

Temperature Effects on Fast Charging Large Format Prismatic Lithium Iron Phosphate Cells

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Abstract—Attempts to fast charge 160 A-h lithium iron phosphate cells at various temperatures are presented in this paper. The tests were done at a charging rate of 2C. The tests were done at three ambient temperatures: 0.0°C, +20°C and +40°C. The current, voltage, and temperature were recorded during the test. It was found that the battery accepts high current for fast charging with little difficulty. The battery charged well at all temperatures. These findings indicate that minimal heating or cooling will be required to compensate for weather conditions in electric vehicles in most climates. The data was obtained at the Battery Evaluation Lab at the University of Massachusetts Lowell which is also briefly described.

Index Terms—Fast Charge, Battery Temperature, Electric Vehicle, Lithium iron phosphate Battery.

I. INTRODUCTION

The U.S. Advanced Battery Consortium (USABC) has been funding battery research since the early 1990's and has set short-term, mid-term, and long-term goals for batteries to be used in electric vehicles. The long-term criteria for electric vehicle batteries are as follows: specific power greater than 200 W/L, energy density greater than 300 Wh/L, life cycle over 1000 cycles, and recharge time between 3 to 6 hours [1]. It is claimed that the lithium iron phosphate chemistry can satisfy these criteria. The experiments described in this paper attempt to confirm that the lithium iron phosphate chemistry can satisfy the requirements for fast charging. The specimens that will be tested are two samples of the TS160LFPAHA like the one shown in Figure 1.

A. Background

The USABC expects that a typical EV battery pack would weigh in the order of 500 pounds (230 kg), which could provide as much as 45 kW-h of energy. In comparison, a lead-acid battery pack weighs over 1000 pounds (460 kg) and provides 16 kW-h of energy; so it has the potential of storing nearly 3 times the energy, with half the mass of today's lead-acid batteries. Lithium has the highest electrochemical potential as well as being one of the lightest elements, making it an excellent choice for use in an advanced battery [2].

The lithium iron phosphate battery has been developed with high energy capacity, and high current capability, making it suitable for use in an electric vehicle [3]. The production cost of these higher-capacity lithium batteries is

decreasing as the technology matures and production volumes increase. The lithium batteries have been made safer, and can be recharged more quickly than previously.

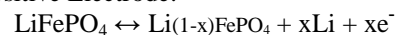


Fig. 1. The TS160LFPAHA 160 A-h Lithium Iron Phosphate Cell.

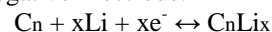
B. Chemistry:

The lithium iron phosphate battery makes use of lithium iron phosphate as the positive electrode and a highly crystallized specialty carbon at the negative electrode. Both the reactions at the electrodes are mediated by a liquid electrolyte LiPF₆ (Lithium Hexafluorophosphate) and organic solvents.

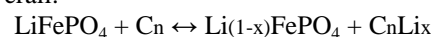
Positive Electrode:



Negative Electrode:



Overall:



The reaction proceeds from left to right during discharge.

C. Requirements for Fast Charging

The definition of fast charging described by the Advanced Lead Acid Battery Consortium (ALABC) is as follows [4]:

- 1) Fully recharge the battery within 4 hours
AND
- 2) a) 80% charge return in no more than 15 minutes
OR
b) 50% charge return in no more than 5 minutes

While fast charging some parameters have to be taken under consideration. Problem with lithium iron phosphate batteries arises from overcharging and over-discharging. The voltage of the battery should not go above the specified voltage limit during charging. Battery should accept the high current at every temperature. Temperature of the battery should be within reasonable limits. Otherwise it can damage the battery. It may not be visible from outside but internal chemistry of the battery gets damaged. Mechanical damage is likely to happen due to gassing. It is important to control the charge in order to maintain the battery in good condition.

D. Battery Evaluation Lab at UML

The Battery Evaluation Lab at the University of Massachusetts Lowell (UML) has three complete battery test systems. The systems are computer controlled and are designed to test batteries ranging from 0.1mV to 20 volts at 1mA to 320 amps. The current regulators are capable of current sinking or sourcing and can change from charge to discharge mode rapidly [5]. Data acquisition system is used to monitor and record voltage, current, temperature and time using computer. According to the data commands to sink or source the current are given to current regulators through A/D and D/A multiplexers. Integral to the battery exercisers are two computer controlled environmental chambers that provide the batteries with the desired ambient temperature.

Some of the equipments available are shown in Figure 2.



Fig. 2. Battery Exerciser at the Battery Evaluation Lab at UMass Lowell. The central tower houses two sets of eight current regulators and their analog/digital multiplexers. One of the environmental chambers is in the foreground.

II. EXPERIMENTAL PROTOCOL

The fast charging tests were done on cells labeled #27 and #28. Because the cells had sat unused for over a year, it was necessary to run several conditioning cycles at 0.5C rate to bring the cells back up to full capacity. This was done to revive/rejuvenate the cells and to verify the A-h capacity. After conditioning, it was found that the cells had lost approximately 4% of their capacity during that time.

The approach to fast charge was Constant Current (CC) followed by Constant Voltage (CV) method (CCCV). The CCCV method is faster in the sense that it reduces the charging time while keeping the voltage and temperature of the battery within safe limits.

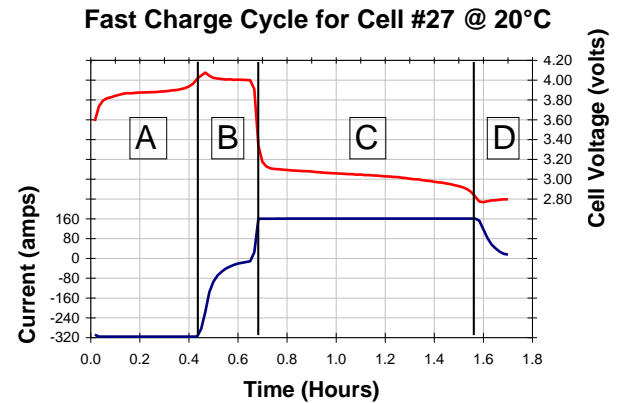


Fig. 3. Showing a full cycle for cell #27 at 20°C. The various stages of the CCCV cycling are delimited as follows. The sections marked "A" and "B" are the constant current (CC) and constant voltage (CV) stages of charging, respectively. The sections marked "C" and "D" are the CC and CV stages of discharging, respectively.

The ambient air temperatures for the tests were 0.0°C, +20°C and +40°C. Two cycles at each temperature for each cell were performed. The results given here are based on the average of each of the two cycles.

The experimental chamber and battery case were set at the required ambient temperature at the beginning of charging. Before each cycle test, the cell under test was allowed to acclimate ("soak") in the environmental chamber long enough for the core of the cell to reach ambient temperature. For the 20°C case, the cells soaked for at least 2 hours. It was assumed that for the 20°C case, the cells would only need 2 hours because the starting temperature was not far different. For the +40°C and 0.0°C cases, the cells were allowed to soak for at least 12 hours or overnight. This temperature soak time was added to the experiment protocol in order to more faithfully emulate cells used in actual electric vehicles.

In each cycle, the attempted fast charging current was 320 amps (2C) and the discharging current was kept at 160 amps (1C). 2C charge rate was used because it is sufficient to fully charge the cell in well under one hour, thereby meeting the USABC requirement for fast charging and because it is a high enough rate to be able to determine what effect, if any, temperature will have on the cells ability to accept charge. All charging cycles were followed by discharging at 160 amps using a CCCV algorithm to determine the actual charge

absorbed by the battery during fast charge, A-h efficiency and W-h efficiency.

poor performance was due to a combination of aging and non-use.

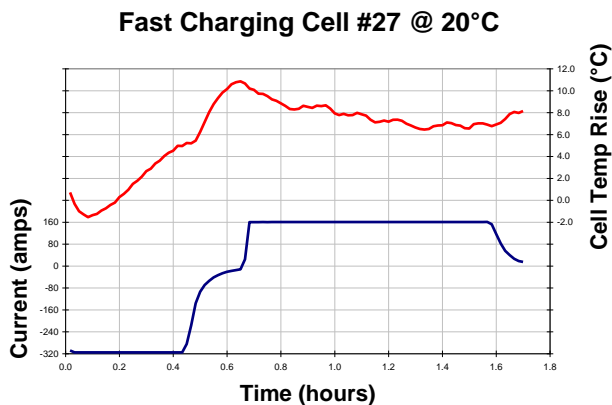


Fig. 4. Cell case temperature rise during a full fast charge / discharge cycle. In the 20°C ambient, the maximum case temperature rise is 11°C. Such a case temperature rise would be considered acceptable.

A typical temperature response is shown in Fig 4. The current during cycle 1 is shown for reference. The case temperature rises continuously during charge phase and falls off during discharge. There is no temperature plateau during charge and the rapid temperature drop during discharge may indicate some endothermic effect.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 5 shows the voltage and current for cell #27 at all three temperatures.

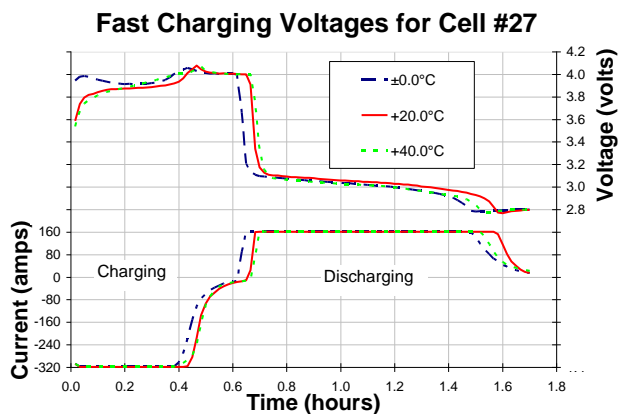


Fig. 5. Cell #27 Voltage and Current during fast charging. The cell voltage rose most rapidly at 0.0°C. Profiles at 20°C and 40°C were virtually identical. In all three cases, the cell was fully charged in much less than one hour thereby satisfying the USABC guidelines for fast charging.

Figure 6 is similar to figure 5 in that it shows the current and voltage for cell #28 during full cycles at the three temperatures mentioned above.

Graphs showing the relationship between temperature and charging are shown in Figures 7 and 8 for cells #27 and #28, respectively. The inconsistency of the performance of the two specimens was striking. The specimen cells had been idle for approximately one year before the conditioning and fast charging cycles were performed. It is possible that the

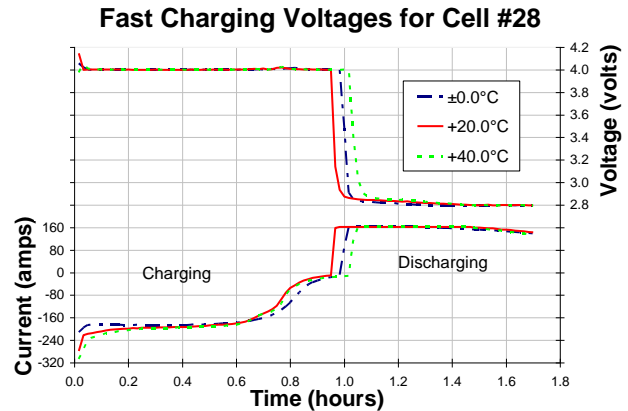


Fig. 6. Cell #28 Voltage and Current during fast charging. At all three temperatures, the cell could not absorb 2C current and went immediately to the constant voltage stage during both charge and discharge.

Temperature Change of Cell #27

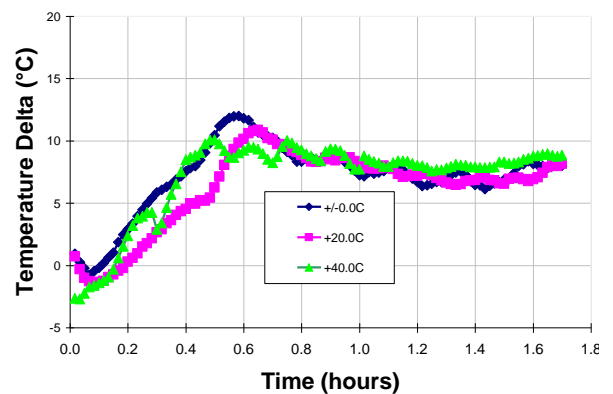


Fig. 7. The temperature rise of cell #27 was acceptable for the fast charge scenario. The temperature rise was not noticeably effected by ambient temperature. The observable oscillations during the discharge phase was due to the cycling of the chiller of the environmental chamber.

Temperature Change of Cell #28

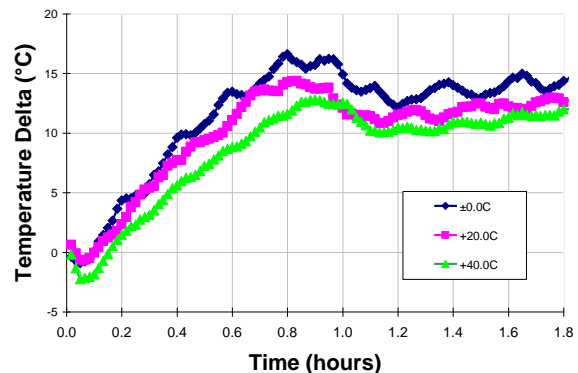


Fig. 8. Case temperature for cell #28 changed by more than 16°C in the 0.0°C attempt at fast charging. This is consistent with high series resistance. The temperature change was markedly effected by the ambient air temperature.

TABLE 1 EFFECTS OF TEMPERATURE ON AMP-HOUR AND WATT-HOUR EFFICIENCY

Cell	Amb. Temp (°C)	Amp - hour			Watt - hour		
		A-h in	A-h out	Eff (%)	W-h in	W-h out	Eff (%)
#27	±0.0	145.6	149.8	102.9	575.0	449.6	78.2
	+20.0	155.6	153.1	98.4	603.5	463.1	76.7
	+40.0	155.8	148.2	95.1	606.0	443.4	73.2
#28	±0.0	149.7	150.7	100.7	598.6	423.8	70.8
	+20.0	150.2	152.5	101.5	600.8	430.9	71.7
	+40.0	157.7	150.1	95.2	630.4	424.3	67.3

The ability of the TS160LFPAHA cell to accept charge is shown in Table 2.

TABLE 2
CHARGING TIME AND RANGE OF BATTERY TEMPERATURE WITH SET
AMBIENT TEMPERATURE 0°C, 20°C AND 40°C

Cell	Ambient Temp (°C)	Time to Reach 80% of Capacity (Minutes)	Time to Fully Charge (Minutes)	Max Case Temp Rise (°C)
#27	±0.0	22	37	12.0
	+20.0	24	39	10.9
	+40.0	24	40	10.1
#28	±0.0	39	59	16.6
	+20.0	36	57	14.4
	+40.0	37	61	12.8

It was found that there were markedly different responses of the two specimen cells to attempts to fast charge. Cell #27 was fully capable of absorbing all the charge that was needed to fast charge while cell #28 showed high internal resistance in both voltage rise and temperature change.

From Table 1, it can be seen that the TS160LFPAHA specimens examined have relatively poor efficiency. In that light, the performance was similar to the fast chargeability of lead acid cells [6]. The efficiency does not appear to be strongly effected by ambient temperature. There is some depression of efficiency at 40°C. These efficiencies are lower than the finding of [7], probably due to aging.

IV. CONCLUSION

It was observed that the TS-LFP160AHA meets the USABC guidelines for fast charging over a wide range of temperatures. That implies that the cell does not need cooling in the summer or heating in the winter.

Moreover, the efficiency of the cells decreased slightly with increasing ambient temperature. However, the amp-hour and watt-hour capabilities were not affected.

Unless a reliable screening regimen is in place, we recommend that caution should be used in considering these cells for an EV application. This is the same caution that has been made for other lithium based cells from other sources [7].

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BIOGRAPHIES

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