

Shock Induced Conductivity of Aluminum Powder for Closing Switches for Ultracompact Explosive Generators

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Abstract – The development of explosive generators that do not require an outside electrical power source, such as ferroelectric generators, requires novel switching components to allow for maximum transfer of the produced electrical energy. One critical component to achieve efficient operation is an effective closing switch. Typically a spark gap is used, although these systems tend to be relatively large compared to the explosive generator, require high pressure containers for reliable voltage breakdown operation, and are costly to manufacture. It may be possible to greatly simplify a closing switch by using a material which uses the explosive shockwave to switch. This can allow for a compact closing switch to be integrated into an explosive generator system. Significant research has been conducted on the change of conductivity of different solid bulk materials – insulators, semiconductors, and metals – under shock loading. A limited amount of research has also been conducted on powders. Aluminum powder has the unique characteristic of being very resistive in powder form due to the thin layer of aluminum oxide which forms on the grain surfaces. However, under shock loading it may be possible to fracture this layer allowing a highly conductive wavefront to propagate through the material. HEM Technologies and Texas Tech University researched different aluminum powder grain sizes as potential candidates for an explosive switch. Comparative results under shock loading and pulsed voltage holdoff are presented for the different aluminum grains researched.

1. Introduction

The study of phase-transitioning materials under shock has been extensively researched over the years for solid materials such as metals, semiconductors, and insulators [1,2,3]. However, only a limited amount of research has been conducted on porous materials and powders [4,5]. Interest has grown significantly in studying powders with the growth of nanopowder technology. Aluminum is a particularly interesting powder because aluminum oxidizes easily forming aluminum oxide on its surface. Aluminum

oxide is a well know insulator thus making the powder act like an insulator. Previous studies have shown that induced shock rapidly destroys the outer layer of aluminum oxide on a powder grain [6,7].

Another possible use for aluminum powder is as a compact closing switch in which induced shock alters the aluminum powder from an insulator to a conductor. We surveyed aluminum powder grains of different size and structure to determine their suitability for an explosive switch.

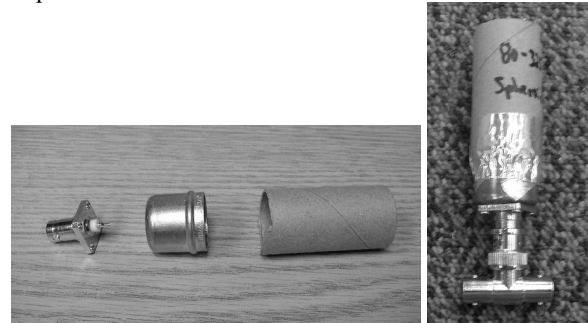


Fig. 1. Shock induced conductivity test setup.

2. Experimental setup

For the shock induced conductivity research, a coaxial configuration was used. This was chosen due to the uniformity of the cross section for the different powders and to minimize shock induced conductivity effects at the electrodes. Figure 1 shows the test setup. It consists of a 50Ω coax feedthrough attached to a copper cap. The cap had an inner diameter of 24 mm and the coax center electrode had a 2 mm inner diameter. The cap cavity was hand packed with the aluminum powder to be tested, then tapped against a hard surface several times to settle the powder and reduce the amount air. On average, 10 gm of powder was used to fill the cavity. An alumina bisque disc, Ø 23 mm x 3 mm, was used to cap off the cavity, isolate the inner electrode from the outer electrode, and prevent movement/sifting of the powder. It would also act as piston during a test, compacting the aluminum to help induce a change in conductivity. Aluminum tape was used around the capsule exterior to isolate it from electrical noise. A cardboard tube was then affixed to the end of the capsule and filled with approximately

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20 gm of high explosives. An exploding bridge wire was used to detonate the assembly.

The test circuit is shown in Figure 2. It consisted of a DC power supply attached to the test assembly through an RG-58 50Ω cable. The coax cable near the test assembly was split to allow a wideband Pearson current transformer, model 2877, to measure the current into the assembly. The coaxial distance from the split to the test assembly was less than 3 ns to minimize any transmission line mismatches created by splitting the cable for current monitoring. The voltage for the assembly was monitored on an Agilent 100 Mhz oscilloscope with a 1 MΩ input resistance.

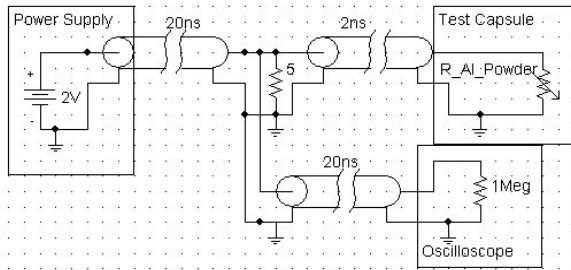


Fig. 2. Conductivity test circuit

For the high voltage holdoff tests, a small spark gap assembly was utilized, shown in Figure 3. The test assembly was filled with the powder to be tested and then closed securely. The casing was then tapped rapidly several times to settle the powder which was hand-packed. A Ross Engineering Hi-Z Megmeter 42 KVDC Hi-Pot/Insulation Leakage Tester, model VMT42A, provided the high voltage source for the tests. The electrodes were gapped at 7 mm with an air breakdown voltage of 19.2 ± 0.5 kV. During testing, the voltage across the spark gap was increased slowly. Breakdown occurred when the current rose rapidly and the voltage fell to zero.



Fig. 3. Spark gap assembly for HV holdoff tests

3. Experimental Results

Table I shows the different types of aluminum powders tested. The powders were acquired from Sky-lighter, Inc. and are commonly used in the manufacturing of pyrotechnic devices. Physically, the 80-325 mesh and 22 μm powders were loose grains, but the 12 μm and 5 μm powders were sometimes in small clumps that required mashing with a pestle and mortar prior to use.

Table I. Aluminum Powders

Grain Size	Manufacturer's description
5 μm	Atomized
12 μm, 400 mesh	Spheroidal
22 μm, 325 mesh	Spherical
177 – 44 μm, 80-325 mesh	Atomized

The initial resistance of the filled test capsule for all types of powders was greater than 1 MΩ. Initial conductivity tests did not include a resistor parallel to the load as shown in Figure 2. The resulting current and voltage data, shown in Figure 4, were too noisy to be properly interpreted. It did, however, show that the powder became highly conductive upon shock loading with over six orders of magnitude in resistance change in under 20ns.

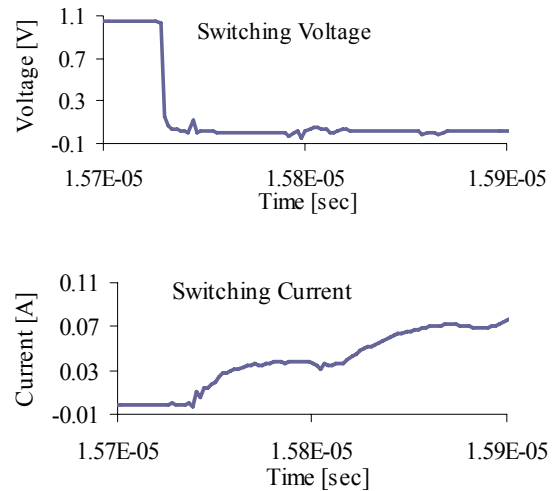


Fig. 4. Voltage and current data for switching time tests for 22 μm powder

Because the critical information desired was how conductive each sample was comparable to the other sample types, a 5 Ω resistor was placed in parallel to the test capsule. The value for the resistor was chosen to be on the same order of magnitude as the expected final load resistance, allowing much greater resolution. Figures 5a and 5b shows a comparison of the measured minimal load resistance after switching for the different types of powder.

The two series of data show only a small variance in the final resistance of the different powders under similar shock loading. The variance may be attributed to how well packed the different powders were. Thus the initial results indicate that different grain sizes do not have a significant affect upon the conductivity of shocked powder.

It should be noted that if the conductivity is related to the density of the powder within a certain volume, then packing of the powder would be a much greater contributing factor than grain size. If we consider all

grains to be spherical, then the maximum density achievable is determined by the Kepler conjecture relation:

$$\rho_{\text{powder_max}} = \frac{\pi}{\sqrt{18}} * \rho_{\text{material}} \quad (1)$$

where $\rho_{\text{powder_max}}$ is the maximum density possible for a group of spheres, in this case powder grains, and ρ_{material} is the density of the material within each sphere, in this case aluminum. Of course this is only the initial density which increases as the shockwave passes and particle momentum compacts the powder into a higher fused density than achievable in the powder state. This can be seen in Figure 6 which shows the compacted, fused remnants of the 80-325 mesh aluminum powder after being explosively shocked.

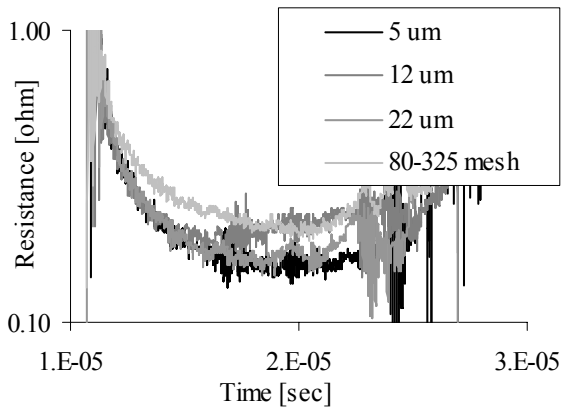


Fig. 5a. Series A switched load resistance comparison

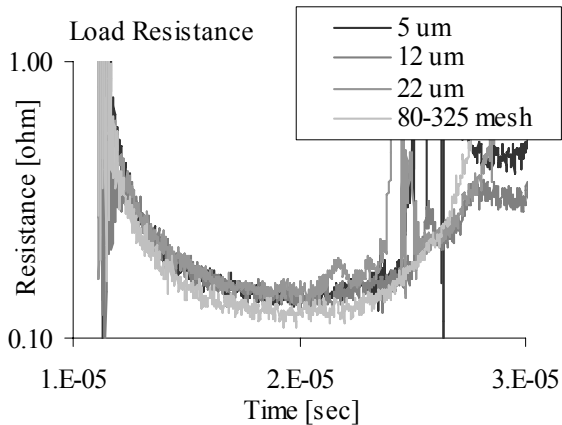


Fig. 5b. Series B switched load resistance comparison

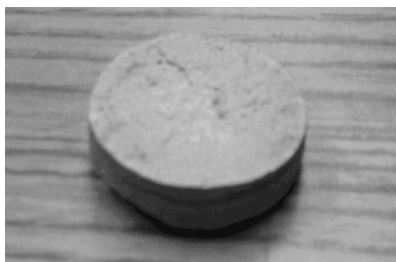


Fig. 6. Fused 80-325 mesh powder after shock loading

Table II shows the high voltage holdoff for the different samples. Each sample was tested several times. After each test, the powder within the spark gap assembly was sifted by rotating the assembly and settled by tapping on the assembly. This destroyed the remnants of the arc channel by redistribution of the powder grains and reset the spark gap for a new test. The spark gap distance remained at 7 mm.

Table II. Aluminum powder high voltage holdoff

Sample	Breakdown Voltage
Air	19.2 ± 0.5 kV
5 μm	2.3, 1.5, 2.05 kV
12 μm	6.3, 3.7, 4.8, 4.0 kV
22 μm	835, 730, 826 V
80-325 mesh	130, 150, 145, 197 V

The data indicates that the aluminum powder performed poorly in comparison to air. Also, except for the tests conducted with 12 μm powder, the voltage holdoff was greatly reduced with increasing grain size. This would indicate that optimal grain size should be small with nanopowders of grain sizes on the order of 100 nm or smaller being possible candidates which need to be tested in the future.

The results for the 12 μm grains, however, were much better than those for 5 μm, which cannot be explained at this time. Possible causes for the difference and better performance at 12 μm may be thickness of the aluminum oxide layer on the grain surface (which has not been determined yet for these samples), the grain structure, and how well the powder was packed prior to testing. It should also be noted that the 12 μm powder had the largest variance in its results.

4. Summary and Conclusions

Several different grain sizes of aluminum powder were researched for conductivity change under shock loading and high voltage holdoff. Results for the conductivity change indicate that the change in conductivity is independent on the grain size but may be influenced by the method used in packing the powder.

The high voltage holdoff tests, however, show a large difference in the holdoff capabilities of different grain sizes with larger grains performing the worst. Nanopowders are, therefore, seen as the most likely candidates for high voltage holdoff.

The use of aluminum powder as a compact explosive closing switch appears to be possible for low voltage applications. Further research is needed to see if nanopowders can achieve the holdoff required for higher voltages.

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