ATK

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Safety and Handling of Nano-aluminum

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Characterization of Nano-aluminum

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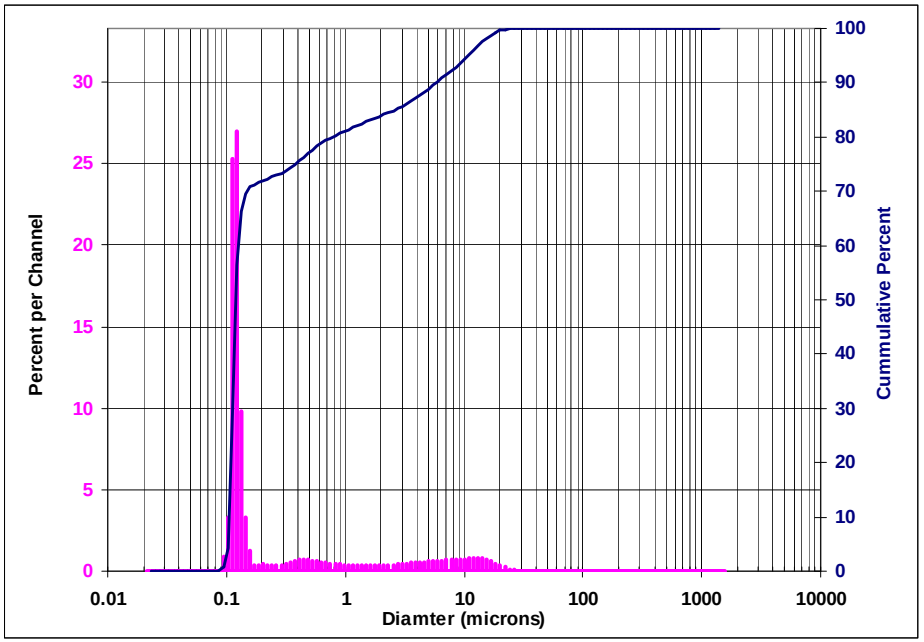
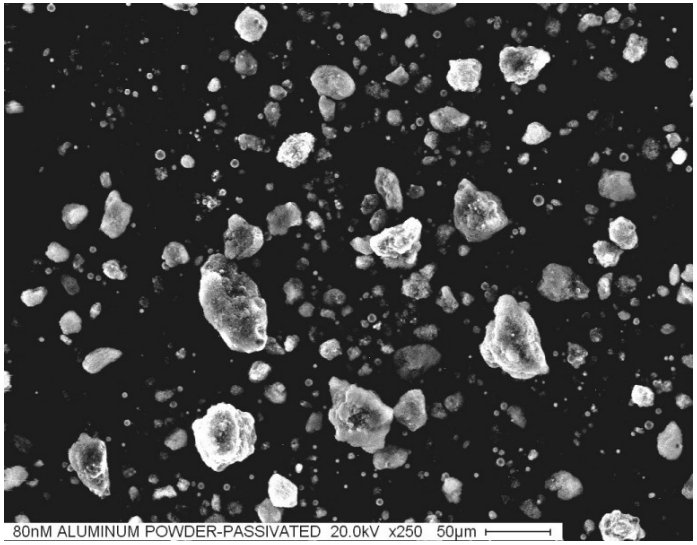
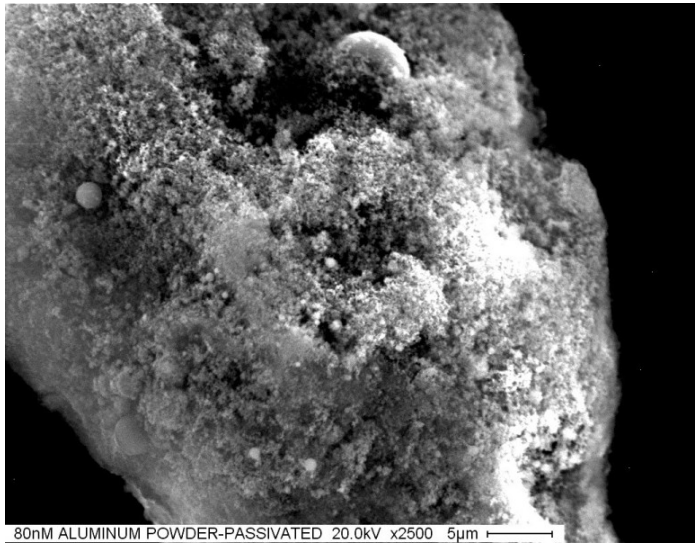
- Comprised of agglomerated 80nm particles
- SEM pictures show the agglomerates are in the micrometer size range
- Sonication prior to size analysis lowers average particle size (100-200nm)



Particle size analysis of 80nm Al



80nm Aluminum at x250 (above) and x2500 (below)



Safety Testing & Handling of Nano-aluminum

- Nano-aluminum is not sensitive to impact, friction or heat
- Nano-aluminum is *very* sensitive to ESD
  - More sensitive than finely ground CL-20
- Material is handled in an argon purged glove-box whenever possible
- All tooling, equipment, and work area is well grounded

	Technanogy	NovaCentrix	Technanogy	NovaCentrix
	80nm Al	**80nm Al**	**45nm Al**	**50nm Al**
ABL Impact, cm	80	80	80	80
ABL Friction, lbs @ 8ft/s	800	800	800	800
ABL ESD, J	<0.025	0.0025		
TC ESD, J			0.05	0.05
SBAT onset T, F	No Reaction	No Reaction	No Reaction	No Reaction

- TC ESD is a Thiokol developed ESD test that typically returned higher values than the more standard ABL ESD test
- SBAT (Simulated Bulk Autoignition Test) is similar to DSC testing, but uses gram quantities and a slower temperature ramp rate
  - We have found it to be a better predictor of bulk behavior than DSC

Burning of Nano-aluminum

Burn video of 4μm aluminum:

4micAlmed.mov

Burn video of 80nm *NovaCentrix* Aluminum:

nanoAlmed.mov

Dust Explosive Hazard Test

- The Dust Explosive Hazard Test
  - Minimum concentration of a material required for a dust explosion
  - Minimum energy required for an ignition
- During a test, the 1.23L chamber is pressurized with gas
- The sample of material is dispersed in the chamber
- Ignition charge is released from a probe 2”-4” above the base
- If the diaphragm at the top is broken, the test is deemed a “go”

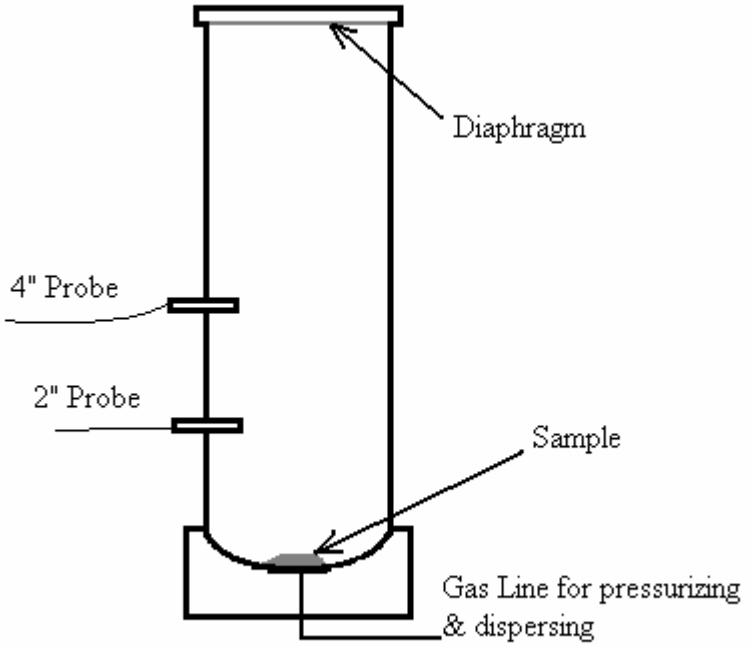


Diagram of dust explosibility test.

Dust Explosibility

- Tests were conducted with 80nm Aluminum from NovaCentrix
- Tests were performed in air, 1%, 4% and 8% O_2 in Ar
- No explosion was observed in the 1%, 4% or 8% O_2 in Ar
- Only a small concentration and small amount of energy is needed for an explosion in air
- The concentration of air in argon may be as high as 40%, without having a dust explosibility hazard (~40% air corresponds to 8% oxygen).

Media	Ign. Position	Pressure	Max Concentration w/ no Reaction	amperage of ignition
	in from bottom	psi	g/L	A
air	4	10	0.146	23.5
air	2	6	0.098	23.5
1% O2 in Ar	4	10	>.976	23.5
1% O2 in Ar	2	6	>.976	23.5
4% O2 in Ar	4	10	>.976	23.5
4% O2 in Ar	2	6	>.976	23.5
8% O2 in Ar	4	10	>.976	23.5
8% O2 in Ar	2	6	>.976	23.5

The highest concentration of aluminum powder that will *not* explode when ignited by 23.5 Amps.

Media	Ign. Position	Pressure	Concentration	Energy req'd for ignition
	inches from bottom	psi	g/L	J
air	4	10	0.854	0.065
1% O2 in Ar	4	10	0.976	>9.56
4% O2 in Ar	4	10	0.976	>9.57
8% O2 in Ar	4	10	0.976	>9.57

The minimum energy required to cause an explosion of the nano-aluminum dust cloud.

Pyrophoricity Testing

- Pyrophorocity is the likelihood of the material to undergo spontaneous combustion
- In micron-sized or larger aluminum powders pyrophorocity is minimal
- Two reactions can lead to spontaneous combustion of aluminum:

$$2Al + 3H_2O \rightarrow Al_2O_3 + 3H_2 + heat$$

$$4Al + 3O_2 \rightarrow 2Al_2O_3 + heat$$

- The lower surface area of larger micron-sized aluminum restricts the reaction rate
  - Heat (and H_2) is able to dissipate quickly
- Nano-aluminum potentially has a high enough surface area that heat could build faster than it can dissipate
- A simple test was designed on a worst-case-scenario to try to force a spontaneous combustion

Pyrophorocity

- The test oven is an insulated 5-gal bucket wrapped with heat trace cable
- The cable was controlled to keep the temperature in the bucket at 37.8° C
- 2 liters of 80:20 glycerol:water solution was placed at the base of the bucket
  - Maintains 48% relative humidity
- 210g of 80nm aluminum was placed in a PPE bucket over the glycerol: water solution
- The aluminum was approximately 15cm in diameter and 6.5cm deep
- Temperature was measured at four areas

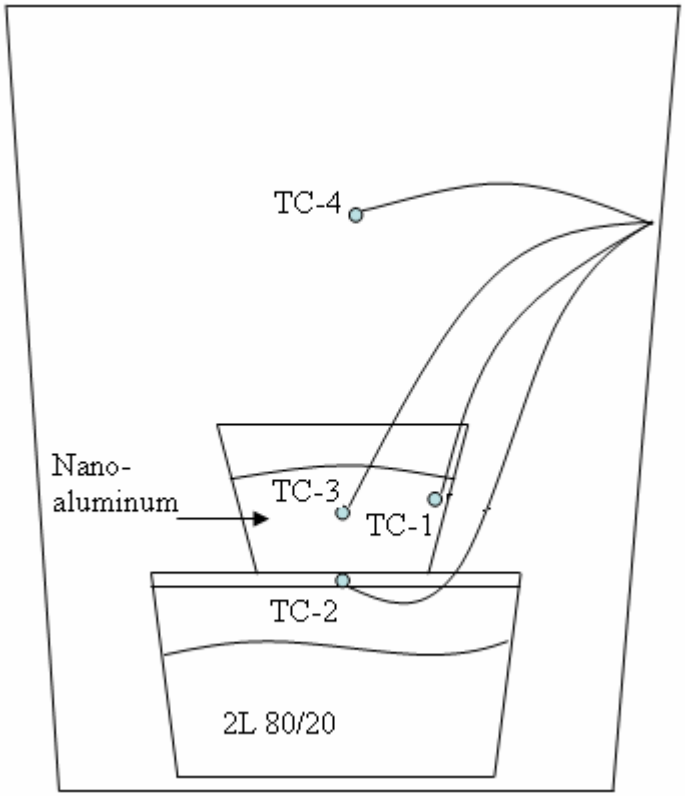
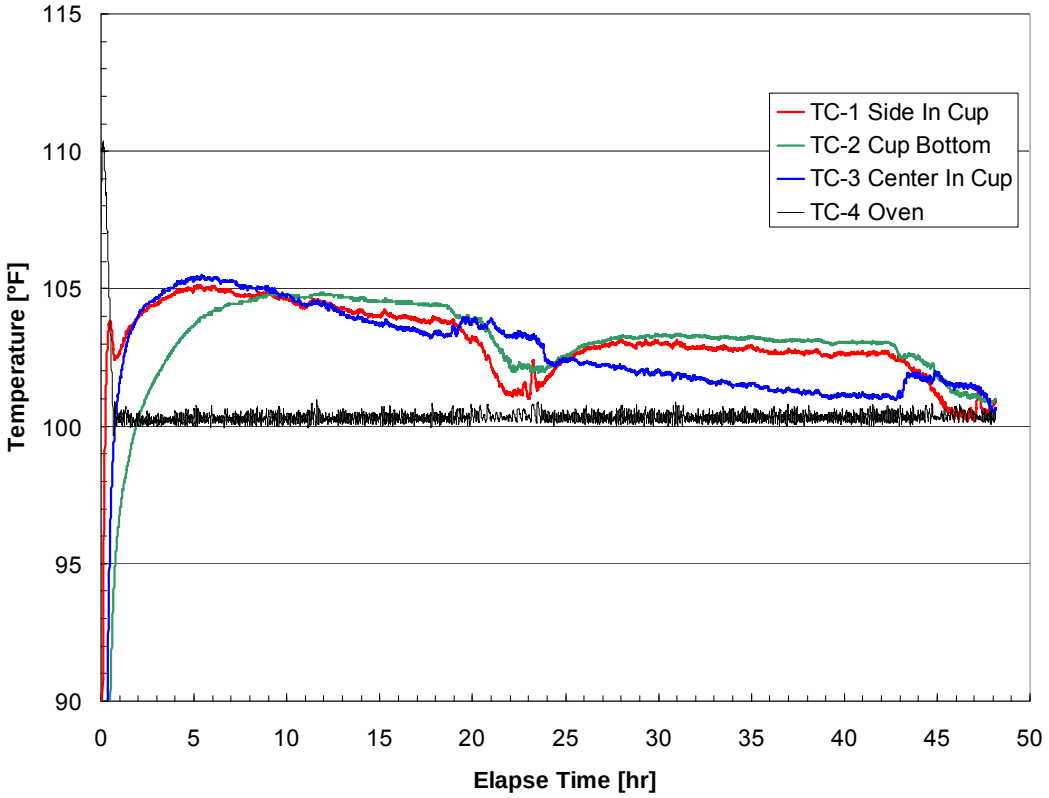


Figure 4: Diagram of test configuration for pyrophorocity testing.

Pyrophoricity

- Data was collected for 48hrs
- Slight exotherm (5° C)
- The temperature of aluminum tapers off, indicating that heat dispersing
- It is suspected that a weather event caused the fluctuation at 24 hrs
- Test was repeated with >300 sample and > 50° C exotherm was recorded
  - No self-ignition



Temperature gage results from pyrophoricity test.

Conclusions

- Nano-aluminum poses hazards not found with micron-sized aluminum powders
- Nano-aluminum is very sensitive to electrostatic discharge
- Dust clouds of nano-aluminum in air present an explosion hazard at even small concentrations of aluminum and small amounts of ignition energy
- Dust clouds of nano-aluminum in reduced oxygen atmospheres did not present explosion hazards, even at high concentrations of aluminum and large energy releases
- Nano-aluminum stored in a humid environment can experience an exothermic reactions
  - Samples of less than 210g nano-aluminum did not build up enough heat to self-ignite, even in a hot, humid environment
  - >300g quantities have demonstrated extreme exotherms