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**A Miniature Shock-Activated Thermal Battery for Munitions Applications**

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**Abstract**

The feasibility of a small, fast-rise thermal battery for non-spinning munitions applications was examined by studying the response of conventional thermal cells to impact (mechanical) energy to simulate a setback environment. This is an extension of earlier work that demonstrated that shock activation could be used to produce power from a conventional thermal-battery cell.<sup>1,2</sup> The results of tests with both single and multiple cells are presented, along with data for a 5-cell miniature (5-mm diameter) thermal battery. The issues needing to be resolved before such a device can become a commercial reality are also discussed.

**Introduction**

Recently, Sandia has been involved in the conceptual evaluation of a miniature shock-activated thermal battery for non-spinning munitions applications. The ambition of the design is to greatly improve the reliability of second-environment (i.e., drag) sensing of safeing and arming devices. These are used for powering a sensor to detect barrel exit, particularly for non-spinning munitions. Because of the poor reliability of an electromechanical arming system, it was desirable to employ one that was electrochemical in nature, i.e., a battery. Alliant Techsystems is investigating a technology that uses a reserve Li/SOCl<sub>2</sub> battery that is 34 mm in diameter by 17 mm tall and is designed to be activated at >1,500 g.<sup>3</sup> The average risetime for this battery is about 50 ms, which is limited by the time required to transfer electrolyte into the active stack.

The target risetime of the shock-activated battery is <2 ms and the battery is to be activated by a maximum setback shock of 56,000 g. Electrical power (a minimum of 5 V at 50 ohms) is to be delivered during the 8-10 ms residence time in the gun barrel. The desired size of the battery is <23 (preferably <12) mm long by 12 mm in diameter

Conventional thermal batteries depend on the burning of a heat-paper fuse strip or a percussion

primer or electrical igniter to ignite the heat pellets in the battery stack. This process is slow, with the burn rates of Zr/BaCrO<sub>4</sub> heat paper and Fe/KClO<sub>4</sub> heat pellets being between 10 and 20 cm per second.<sup>4</sup> This is not fast enough for the intended application. The fastest activation of thermal batteries is with a center hole in the stack where the heat pellets can be ignited directly by the hot gases and hot particles emanating from the igniter or percussion primer.<sup>5</sup>

The goal of the present work was to develop a practical method of using shock compression for activation of a thermal battery. Earlier preliminary work indicated that shock-induced melting could be realized in a cell based on the Li(Si)/LiCl-KCl/FeS<sub>2</sub> electrochemical couple. At a shock pressure of 7.5 GPa generated with an explosive charge, currents of up to 3 A were obtained for 20 to 30 μs for a single cell.<sup>1,2</sup>

This paper discusses the efforts to attain similar activation, but using mechanical impulse loading to provide the input energy, rather than an explosive shock. The effort was extended to include multiple-cell stacks and alternate electrolytes. In addition, a miniature thermal battery 5 mm in diameter was designed and tested to characterize the performance that could be realized once a unit was successfully shock activated.

**Experimental**

Test Procedure - The test fixture that was used for the impulse tests is shown schematically in Figure 1. It consisted of a steel retaining block in which the sample holder was placed. The holder contained the cell stack comprised of the anode, separator, and cathode pellets. The block served as one electrode connection for the cell anode. A steel drive piston, insulated from the retaining block with a nylon or polyimide sleeve, served as the connection for the cathode.

Energy was imparted to the system by dropping a predetermined weight (20.4 kg) from a specific

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### Setback Activated Fast Rise-Time Battery

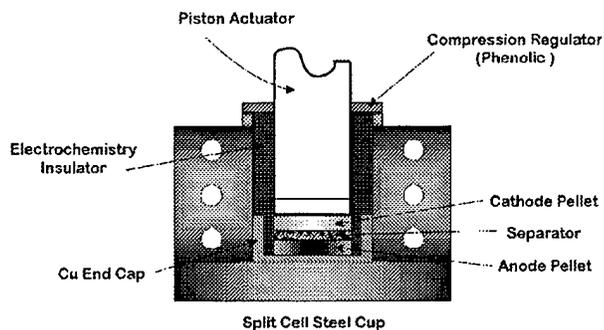


Figure 1. Test Fixture Used to Impart Impact Energy to LiSi/FeS<sub>2</sub> Cell.

height (102 cm) onto the piston. The typical energy input was 50 cal. A 50-ohm resistor was placed across the test cell to serve as the electrical load. The test fixture was instrumented with a load cell and accelerometer to record force and acceleration, respectively. The outputs of the accelerometer, load cell, and battery (voltage and current) were recorded using a high-speed data-acquisition unit. Most of the drop tests were done with the test fixture at room temperature. Additional tests were also performed after equilibration of the test fixture at 65°C.

The test fixture shown in Figure 2 was used to test a miniature thermal battery that was made with the same-size pellets used in the drop fixture. This cell configuration was similar to that used in the drop tests, except that five cells were used along with Fe/KClO<sub>4</sub> heat pellets in each cell (plus extra heat pellets at each end) and a heat-paper fuse strip, as in a conventional thermal battery. An electrical igniter was used to activate the small battery. A split MgO tube was used to contain the spring-loaded stack. Various resistive loads were used across the cell and the current and voltage outputs were recorded with a high-speed DVM under computer control. The heat strip was ignited by an electrical igniter (EP200, Eagle-Picher) placed at the bottom of the split MgO tube.

**Materials** – The anode used in the tests was 44% Li/56% Si. Two electrolytes were used: the standard LiCl-KCl eutectic (melting point of 352°C) and the LiBr-KBr-LiF low-melting eutectic (melting point of 324.5°C). The separator consisted of the electrolytes with 35% and 25% MgO binder, respectively. The catholyte composition was 73.5% FeS<sub>2</sub>/25% separator/1.5% Li<sub>2</sub>O. The pellets used for the tests were pressed

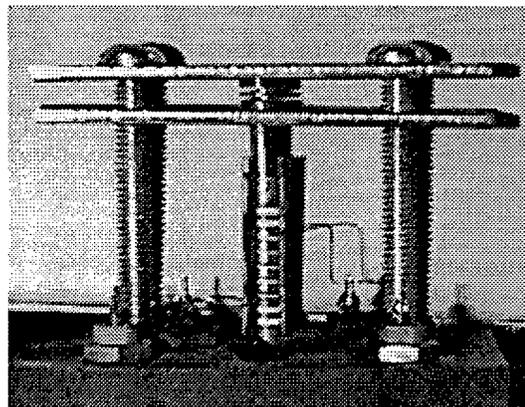


Figure 2. Test Fixture Used to Test Miniature (5-mm Dia.), 5-Cell Thermal Battery (Prior to Application of Heat-Paper Fuse Train).

to between 30 and 50% of theoretical density and were 5 mm in diameter. All handling and loading operations were carried out in a dry room maintained at <3% relative humidity.

### Results and Discussion

**LiCl-KCl Eutectic** – In initial drop tests, the LiCl-KCl based electrodes were used in a loose powder form. However, at times, this led to blow-by of materials. Better results were obtained when pellets were used. Typical voltage and load traces for a cell using this system are shown in Figures 3 for a load of 50 ohms. The inset shows a blowup of the first 5 ms. The test fixture was equilibrated at 65°C for 60 min prior to testing. The mechanical energy for this test was 50 cal.

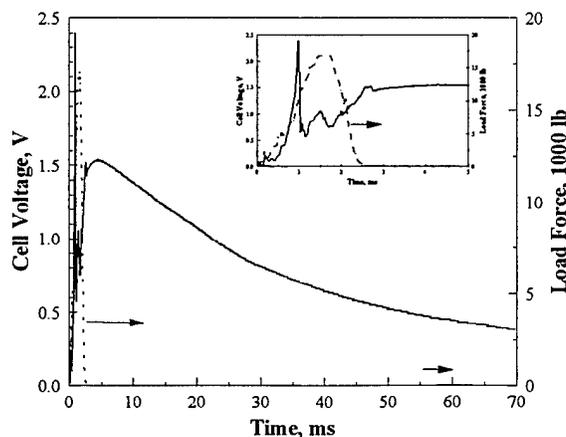


Figure 3. Voltage/Current vs. Time for Single LiSi/LiCl-KCl/FeS<sub>2</sub> Cell with a 50-Ohm Load and Equilibrated at 65°C for 60 Min.

A sustained voltage (~1.5 V) did not occur until 2.7 ms. This corresponds to currents of 48 mA and 30 mA, respectively. The intermediate voltage hump near 1.5 ms coincides with the maximum measured load of 16,800 lb. which translates into a pressure of  $5.36 \times 10^6$  psig or 3.69 GPa. The voltage fluctuation tracked the observed acceleration that the cell saw, which was as high as 12,000 g.

Compared to unheated samples, the preheating at 65°C tended to help extend the cell lifetime by reducing cooling, as there was no thermal insulation on the ends of the cells. This did not always improve the performance, however. There was a large amount of scatter intrinsic in the performance data that made it difficult to discern parametric effects. The difficulty in reproducing these data was likely due to variability in friction in the test fixture from run to run and the tendency of the insulating sleeve to crack due to the stress generated on impact.

The nature of the sleeve has a major influence on the manner in which the energy is transferred to the pressed pellets. Using a rigid material such as a ceramic or glass was not possible due to their brittle nature. An attempt to use an anodized aluminum sleeve was unsuccessful and may have failed from the loss of electrical insulation of the anodized film from scoring on impact.

LiBr-KBr-LiF Eutectic – The use of the lower-melting LiBr-KBr-LiF eutectic electrolyte was explored in an attempt to extend the operating life of the cell. Typical results are shown in Figure 4 for a 50-ohm load after preconditioning the test fixture at 65°C for 30 min. The mechanical energy input for this test was 50 cal. The inset shows a blowup of the first 5 ms.

Using the low-melting electrolyte, the initial voltage spike was smaller than the sustained (second) voltage peak. The initial transient occurred at about 1 ms and the time of the sustained voltage was 2.7 ms. These risetimes are similar to those observed for the LiCl-KCl-based system. The peak load was 22,000 lb. or about 30% higher than that for the test with the LiCl-KCl system (Figure 3). It occurred between the initial voltage spike and the sustained voltage. As mentioned earlier, these data are not as reproducible as would be desired. Other tests with the low-melting electrolyte produced results that were superior to the data shown in Figure 4. One

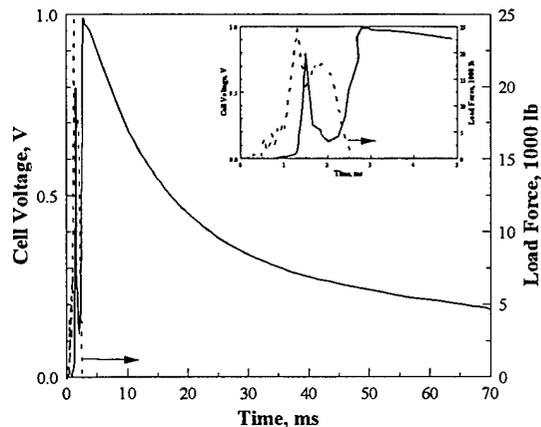


Figure 4. Voltage/Current vs. Time for LiSi/LiBr-KBr-LiF/FeS<sub>2</sub> Cell at Ambient and when Preconditioned at 65°C for 30 Min.

test at room temperature, for example, yielded a risetime of 1.7 ms to a sustained voltage of 1.5 V which dropped to only 0.84 V after 50 ms with a 50-ohm load.

Attempts to activate a battery stack containing two and three cells produced results that were comparable to those for a single cell. Currents and voltages for the two sets of conditions were comparable. The reasons for this behavior are not known at this time. More-detailed studies will be necessary to elucidate the mechanism responsible for the failure to completely activate multicell stacks.

Miniature Thermal Battery – In parallel with the drop tests, experiments were carried out with a potential prototype 5-cell thermal battery that used the same-size pellets but that also utilized heat pellets. This test battery was not subjected to a shock environment, however. The intent of the tests was to determine how well such a small battery would work upon successful activation (e.g., maximum currents and lifetime). For this concept to be practical, it would be necessary to also shock activate the pyrotechnic in the stack upon setback. The initial setback would provide the primary energy pulse to the load. The heat provided by the pyrotechnic would then melt the electrolyte to allow the battery to sustain the load in the manner of a conventional thermal battery.

Although there was no problem igniting the fuse strip, it was very difficult to reliably ignite the heat pellets. The lack of good intimate contact between the fuse strip and heat pellets resulted, at times, in not all of the pellets firing on activation. This was aggravated by the use of heat pellets

with the same diameter as the active stack. More importantly, with such a small stack, heat-sinking effects dominated the ignition process. Use of heat paper in place of heat pellets worked well but required electrical jumpers between the cells, which is not practical. Widening of the slot in the MgO tube also helped.

The lack of any insulating wrap resulted in rapid cooling of the battery stack when successfully activated. Consequently, it was necessary to use a high heat balance—up to 137 cal/g of total cell mass. The results of a typical successful test under these conditions is summarized in Figure 6 for a load of 46.7 ohms

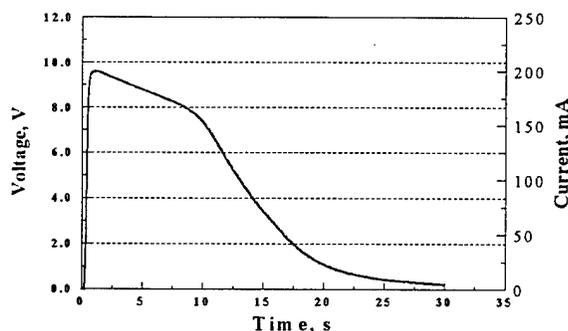


Figure 6. Response of 5-Cell LiSi/LiBr-KBr-LiF/FeS<sub>2</sub> Miniature Thermal Battery Under 46.7-Ohm Load.

The maximum current of 210 mA corresponds to a current density of almost 1,000 mA/cm<sup>2</sup> which is impressive for such a small-diameter stack. There was evidence of cell damage, however, at this heat balance. No such damage was observed at a lower heat balance of 125 cal/g.

### Conclusions

The feasibility of using impact energy (to simulate shock activation) with thermal cells using the LiSi/FeS<sub>2</sub> electrochemical couple was demonstrated using the standard LiCl-KCl eutectic electrolyte and the low-melting LiBr-KBr-LiF eutectic. An energy level of 50 cal is sufficient to activate single cells comprised of pellets pressed to 30 to 50% of theoretical density. Rise times of <2 ms were obtained in our experimental test fixture using the both the standard LiCl-KCl eutectic and the low-melting LiBr-KBr-LiF electrolyte. The performance of the cells from run to run is quite variable due to uncontrolled frictional effects in the test fixture. This makes it

difficult to separate the thermal and electrolyte effects on performance.

Peak output voltages of up to 9.4 V and peak current densities of up to 1,000 mA/cm<sup>2</sup> can be obtained for times in excess of 10 s with a miniature (5-mm-dia.) thermal battery, with minimal insulation, and using the same-size pellets.

It was not possible to activate multiple-cell stacks containing two or three cells with our existing test fixture. The reason for this is unknown at this time but likely involves the manner in which the mechanical energy is transferred to the pellets.

Before the shock-activation approach can be realistically applied to a munitions application, successful, reliable activation of multiple cells must be demonstrated. Even more important will be development of suitable packaging that can sustain the high-g loadings and function under the envisioned munition setback environment. Lifetimes greater than several hundred milliseconds will require incorporation into the battery of a suitable pyrotechnic that can be simultaneously activated so that the battery will then function as a normal thermal battery. Reliable ignition of such small pellets will also require careful study.

### Acknowledgments

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