NAVSEA
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Reactive Materials

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What are Reactive Materials?

- An energetic material consisting of two or more solid-state reactants that together form a thermo-chemical mixture
- Typically metal-metal and/or metal-metal oxide mixtures with and without binders
- Materials with higher predicted energy per unit volume than conventional energetics
- Provide alternate kill mechanisms besides those obtained for conventional energetics

Benefits of Reactive Materials

- Self-propagating High-temperature Synthesis (SHS) Reactions - **more energy**
  - More efficient pathways to energy delivery
  - More energy per unit volume than conventional explosives
  - Shock sensitivity can be tailored
- Ultra-fine powders - **energy management**
  - Energy release rate can be tailored
  - More energy than chemical energy (ESM)
  - Reactions with water and external air are possible

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Classes of Reactive Materials

- Self-Propagating High-temperature Synthesis (SHS)
  - Thermitic - metal/metal oxide reactions
    - Thermite and MIC reactions
  - Intermetallic reactions
    - Aluminides
    - Borides
    - Carbides
  - Metal/fluorine systems
- Ultra-fine powders
  - ALEX (exploded wire)
  - MIC ingredients
  - Nano-laminates
  - Mechanochemical Synthesis (MCS)
  - Energy Saturated Media (ESM)
  - Hf and Ti powders

Standard Heats of Oxidation of Selected Metals and Fuels

Metal/Fuel	Density of Fuel gm/cm3	Main Oxide and Standard State	Gravimetric Heat of Oxidation KJ/gm Fuel	Volumetric Heat of Oxidation KJ/cm3 Fuel
Aluminum (Al)	2.7	Al2O3(s)	31.06	83.86
Boron (B)	2.34	B2O3(s)	58.74	137.45
Beryllium (Be)	1.85	BeO(s)	66.46	122.95
Carbon (C)	2.25	CO2(g)	32.78	73.76
Iron (Fe)	7.86	Fe2O3(s)	7.39	58.09
Hydrogen (H)	--	H2O (l)	141.85	--
Lithium (Li)	0.534	Li2O(s)	43.16	23.05
Magnesium (Mg)	1.74	MgO(s)	24.73	43.03
Silicon (Si)	2.33	SiO2(s)	32.26	75.17
Titanium (Ti)	4.54	TiO2(s)	19.73	89.57
Tungsten (W)	19.35	WO3(s)	4.59	88.82
Zirconium (Zr)	6.49	ZrO2(s)	12.04	78.14
HTPB (R45-HT)	0.92	--	43.28	39.82

SHS Efficiency

- Beryllium – most energetic metal based on weight

- Boron – most energetic metal based on volume

$Ti + O_2 \longrightarrow$	TiO_2	efficient
$2B + 3/2\ O_2 \longrightarrow$	B_2O_3	inefficient
$Ti + 2B \longrightarrow$	TiB_2	~ 7200 °F
$TiB_2 + 5/2\ O_2 \longrightarrow$	$TiO_2 + B_2O_3$	efficient

SHS Reactions

SHS System	Reactions	Energy Output (cal/g)	Energy Output (cal/cm3)	Adiabatic Rxn Temp (^{o} K)	Theoretical Max Density (g/cm^3)
Aluminides	Li + Al	1130	1672	2613	1.48
	Ni + Al	329	1700	1973	5.17
	Zr + 2AL	412	1759	1923	4.27
Borides	Ti + 2B	1115	3992	4043	3.58
	Hf + 2B	394	3550	3653	9.01
	Ta + 2B	308	3175	2673	10.31
Carbides	Ti + C	813	3056	3873	3.76
	Hf + C	277	2820	4473	10.18
	Ta + C	200	2386	3073	11.93

Values from GSI SBIR

Comparison of Energy Release from SHS and Explosive Reactions

Composition	(-ΔH) [cal/g]	(-ΔH) [cal/cm^3]
TNT	1,040	1,530
RDX	1,320	2,420
HMX	1,280	2,510
Ti+2B	1,115	3,992

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Potential Applications

- Force Protection
- Metal cutting/concrete cutting - NSWCIHD
- Reactive breaching
- Structural energetic composites - NSWCIHD
- Reactive explosively forged penetrators
- Reactive fragments - NSWCDD
- Reactive filled darts - NSWCIHD
- Underwater energy release - NSWCIHD

Potential Applications (Cont.)

- Thermochemical Warheads - NSWCIHD
  - High temperature thermal radiators (HTTRs)
  - TBXs
  - Metal/Vapor Clouds
- Agent defeat (heat and biocides) - NSWCIHD
- Primers/Detonators
- Explosives and burster charge
- Propellant additives - NSWCIHD
- Decoys

Advantages of Intermetalic RMs

- Adaptable to a variety of applications
- 4.1 flammable solid versus 1.1 detonable explosives
- Meets Insensitive Munitions (IM) requirements
- Minimal gas evolved during combustion
- Warhead fill would survive high impacts from penetration

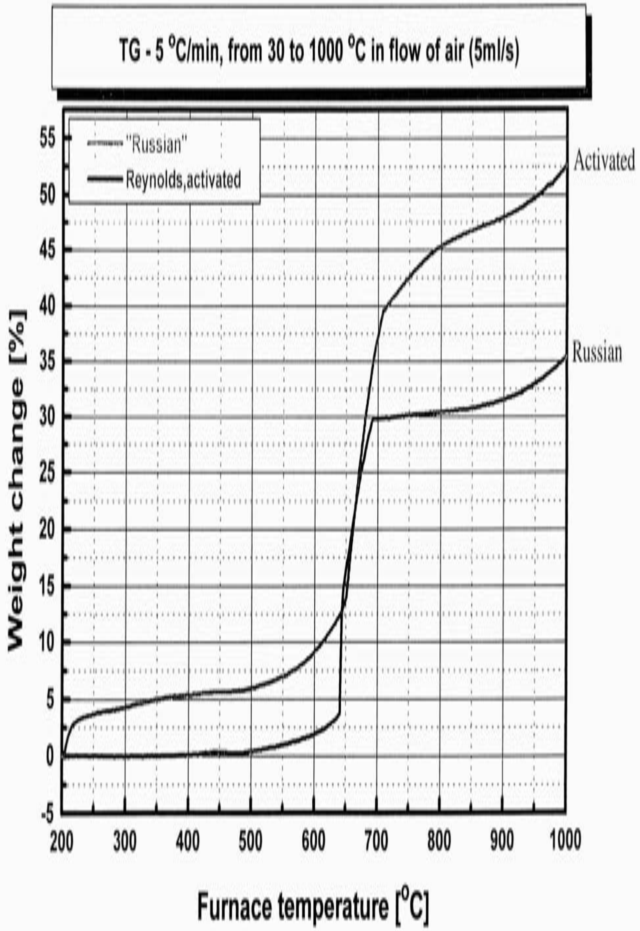
Appendix

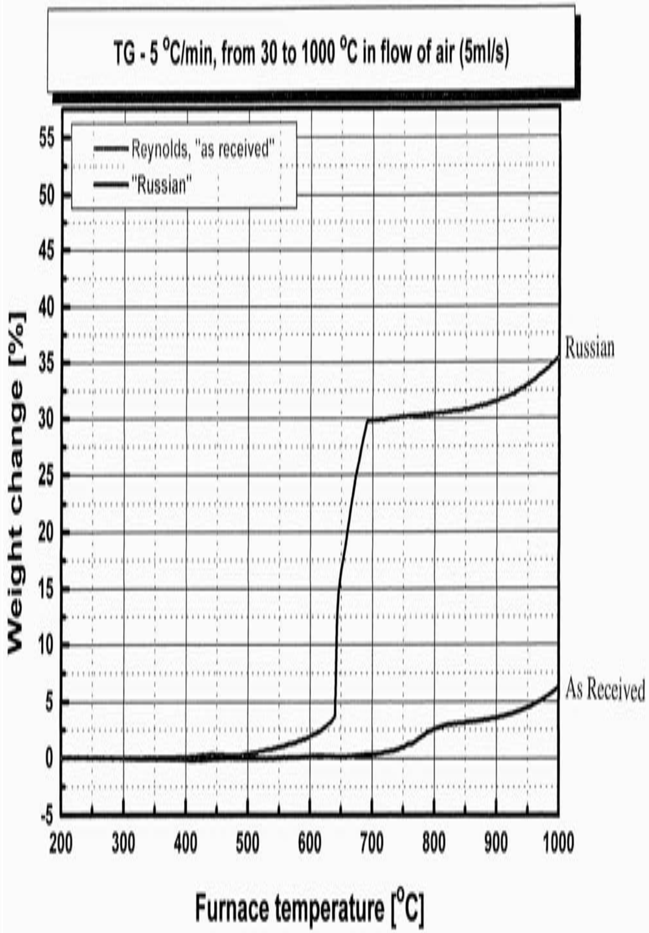
Example of Energy Saturated Media (ESM) and Underwater Applications

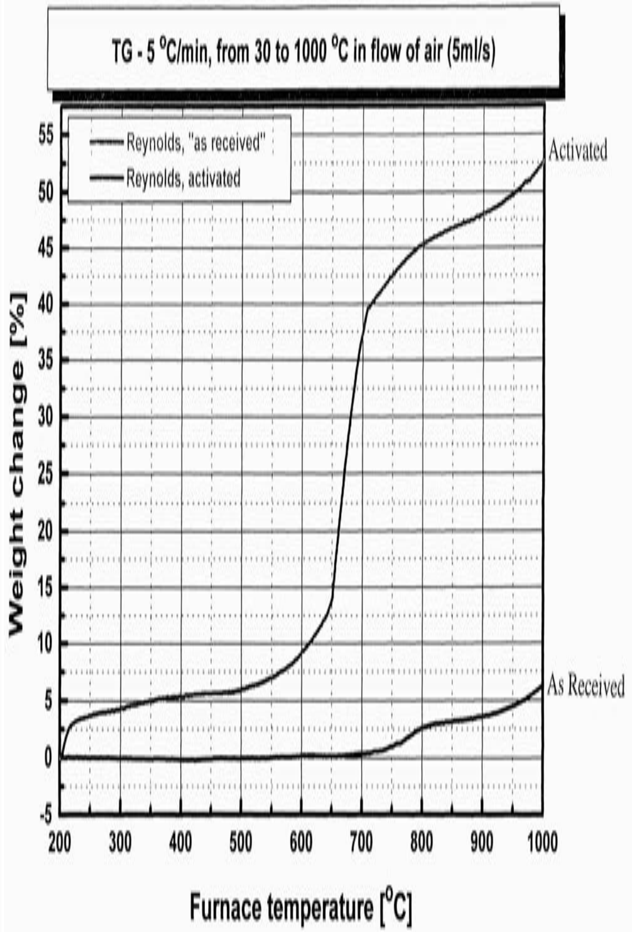
Why Mechanochemical Synthesis

- Produces activated ultra-fine metal powders (ESM)
- Less expensive than vapor deposition
- More total energy
  - Physical energy
  - No oxide coating
- Issues
  - Less known
  - Configuration management
  - Processing into compositions

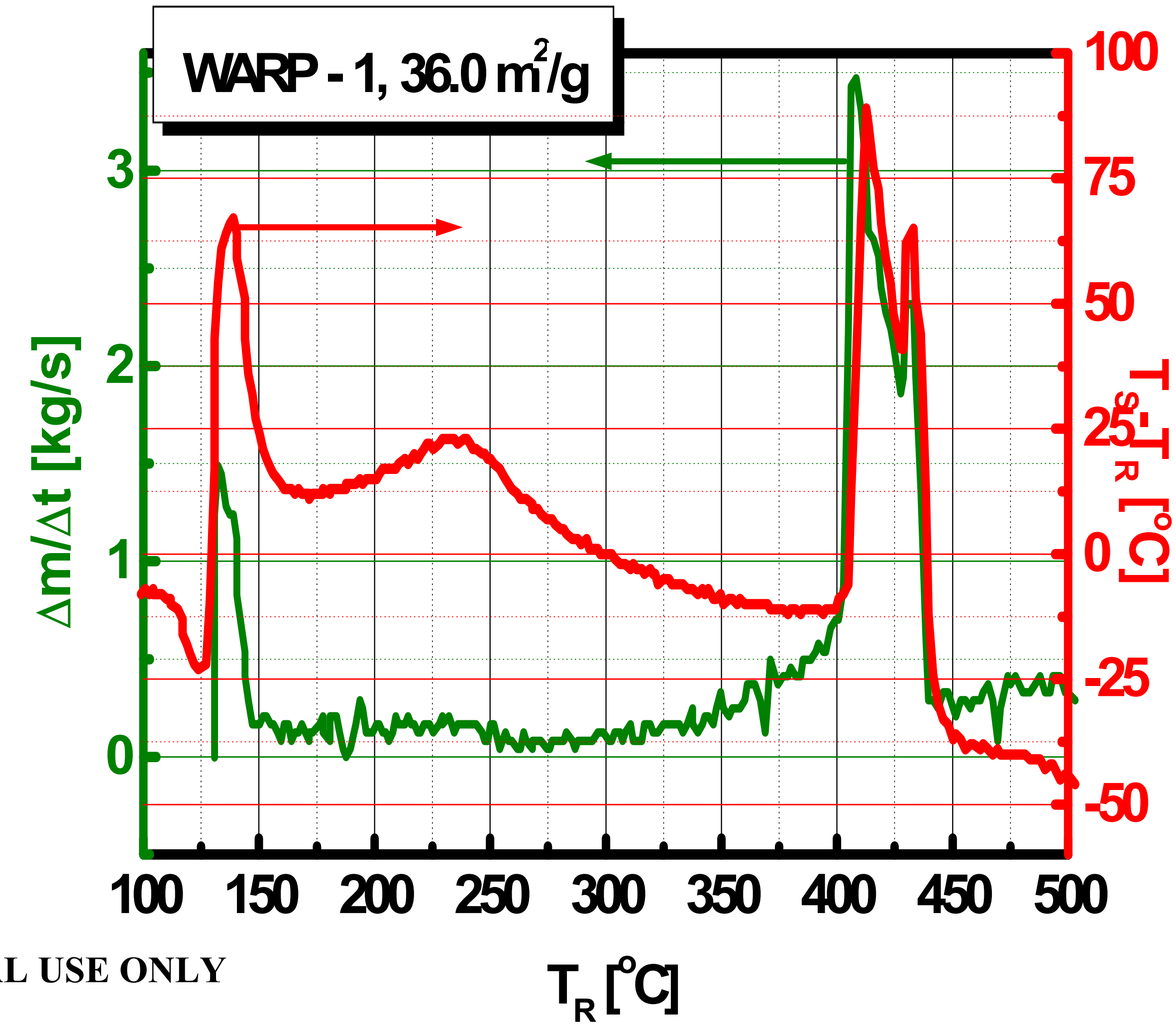
Thermogravometric Data on Aluminum Powders



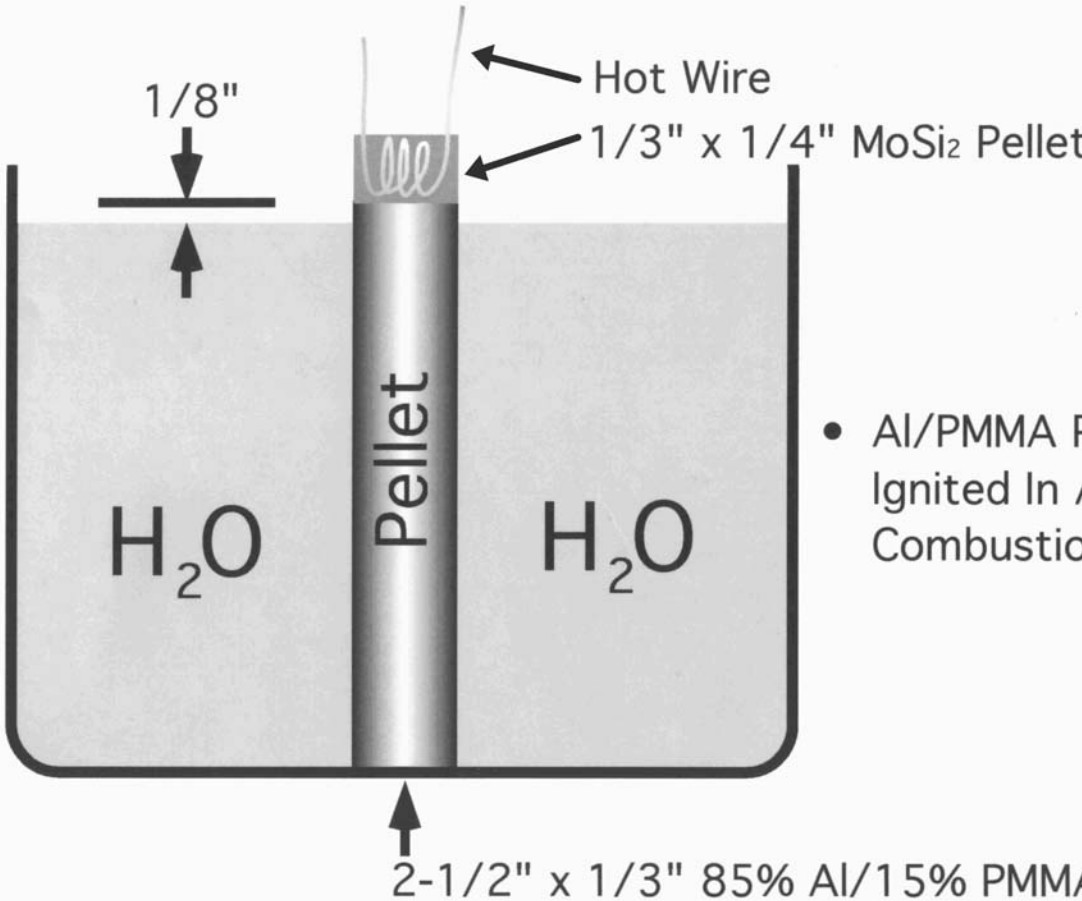




Example of Stored Energy in Water Activated Reactive Powder



Activated Al/$H_2$0 Combustion Experiment



- Al/PMMA Pellet When Ignited In Air Sustained Combustion In H_2O.