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A Study of the Ignition Processes in a Center-Hole-Fired Thermal Battery*

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Abstract

The ignition processes that take place during activation of a 16-cell, center-hole-fired thermal battery were examined by monitoring the voltage of each cell during activation. The average rise time of each cell to a voltage of 1.125 V was determined for the LiSi/LiCl-LiBr-LiF/FeS₂ electrochemical system. The effects of heat-pellet composition, center-hole diameter, and the load on the activation parameters were examined for three different igniters. A large variability in individual cell performance was evident along with cell reversal, depending on the location of the cell in the stack. It was not possible to draw detailed statistical information of the relative ignition sequence due to the intrinsic large scatter in the data.

Introduction

Thermal batteries depend on either of two modes of ignition. One method involves the ignition of the Fe/KClO₄ heat pellets (pyrotechnic) in the stack by Zr/BaCrO₄-based, heat-paper fuse strips. The fuse strips—typically, two or three spaced equally around the perimeter of the stack—are pressed tightly against the heat pellets to ensure intimate contact and, thus, reliable ignition. The fuse strips, in turn, are ignited directly by the output of an electrical igniter, match or percussion primer. The ignition sources can also directly ignite an igniter heat pellet which in turn ignites the heat paper.

A second technique uses a hole down the center of the battery stack into which the output of the electrical igniter or percussion primer is directed for ignition of the heat pellets. This method depends on the hot particles and gases generated by the ignition source for reliable ignition, although sometimes, heat paper is placed into the hole.

In the first technique, the sequence of ignition is sequential, i.e., the first pellet in the stack is ignited first, the second one is second, etc.

However, in the center-hole-fired battery, the actual sequence of ignition is unknown. This paper reports on a study of the ignition processes that occur when a center-hole-fired battery is activated by electrical igniters. For the study, a 16-cell battery was used, one that had been in commercial production. Each cell in the stack was monitored during activation and discharge. The variables that were examined in the study included the hole diameter, the type of igniter, the load, and to a more-limited extent, the composition of the Fe/KClO₄ heat pellets

Experimental

Materials – Thin-cell technology was used in this study with a battery stack 31.8 mm in diameter with the LiSi/LiCl-LiBr-LiF/FeS₂ system. The anodes were 44% Li/56% Si and were 0.36 mm thick. The separators contained 35% MgO and were 0.24 mm thick. The cathodes contained 73.5% FeS₂/25% separator/1.5% Li₂O and were 0.37 mm thick. They were pressed onto a Grafoil backing. The heat pellet compositions used in the study were 86% Fe/14% KClO₄ and 84% Fe/16% KClO₄. The heat pellets were 0.47-0.60 mm thick. The battery heat balance was 104 cal/g of total cell mass. The battery closing force was 500 lb.

Test Procedure – Each cell in the 16-cell stack was monitored for voltage through a 304 stainless steel current collector with a tab for electrical contact. Initially, attempts were made to test the stack in a reusable test fixture, as normally done, except that a header was used on each end for electrical connection to the cells. This proved too cumbersome and the stack was activated at room temperature while still in the stacking fixture in the dry room which was maintained at <3% relative humidity.

Loads of 50 ohms and 1 ohm were used in the tests and the rise times to a voltage of 1.125 V/cell were measured. This value was used because of the requirements of the original production battery on which the test module was based. Three battery stacks were activated under each of the experimental test conditions.

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The stacking fixture was enclosed within an acrylic shield through which high-purity argon was passed. The test fixture was purged for at least 30 minutes prior to a run, to remove the dry-room air inside. The actual oxygen content in the surrounding atmosphere around the stack was not critical, since we were interested in only the first 500 ms or so of the activation process. Under these conditions, traces of oxygen would not affect the rise times.

The voltages of the cells were measured under computer control using a HP3852A data acquisition unit with a 44704A 16-bit internal DVM and 44711A multiplexer. Ground-loop difficulties were encountered when using this DVM in this mode, as the positive electrode of one cell was connected to the negative electrode of the adjoining cell. If the voltage exceeded 10 V anywhere on the board, meaningless voltage readings were observed. It was necessary to use an isolation amplifier on each channel to avoid this problem.

Center-hole diameters of 3.18 mm (1/8 in.) and 6.35 mm (1/4 in.) were used for these tests. The igniters examined in the study are listed in Table 1. All of these units have 1-ohm bridgewires and are rated at 3.5-A all-fire/1-A no-fire. The MC2046 uses a silicone plug for closure while the EP200 and MC4170 use scored ends that petal on firing. The igniters were between 4.2–5.4 mm long by 4.2–4.8 mm in diameter. The closure end was positioned approximately 1.3 mm from the first heat pellet in the stack. The igniters were fired using a Kepco 1.5-A/50-V power supply that was activated under computer control.

Table 1. Igniters Used in Study

Igniter	Source	Composition
EP200	Eagle Picher	B/CaCrO ₄ - Zr/Fe ₂ O ₃
MC2046	Sandia	10 mg Ti/KClO ₄
MC4170	Sandia	10 mg Ti/KClO ₄

Results and Discussion

Figure 1 shows typical responses for several of the cells in a stack ignited with the EP200 igniter. The 1.125-V rise-time limit is shown by

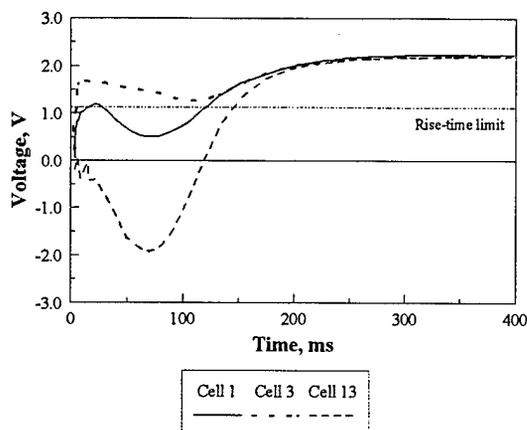


Figure 1. Response of Select Cells in a 16-Cell Stack During Activation with an EP200 Igniter with 84/16 Heat Pellets and a 6.35-mm-dia. Center Hole.

a dotted line. For this test, the 84/16 heat pellets were used with a 6.35-mm-dia. center hole. The cells are numbered starting with #1 at the header (igniter) end of the stack.

Cell #1 showed a severe dip in voltage near 70 ms, while cell #3 showed a less severe dip near 120 ms. Cell #13 went into reversal at 70 ms. The dip in voltage is not unexpected and is due to premature melting of the electrolyte near the center hole of the stack. There is not enough electrode area melted early in the activation process to sustain the load current, so the voltage drops until all the electrolyte in the cell is completely melted. Under severe conditions, this can lead to the cell reversal for the cells that cannot carry their share of the load (e.g., as for cell #13).

The cell-reversal phenomenon was commonly observed during the study for all the activation conditions that were examined. Typically, the cells at the middle or far end of the battery stack furthest from the igniter experienced the highest degree of cell reversal. When the voltage of the full battery is examined (see Figure 2), there is no indication that individual cells are exhibiting widely varying responses.

The rise time to 1.125 V/cell (18 V/battery) was selected to characterize the response of the individual cells during activation. Because of voltage dips, sometimes two values for this rise time were obtained: the initial transient value (before the voltage dip) and the second value (after the sustained voltage).

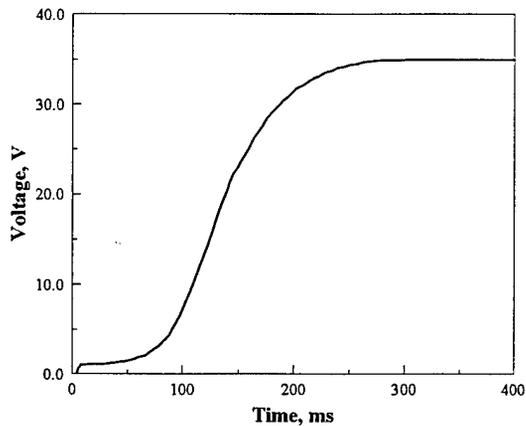


Figure 2. Response of 16-Cell Battery Stack Built with EP200 Igniter, 84/16 Heat Pellets, and with 6.35-mm-dia. Center Hole.

Figures 3 through 5 present representative rise-time data for the first voltage match (to 1.125 V/cell) for various igniters and 86/14 heat pellets for a 3.18 mm-dia. center hole and a 50-ohm load. The data symbols represent the average of three tests and the bars represent one standard deviation about the mean.

For the batteries with the MC2046 igniter, the last eight cells had a much greater scatter in the rise times than did the other two igniters, although the means were somewhat lower. The first five cells for the stacks with the EP200 igniters had the lowest rise time of all, with the smallest standard deviations. There was a large difference in the average rise times for these cells versus the last seven cells in the stack. In contrast, the average rise times for batteries with the MC4170 igniter were more closely spaced over the length of the stack.

The trends in the relative rise times of the cells using the various igniters for the second (sustained) voltage match were similar to those for the first voltage match. There was no general trend in the sequence of ignition because of the nature of the ignition process with a center-hole-fired battery. On ignition, hot particles bounce around inside the center hole in an unpredictable fashion. This is also complicated by any variability in the scored ends of the igniters which open when the internal pressure becomes great enough. There is an intrinsic variability in this process which changes the proportion of gas and hot particles which are emitted. When the center hole was increased to 6.35 mm in diameter, the scatter in the cell rise times generally increased relative to

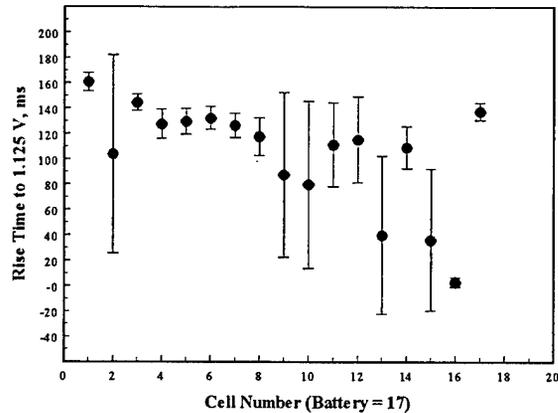


Figure 3. Average Rise Times for First Voltage Match for Stack with MC2046 Igniter with 86/14 Heat Pellets and 3.18-mm-dia Center Hole and 50- Ohm Load.

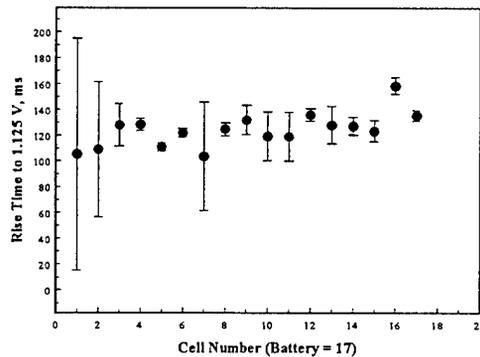


Figure 4. Average Rise Times for First Voltage Match for Stack with MC4170 Igniter with 86/14 Heat Pellets and 3.18-mm-dia Center Hole and 50-Ohm Load.

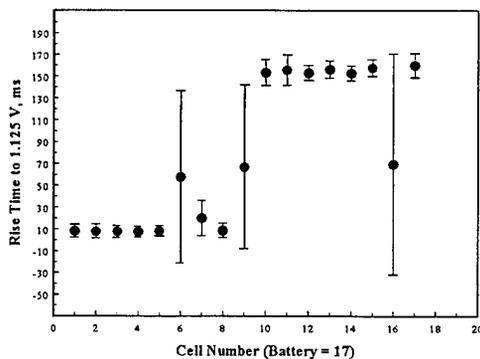


Figure 5. Rise Times for First Voltage Match for Stack with EP200 Igniter with 86/14 Heat Pellets and 3.18-mm-dia Center Hole and 50-Ohm Load.

a center-hole diameter of 3.18 mm.

When an EP200 igniter was used with a battery stack with a 3.18-mm-dia. center hole, 84/16 heat pellets, and a 50-ohm load, there was more scatter in the data relative to those with the 86/14 heat pellets (Figure 5). The first five cells in stacks ignited with the EP200 had the fastest rise times in all cases. This is most likely the result of the much higher energy output from this device, relative to the other igniters.

Table 2 summarizes battery rise time data for various experimental conditions. These results are averaged over the entire cell stack, thereby smoothing out much of the variability observed from cell to cell. For comparison purposes, one of the battery stacks with a center hole was activated under a 1-ohm load but with a heat-paper fuse strip. As expected, the ignition sequence was linear in order from cell #1 to cell #16, validating our test procedure and data-acquisition system. The rise time for the first cell was 300 ms and the rise time for the 16th cell was 389 ms. The battery rise time to 18 V was 350 ms, which compares to 224-227 ms for the center-hole-fired batteries (Table 2). This translates into an effective "burn rate" of 23.5 cm/s.

Conclusions

For the EP200 igniter, the rise times of the first five cells in a 16-cell stack are consistently low with small standard deviations for both heat compositions and center-hole diameters. The use of 86/14 reduces the scatter in the rise time for cells 10-15. There was a large increase in the rise times for these cells, relative to what is

observed for the other igniters. The low rise times and good reproducibility are a result of its more energetic output relative to the other igniters. For the MC4170, the smaller (3.18-mm-dia.) center hole results in smaller variations among the cells compared to the larger (6.36-mm-dia.) center hole. The largest variability is observed with the first two cells. For the MC2046, the first eight cells have much higher rise times than does the EP200. There is less difference among the rise times for the cells, however, relative to the EP200. Voltage reversal is common on activation for cells in the middle or ends of the stack. Because of the intrinsic scatter in the data, no statistical correlation could be made as to the sequence of ignition with the various test parameters.

In 16-cell battery tests with the EP200, the center-hole diameter has little effect, except to increase the scatter for the larger center hole and the 84/16 composition. This increases the average rise time. Batteries with the MC2046 and the MC4170 igniters have faster average rise times than those with the EP200 igniter. Increasing the center hole for the batteries with the MC4170 also increases the average rise time. The use of a 1-ohm load results in a dramatic increase in the average rise time relative to a 50-ohm load for all igniters.

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Table 2. Summary of Rise-Time Data for 16-Cell Batteries for Various Test Conditions.

<u>Igniter</u>	<u>Center Hole Dia., mm</u>	<u>Heat Composition</u>	<u>Load, ohms</u>	<u>Avg. Battery Rise time, ms</u>
MC2046	3.18	86/14	50	137.6 ± 6.7
MC2046	3.18	84/16	1.0	226.6 ± 13.7
MC4170	3.18	86/14	50	135.5 ± 4.1
MC4170	6.36	86/14	50	145.3 ± 5.5
EP200	3.18	86/14	50	159.9 ± 11.2
EP200	3.18	84/16	50	147.0 ± 10.2
EP200	3.18	84/16	1.0	224.1 ± 4.2
EP200	6.36	84/16	50	148.7 ± 2.2

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