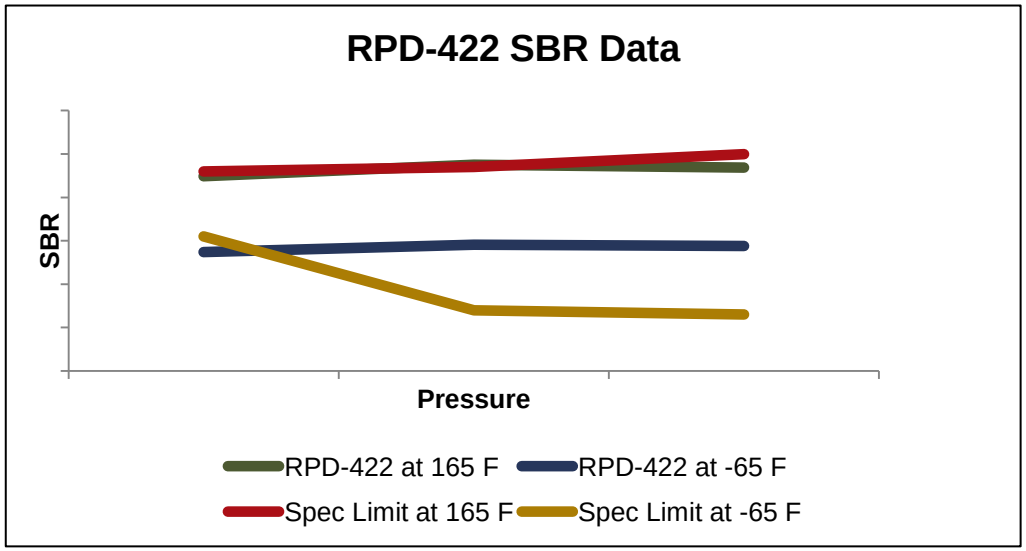
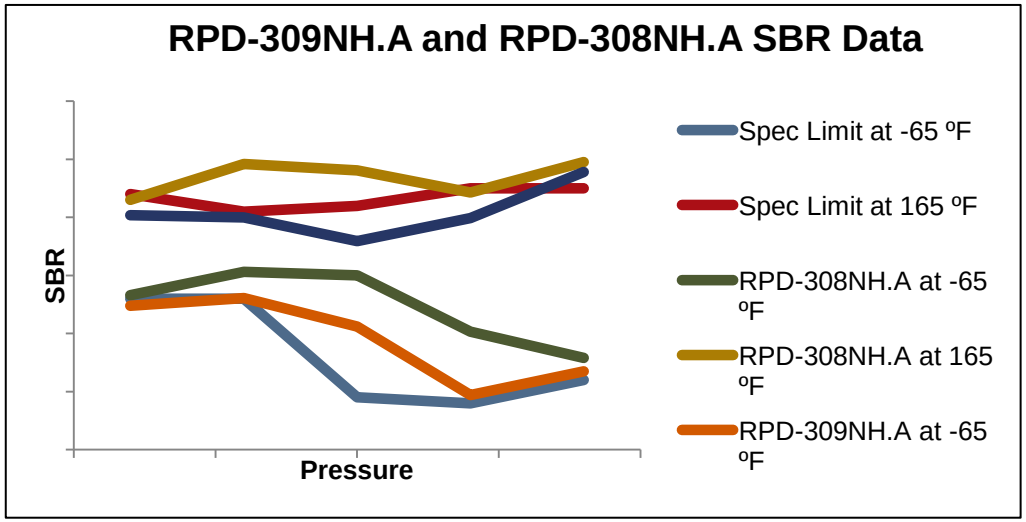
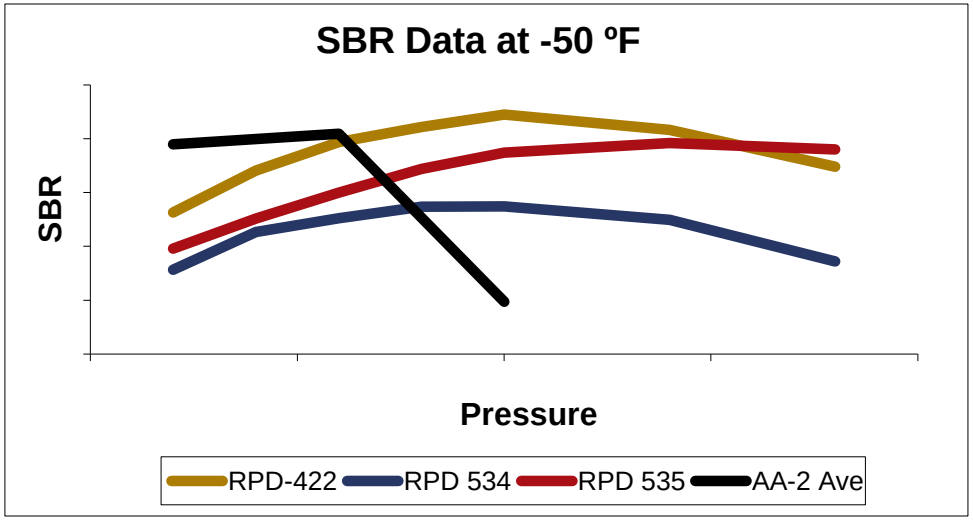


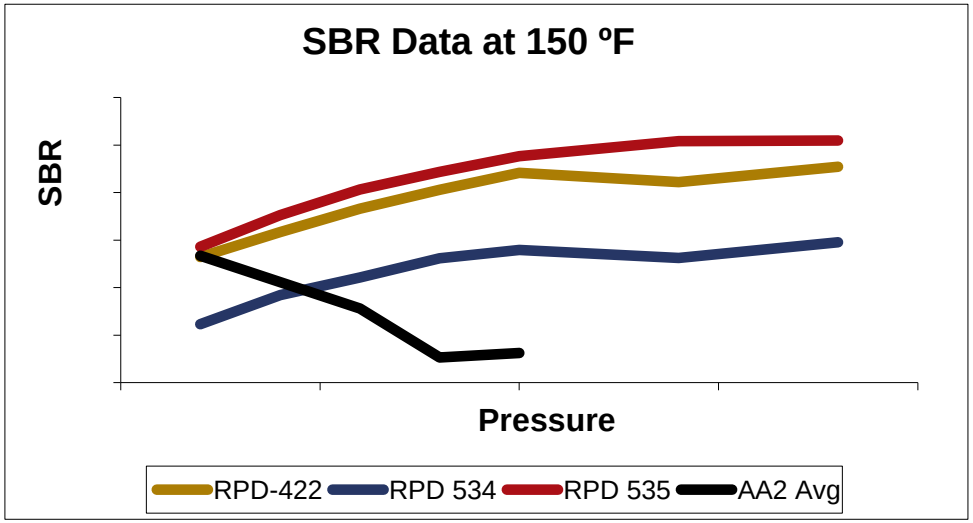


- Past studies yielded formulations with excellent SBRs and poor aging properties
- Formulations RPD-309NH.A, RPD-308NH.A and RPD-422 were modified in order to improve their aging properties
- All formulations were based on copper and bismuth compounds
- Previous data had indicated that monobasic copper (II) salicylate was causing aging problems for RPD-422

Excellent SBRs and unacceptable shelf-life

First Prong: Optimizing Aging of RPD-422

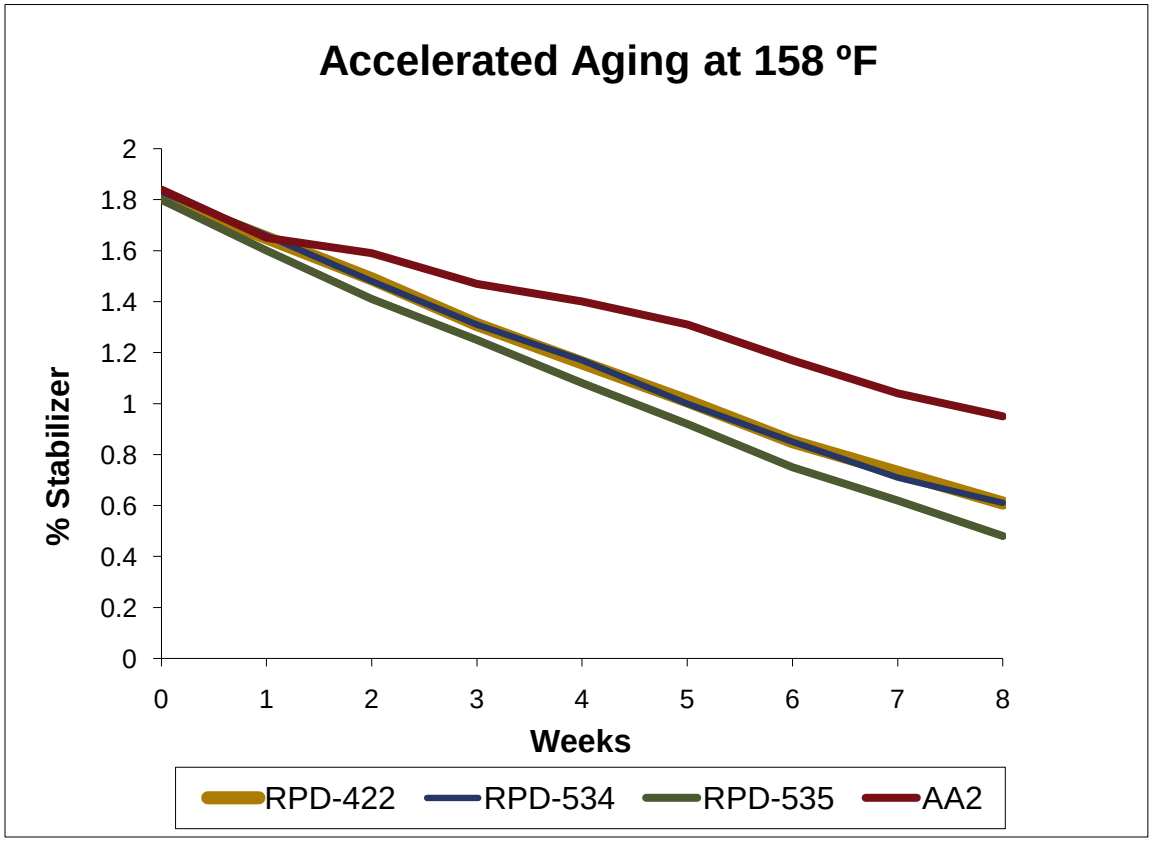




- RPD-534 identical in formulation to RPD-422 except a monobasic cupric salicylate was coated
  - Identical slopes to RPD-422 with lower SBRs
  - Lower SBRs expected due to addition of inert coating
- RPD-535 identical to RPD-422 except monobasic copper (II) salicylate was swapped out for copper (II) salicylate
  - SBRs for 535 were very similar to 422 as expected

Successful mimicking of RPD-422 ballistic modification

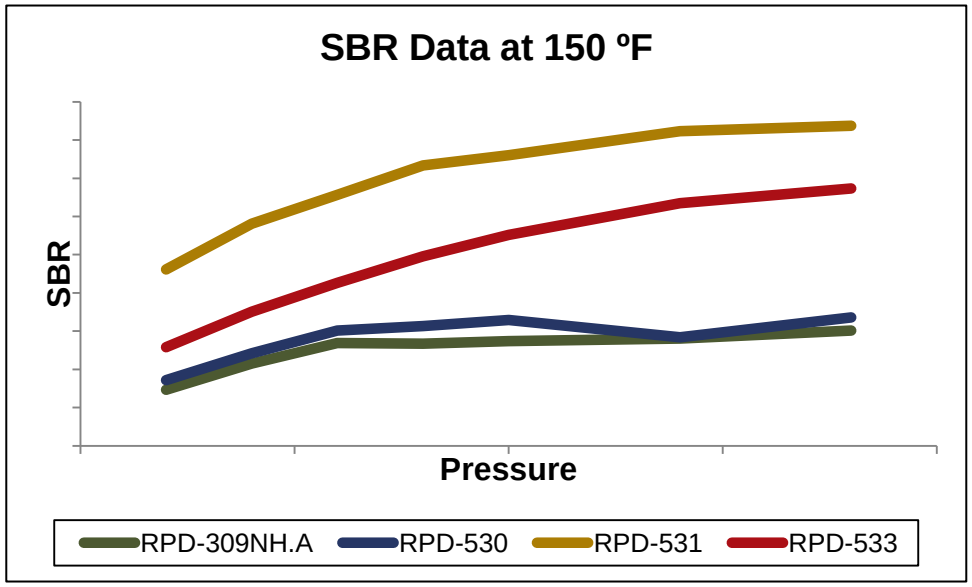
First Prong: Optimizing Aging of RPD-422

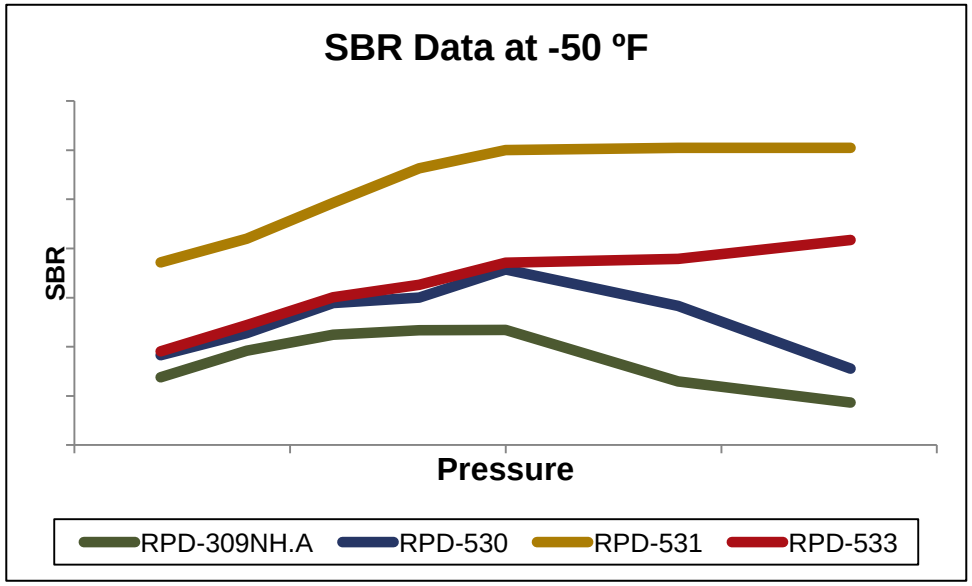


- RPD-422 and it's derivatives were subjected to an 8-week accelerated aging study
- Modifications to RPD-422 did not improve aging
- RPD-534 (coated modifier formulation) aged identically to RPD-422
- RPD-535 aged slightly worse than RPD-422

Efforts to Improve RPD-422 aging unsuccessful

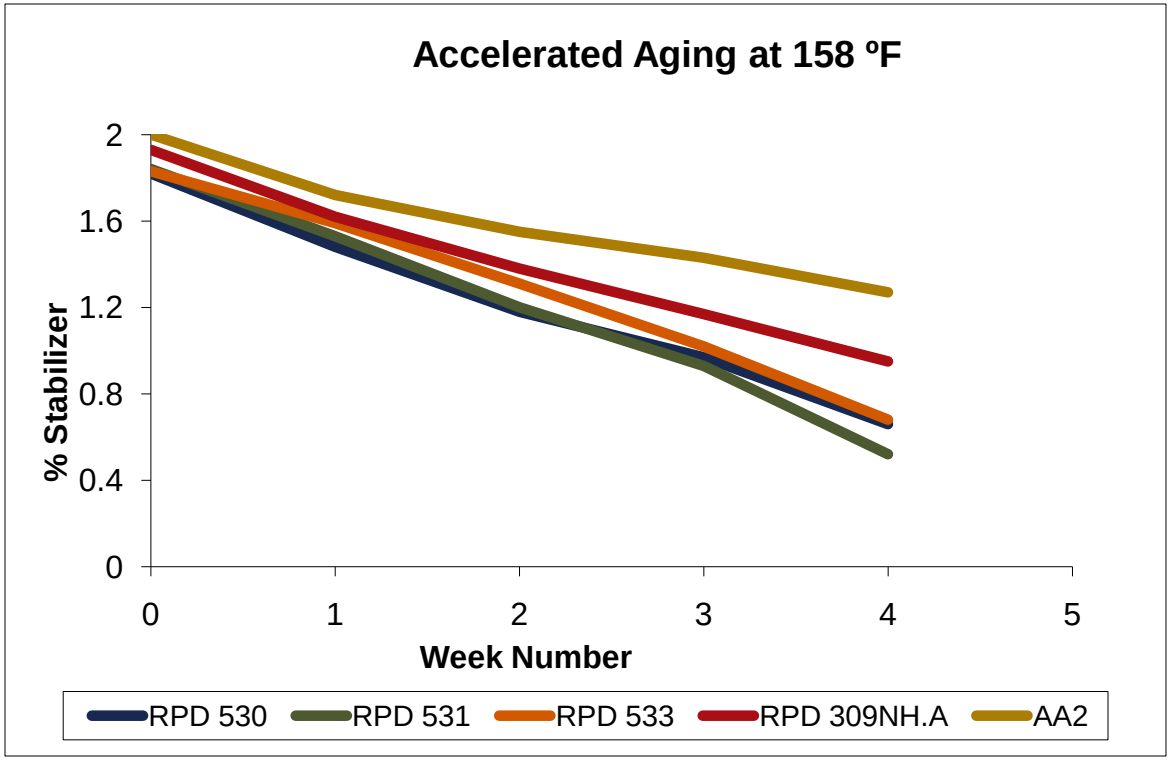
First Prong: Optimizing RPD-308NH.A and 309NH.A





- RPD-530 identical to RPD-309NH.A except copper and bismuth hydroxides were replaced with acetates
  - Performed very similarly to RPD-309NH.A
- RPD-531 identical to RPD-309NH.A except copper and bismuth hydroxides were replaced with oxides
  - Performed well in terms of slope but had increased burn rate over RPD-309NH.A
- RPD-533 identical to RPD-309NH.A except sodium bicarbonate (present in small amount) was removed
  - Acceptable performance in terms of slope, higher burn rate at hot temperature

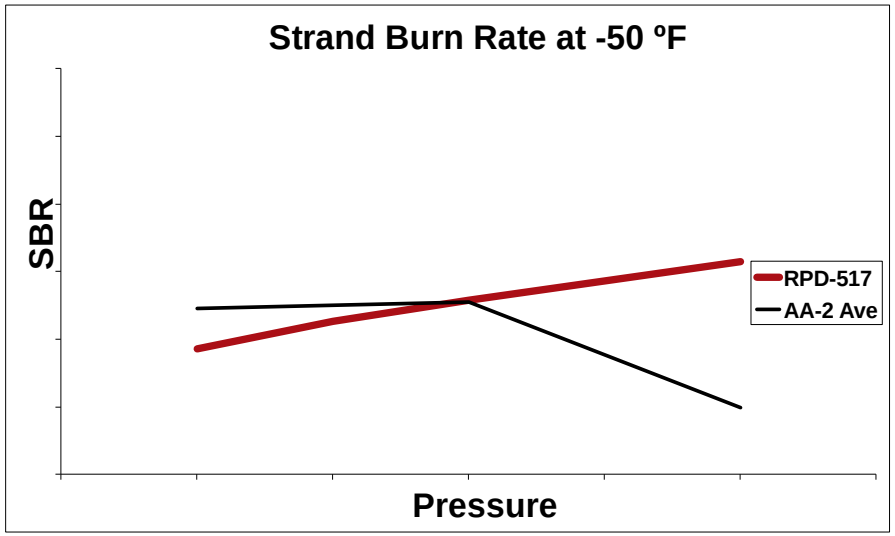
First Prong: Optimizing RPD-308NH.A and 309NH.A

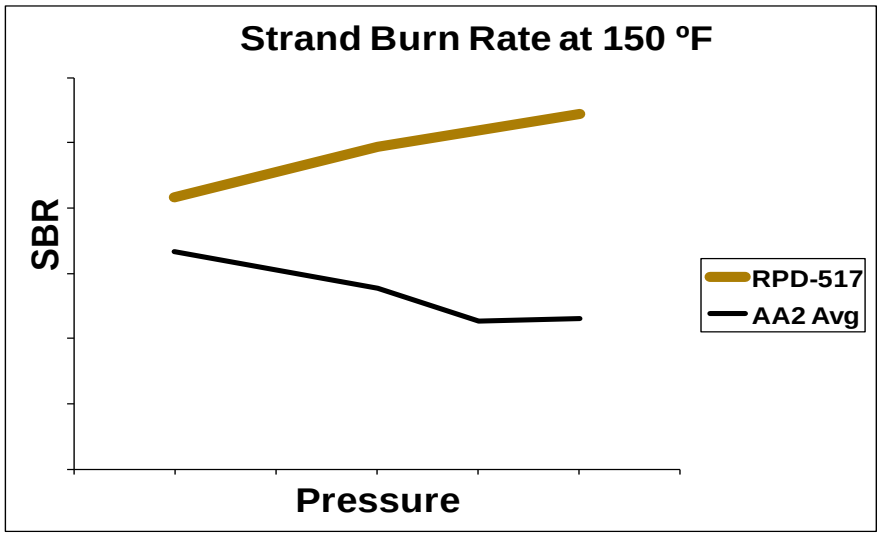


- Data showed that no formulations aged similarly or better than AA-2
- Aging study was discontinued at 4 weeks due the unacceptable aging results

Efforts to Improve RPD-309NH.A and 308NH.A aging unsuccessful

Second Prong: Strand Burn Rates of RPD-517





- **Modifier matrix based on work conducted at ABL on cast cure propellants**
  - **Bismuth based modifier system**
- **Fairly flat slopes at both high and low temperature**
- **Burn rate at low pressure is low**
- **Chosen for further optimization**

RPD-517 shows promise

Second Prong: RPD-517 Aging Study Results

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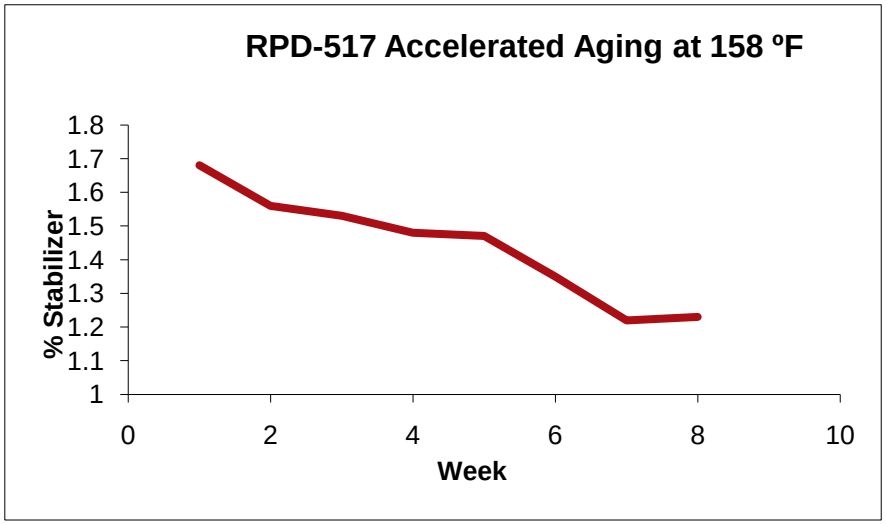
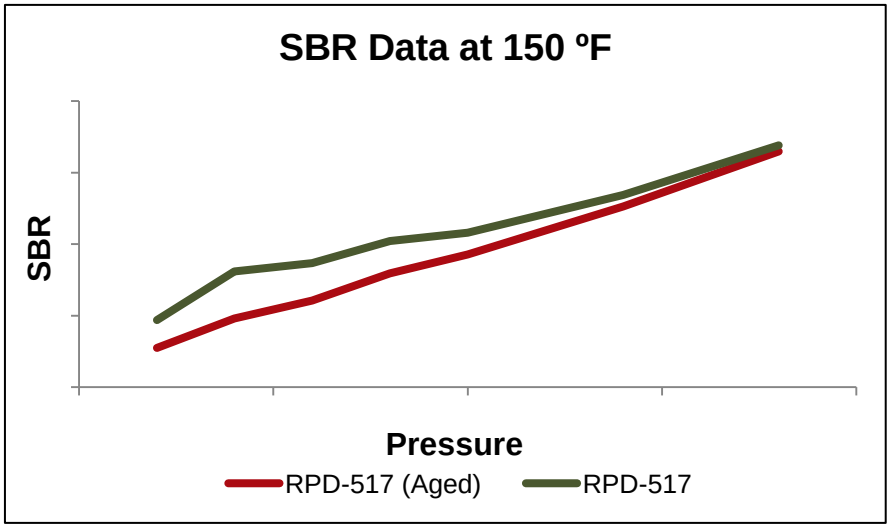
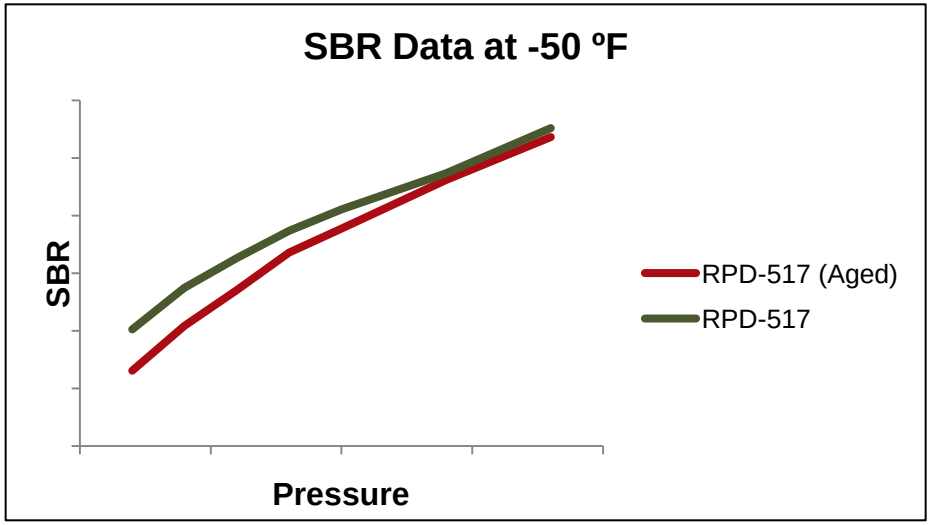


- RPD-517 lost 27% of its stabilizer after 8 weeks of aging
  - The presently used NOSIH-AA-2 propellant loses 50%
- RPD-517's SBR data before and after aging virtually the same





RPD-517 retains 46% more stabilizer than AA-2 in aging studies

Second Prong: Optimization of RPD-517

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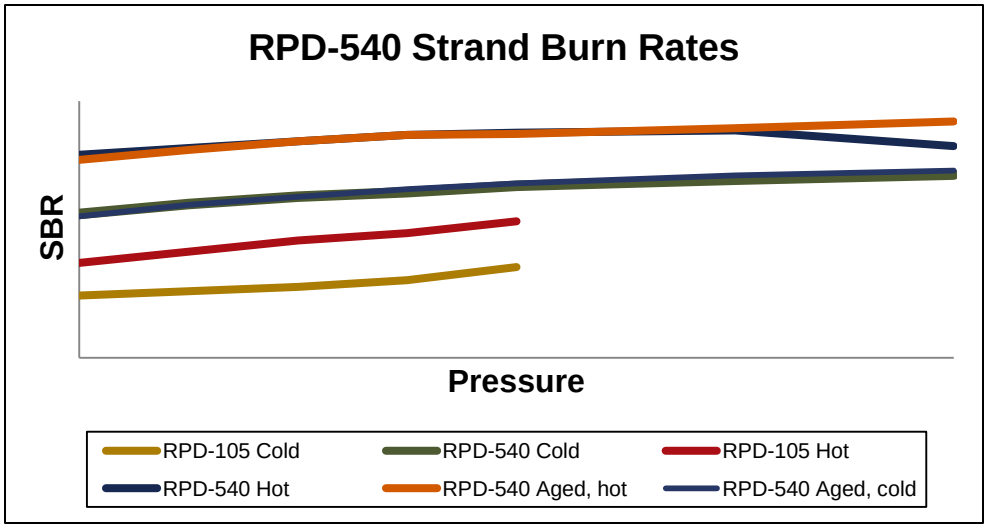
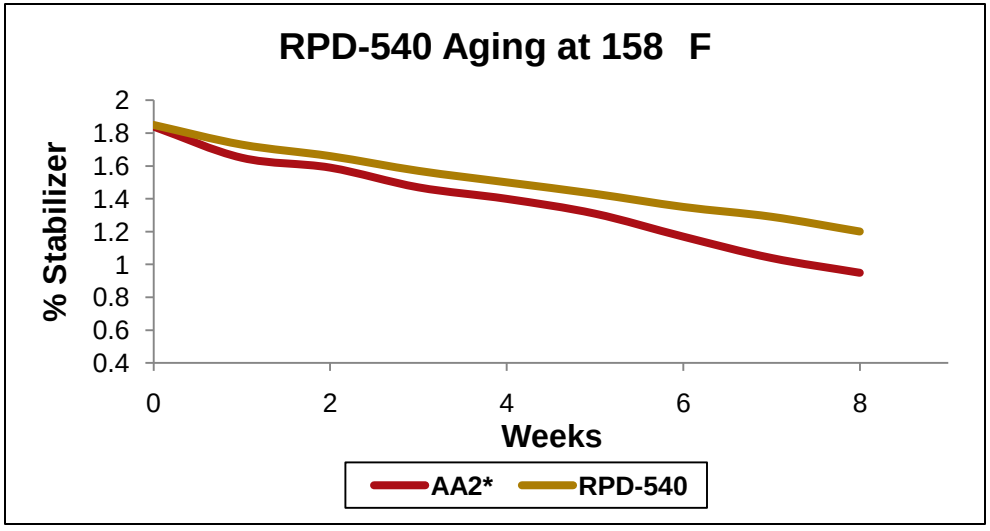
- RPD-540 exhibits the required strand burn rate (SBR) plateau behavior
- Retains SBR behavior after accelerated aging
- RPD-540 retains MORE stabilizer after accelerated aging than NOSIH-AA-2





Novel formulation improves aging over legacy

Summary

- A two-pronged approach was implemented to develop novel lead-free formulations
- First prong involved developing novel formulations aimed at improving aging characteristics of lead-free formulations that performed well in the past
  - Novel formulations did not achieve the desired goal
- Second prong involved applying successes from previous cast-cure work to EDB propellants
  - RPD-540, the most promising formulation, was developed using this approach
- Future plans are to static test RPD-540 heavy weight test configuration

Acknowledgements

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