BATTERIES UNDER FIRE

The analysis of an arced wire presents the proverbial question of which came first: the chicken or the egg. In recent years, numerous claims have been made in regards to lithium-ion (Li-Ion) batteries regarding their propensity to start fires. Regrettably, determining whether a Li-Ion battery failed and caused a fire or simply is a fire victim is a very difficult task and many times impossible.

This article outlines the construction and safety protections of Li-Ion packs and cells as well as chemistry, manufacture, and forensic analysis. The difficulty of determining fire cause vs. fire victim is also discussed.

BACKGROUND

Li-Ion batteries are generally referred to as secondary batteries, meaning they can be charged and discharged multiple times. Li-Ion batteries are commonly used in portable devices, such as mobile phones, laptop computers, power tools, and numerous other products. An important quality for secondary batteries is the energy that can be stored per unit mass. Table 1 shows various chemistries, as well as the corresponding gravimetric energy density range. Based on this one data point, it is clear that Li-Ion offers real advantages for portable devices.

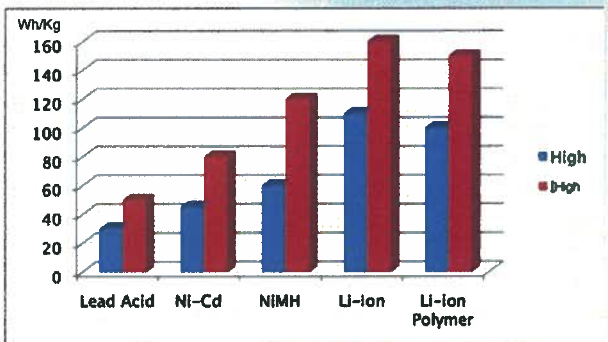

Table 1 - Gravimetric Energy Densities[1]

Jonathan Jordan BSEE, CFEI

Goodson Engineering
Denton, Texas

Li-Ion cells also present some challenges to the design engineer. The batteries do not fare well when overcharged or over discharged, thus they have to be charged in a safe fashion. Contrary to other chemistries, they are not aqueous cells, and oxygen is available within the cell as well as fuel – separator, active material, electrolyte, and electrodes. Therefore, sufficient heat can ignite the interior of the cell. A pressurized cell with internal combustion can have explosive results. For this reason, Li-Ion battery packs contain multiple safety mechanisms to reduce the risk of failure, which will be discussed in detail later. There are other possibilities for battery pack failures; however, the most common in my experience is a fault within a cell. The discussion will be primarily limited to cell internal faults in this article.

Determining cause of the fault is the real issue in post fire forensic analysis. That is, determining if the cell experienced an internal fault that resulted in fire or if fire caused the fault. An internal fault is caused by a short between electrodes. The insulating film between electrodes melts at low temperatures relative to fire. During almost any fire this film can easily be breeched by environmental heat allowing the electrodes to short. This results in the same pressurized exothermic event as an internal cell fault.

BATTERY PACK CONSTRUCTION

Before further discussion, the reader should clearly understand what a Li-Ion battery pack is compared to a Li-Ion battery cell. The battery pack is generally an enclosure containing multiple battery cells, connection straps and/or conductors, the battery management unit (BMU), monitoring devices such as thermistors, and a connector that connects the battery electrically with its host device. The term "battery" is often referring to the pack while other times referring to a cell, which can obviously be confusing. The terms "pack" or "cell" will be used so the reader is clear to which is being referred. The reader should also understand that battery packs and cells vary in chemistry and construction; therefore, they are discussed in general terms. The battery packs and cells discussed in this document are those produced by reputable manufacturers used in reputable products unless otherwise stated. Lastly, this discussion will limit its scope to "smart batteries", which are those packs with intelligence onboard the pack.

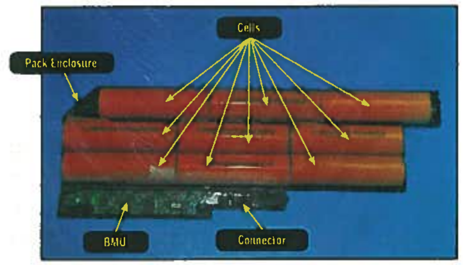

Figure 1 - Li-Ion 18650 Battery Pack Shown Disassembled

The BMU is a printed circuit board within the pack enclosure that controls all aspects of the battery pack including when it is charged. For example, a battery pack is inserted into the host device, the BMU requests charge current from the host device and ceases charge current when it senses full charge. The host device cannot charge the pack without the BMU allowing charge. Furthermore, the BMU tracks the charge state of the battery pack. If the battery pack is depleted to a 10% charge level, and a full 100% charged pack is inserted into the host device, the original pack will internally store its data so that it is aware that it is at the 10% charge level.

The data is not stored on the host device, per se. If the battery pack is overcharged, the issue lies within the BMU, not the host device. Via its safety controller chip, the BMU also continuously monitors voltage, current, charge, and temperature. While Li-Ion batteries offer many advantages for consumer products, they are also more susceptible to overcharge, over discharge, mechanical damage, and heat. Should an internal fault occur, they are more susceptible to highly energetic reactions. Reputable battery manufacturers have designed and implemented multiple safety mechanisms to prevent each of these from occurring.

The safety mechanisms that protect against charge and temperature issues begin with BMU components – safety controller chip, charge and discharge FETs, and fuse. The safety controller chip monitors the voltage, current, charge, and temperature of each cell. If over current or high temperatures are detected, the charge FET is turned off. If overcharge is detected, the charge FET is turned off and the fuse is blown as necessary. Charge and discharge FETs can be turned on and off. If the fuse is blown, the battery is permanently disabled.

CELL CONSTRUCTION

Currently, the most common Li-Ion cells used for portable devices are cylindrical 18650 cells, prismatic cells, or lithium polymer cells (Li-Po). The construction of cylindrical and prismatic cells is essentially the same; however, the prismatic cell is physically different as it has a slimmer profile and rectangular shape. Construction of both is shown in figure 2 below.

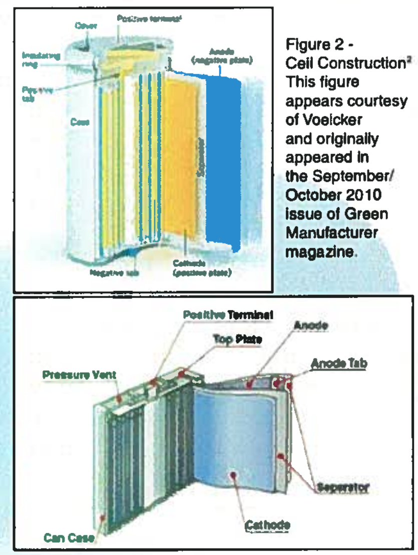

Figure 2 - Cell Construction[2] This figure appears courtesy of Voelcker and originally appeared in the September/October 2010 issue of Green Manufacturer magazine.

continued on page 14

Figures 3 and 4 show the cylindrical cell also known as an 18650 cell due to its dimensions, diameter (18 mm) and length (65 mm).

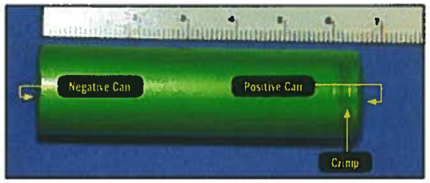

Figure 3 - Length of 18650 Cell

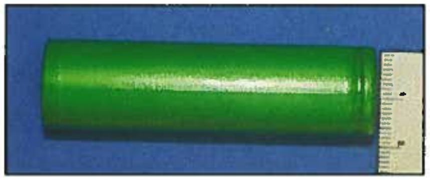

Figure 4 - Diameter of 18650 Cell

Figure 5 shows an oblique X-ray view of an 18650 cell, which shows the negative can. The can is the steel enclosure of the cell. The figure also shows the positive cap, general position of the windings (electrodes), vent tube, and negative electrode spot welded to the bottom interior of the can.

Figure 5 - X-ray of 18650 Cell

The 18650 cell body is typically a nickel coated steel can with a crimp near the top (figures 3-4). Above this crimp are the cell's safety devices topped with a positive cap. The cap is separated by a gasket from the remainder of the negative can. Below the crimp are copper and aluminum rolled sheets known as the electrodes. Each electrode has a lead, one is spot welded to the positive cap while the negative is spot welded to the bottom interior of the can as shown in figure 5. The electrodes are separated by an insulating film known as the separator. The separator is a micro porous thin film, which is typically a polyethylene or polypropylene film. Polyethylene film melts at approximately 135°C3 while polypropylene melts at approximately 165°C3. The film is generally about 20µm thick but tends to get thinner as cells progress – the thinner the separator, the higher the capacity of the cell. Currently, some separators may be as thin as 16µm. The separator is rolled between the electrodes over their width and length to separate them over their entire area. All three sheets are rolled and inserted into the can prior to the crimp. Naturally a roll creates a void at its center. Many times a vent tube is used in this void. The purpose of this tube is to direct pressure toward the vent/CID should an overpressure condition occur. This tube can also be seen in figure 5.

While the battery pack has safety mechanisms to prevent battery failures, each cell is also equipped with its own safety mechanisms. The cells' safety mechanisms react to temperature and pressure. The PTC (Positive Temperature Coefficient), also known as a Polyswitch, is a ring shaped device above the crimp in the cell. PTCs are used in multiple applications as by their nature they increase in electrical resistance when their temperature is raised. In a Li-Ion cell the PTC limits charge current as temperature increases. If high enough temperatures are achieved, the PTC will increase resistance to a point where no charge current is allowed to the cell.

The separator acts as a safety mechanism because as temperature approaches the melting point of the separator, pores collapse. As pores collapse, impedance increases; slowing and ultimately ceasing ion flow between electrodes. This restricts current flow.

The two safety mechanisms that react to pressure are the CID (Current Interrupt Device) and the vent. These devices are also located above the crimp of each cell and are essentially one in the same mechanism. If a cell should experience excessive pressure, this mechanism deforms such that it removes the positive lead and cuts off charge current to the cell. This is the CID portion of the mechanism. If the overpressure condition does not dissipate, this mechanism further deforms and opens to allow pressure to escape the cell. This portion of the mechanism is referred to as the vent. Excessive pressure in a cell or cells can result from overcharge, internal cell short, or environmental heat. CID deformation or the vent opening alone without flaming combustion is a safe failure.

The 18650 cell has been used widely within the laptop computer industry as well as other portable device industries. However, as manufacturers turn to thinner profile products, lithium polymer is increasingly the cell of choice. Li-Po cells can be manufactured to any shape or size and are enclosed in a polymer coated aluminum pouch. Due to the protective limitations of the pouch, these cells rely upon mechanical protection from the enclosure of the device in which they are utilized. Contrary to the steel cans for 18650 and prismatic cells, Li-Po pouch seals are defeated at relatively low temperatures and pressures, eliminating the need for a vent mechanism. Electrodes are stacked with separators cut to size and placed between electrodes. Leads protrude from each cell making connection as necessary at the BMU or similar. Electrolyte of Li-Po cells can vary, but gel electrolyte is common.

CELL CHEMISTRY

As previously described the electrodes are copper and aluminum foils insulated from one another by a separator. The aluminum electrode is coated its length and width with a powdered metal oxide referred to as the active material. Active material can vary, but lithium cobalt oxide ($LiCoO_2$) is common. The copper electrode is coated with a powered carbon material, which in many cases is graphite. Electrolyte is the medium in which lithium ions are transported during electrochemical reactions within the cell. In Li-Ion cells, typically the electrolyte is lithium hexafluorophosphate ($LiPF_6$) dissolved in an organic solvent.

During charging, lithium ions migrate from cathode (Al electrode) through the separator to the anode Cu electrode). The reverse is true during discharge, which is when the host device is being powered by the battery. Figure 6 provides a visual example of this action.

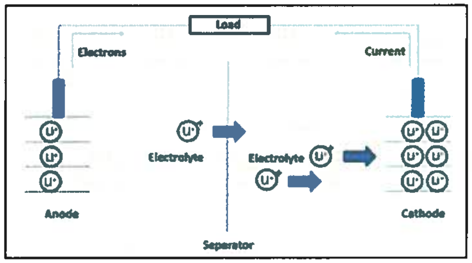

Figure 6 – Li-Ion Discharge Illustration

It should be noted that only lithium ions migrate during charge and discharge. If the quantity of lithium ions reaching the anode surpasses the anode's capacity, metallic lithium is deposited on the anode surface. This occurrence is due to overcharge, which can result in plating and/or dendritic growth and ultimately shorting between electrodes. Over discharge of a cell can begin dissolving the copper electrode and result in copper plating and dendritic growth as well.

LITHIUM ION CELL MANUFACTURING

Li-Ion battery cells are a machined product – steel can, copper and aluminum electrodes, electrode leads, spot welds, and the like. As with any machined metal, there exists a possibility for unwanted byproducts to develop, particularly as machine parts wear. If said machine parts wear and are not monitored and/or replaced in a timely manner to maintain sharp edges, etc., the probability for unwanted byproducts increases. Unwanted byproducts with regard to machining metals would be burrs, metal particles, weld spatter and the like. The battery manufacturing process has opportunities to induce such

continued on page 16

byproducts, which is why a solid quality control system is vital to the Li-Ion battery manufacturer.

Another issue cell manufacturers face is precision and consistency during the manufacturing process. A few examples where this is key follow.

- Electrode windings must match edge to edge
- Electrode leads must be free from deformation such as kinks
- Electrode leads must meet specified length tolerance
- Electrode coatings must maintain consistent thickness

Manufactured cells are subjected to testing in an effort to ensure safety of Li-Ion batteries. UL1642 is the Underwriter's Laboratory standard for lithium batteries, and UL 2054 is the standard for household and commercial batteries. Both address construction, performance, and testing. Manufacturers must meet such requirements to obtain the UL safety agency mark.

AFTERMARKET AND COUNTERFEIT PACKS

The Li-Ion battery market has become a $15 billion industry as of 2011 and is projected to grow to $37 billion by 20154. With such growth fire investigators will also likely see growth in cases where they collect Li-Ion batteries as evidence. With such demand, Li-Ion batteries will likely remain expensive relatively speaking. Enter the aftermarket Li-Ion battery industry. To be clear, the author defines aftermarket batteries as packs assembled by parties other than battery manufacturers contractually supplying packs to their manufacturer customer (OEM – Original Equipment Manufacturer). In other words, generally speaking most of those battery packs that have a generic brand as opposed to a brand name that most people recognize.

Aftermarket battery packs that are engineered with safety mechanisms and meet the same safety standards as ODM (Original Design Manufacturer) packs do exist. However, there is aftermarket packs that are produced with little to no engineering involved as they are basically just assembled from parts. To avoid confusion, these packs will be referred to as assembled aftermarket packs. It should be noted that assembled aftermarket packs may contain brand name cells as there are few Li-Ion cell manufacturers in the world.

Assembled aftermarket packs have a market because they are cheaper than engineered battery packs. To achieve a significant price difference, assembled aftermarket pack producers often cut costs to compete. The issue is that many products have become commodities. As such, turning a profit has become more difficult, and a cost cutting war has ensued. To compete and maintain the ability to offer packs at significantly cheaper prices, assembled aftermarket battery pack producers may cut costs further by a variety of means such as using cheaper components or bypassing testing and compliance with safety standards. This is evident in evaluating assembled aftermarket packs as many do not carry safety agency mark(s). An uncertified pack may have insufficient components for proper safety control. If a pack were assembled with little to no safety protection, the pack could regularly be exposed to overcharge and/or over discharge conditions.

Counterfeit packs are packs assembled by parties other than those contracted to OEMs, but they actually use the OEMs brand name without permission. Some counterfeits are very good as to how they visually compare to the brand logo and safety labels. Similar to assembled aftermarket packs these packs may be insufficient regarding safety mechanisms.

In examining cells or a pack after a fire, it may be very difficult to determine if the pack is a brand name manufacturer or an aftermarket. The manufacturer of the host device or a battery expert may be able to assist in making this identification, even if very little remains of the pack or cells.

BATTERY INTERNAL CELL SHORT

Consider a two conductor line cord to any appliance. The cord will have a hot conductor and a neutral conductor. Each conductor will be insulated such that the two conductors cannot make contact with one another since they are at different potentials when energized. If they were to make contact with one another a short would occur, producing heat. The short would result in arcing and would likely be interrupted by a circuit breaker or fuse within the structure to cease the event.

As already noted a battery contains two conductors, however, they are referred to as the positive and negative electrodes or cathode and anode instead of hot and neutral. Instead of being coated with insulation, they are protected from one another by the separator. If the cathode and anode were to make contact, it would also result in a short producing heat. Cells may have a soft short or a hard short. In fire investigation we are more interested in hard shorts, so soft shorts will be left for another day. A hard short is low impedance and quick discharge of the cell, thus thermal runaway is more likely. Oxygen and fuel are also present within the cell; therefore everything needed for flame is contained within the cell. Pressure is proportional to temperature, so as temperature rises so does the

continued on page 18

pressure within the cell. This pressure will activate the vent mechanism and flaming combustion escapes the cell.

In both discussions regarding the line cord and the battery cell, a short has occurred between conductors of potential difference. The question everyone wants to know is, what is the cause of the short? In the case of the line cord, another way to ask the same question is, what is the cause of the arc bead? The arc bead was caused by a breech in insulation that allowed the conductors to make contact and result in the arc. This breech in insulation could have been caused by mechanical means where arcing results and causes fire, or heat from a fire already in progress could have caused the arcing. Regardless, when arcing occurs the temperatures are so high that they consume almost everything in that small localized area. Making any determination regarding the arc as a fire cause or fire victim is very difficult if not impossible to determine based solely on the arc.

The same scenario holds true for Li-Ion batteries. If a short occurs within the cell, many times the cause of the short is consumed or ejected from the cell. Typically the aluminum electrode is consumed and the copper is heat damaged or expelled from the cell. A Li-Ion cell exposed to heat will also short when the separator melts. Therefore, thermal runaway in a battery cell will also occur due to external heat. Thermal runaway due to a short between electrodes is exactly the same whether the battery failed internally or is merely a victim of the fire. Much like the arc bead, cell(s) that have experienced thermal runaway may not provide the answer to the chicken or the egg. The investigator must evaluate the evidence as a whole to make any determination regarding the cause of fire.

INVESTIGATIONS

If a Li-Ion battery is located in the origin area, it should obviously be taken as evidence since it is a potential ignition source. However, what many investigators miss is that many times the Li-Ion cell(s) has reacted so violently that it shot across the room, so the cell(s) may be in an area away from the origin. At the fire scene be sure that all of the pieces of the battery pack are obtained. This may mean delayering an entire room to find those pieces of evidence possibly hurled away from the origin. It would help the investigator to know the quantity of cells within the suspect pack, but this will likely require the investigator to do some research and possibly enlist the assistance of the OEM to determine. Please keep in mind that the number of cells per pack can vary even within the same product.

Once all of the evidence that can be associated with the battery is found, further examination is necessary to attempt to identify whether there is a likely cause for failure internal to a cell or not. The tools generally needed for proper analysis are a real time X-ray, digital stereo microscope with montage capabilities, SEM/EDX (or SEM/EDS), and a CT (Computerized Tomography) scanner.

A battery pack and cell analysis is like any other evidence analysis in that all potential nondestructive analysis should be considered prior to any destructive analysis. First, we want to note observations regarding the cells as pulled from the scene, some of these observations might be the following.

- Cell lengths
- Cell diameters (measure multiple points)
- Cell voltages
- Cell weights
- Vented cells
- Ruptured cells
- Cell impedances

We also want to use nondestructive tools that allow further analysis of the cell or cells – X-ray and CT scans. X-rays of damaged cells allow visibility of the overall damage and/or identification of obvious defects. For example, the investigator may be able to determine if the BMU is intact, which cells vented, and determine the general condition of the windings. Depending on the severity of the damage, the investigator should be able to view the extent of damage to the cell interior.

Attempting to determine if an internal cell fault has occurred, one would need to use a CT scanner or disassemble the cell. The former is nondestructive and many times can eliminate the need to disassemble the cell, but it is also more costly. If a CT scanner is to be used, one should expect a cost of about $300 per hour or more, with one cell taking 1.5 - 2 hours to complete for newer CT scanners. Older CT scanners may take 4-5 hours or even upwards of 18 hours to complete the scan and reconstruction. Depending on analysis needed it is sometimes possible to scan more than one cell at a time, but the tradeoff is loss of resolution. As resolution decreases, particles on the order of microns will likely go unseen in the results.

To describe the CT scanner in layman's terms, the scanner is essentially an X-ray that allows the viewer to see through an object a slice at a time. In performing a CT scan of a typical 18650 cell, the scan can begin at the top (positive cap end) and move down the length of the cell. As one views the CT scan results one slice at a time the entire cell interior can be examined. The cause of a short may be identified with such analysis. The CT discussion thus far only concerns one dimension, the Y axis if the cell is stood on one end. CT scanning also offers three dimensional scanning where the X and Z axis can also be scanned. This means all areas of the cell can be viewed from multiple angles and allows the investigator to see the entire structure in any direction. Examples of CT scans of an 18650 cell can be seen in figures 7-9.

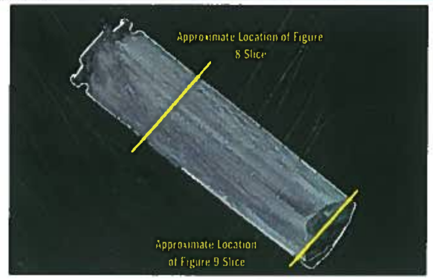

Figure 7 - CT of 18650 Cell Along X axis

Figure 7 is a view of a vented cell at about the halfway point on the X-axis. In other words, if one were to cut the cell down its length in half, this image would be viewed. The images in figures 8 and 9 below are taken on the same cell down the Y axis. Figure 8 shows the windings near the top of the cell while figure 9 shows slices near the bottom.

Figure 8 - CT of Cell Y Axis Upper Portion of Cell

If the examination needs to proceed further, destructive analysis will need to be performed once all non-destructive analysis is complete. If a CT scanner is not available or not feasible, the cell may be disassembled. The reader should note that disassembly of a Li-Ion cell can be dangerous. If one has never disassembled a Li-Ion cell, the author strongly advises utilizing a Li-Ion battery expert to perform the disassembly. Once the cell(s) is open, the interior of

continued on page 20

the cell should be examined carefully for causes of a short, i.e. defects or contaminants. Then the electrodes can be removed, unrolled, and examined for the same.

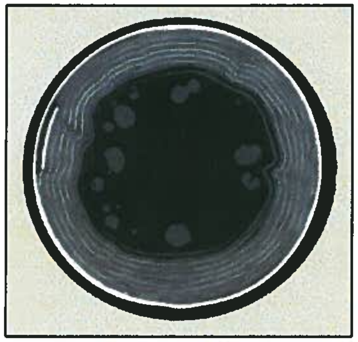

Figure 9 - CT of Cell Y Axis Lower Portion of Cell

If a contaminant is identified as the cause of a short, the contaminant may be extracted at this point and analyzed further. Prior to extraction we need to microscopically document the contaminant. Because the battery is a three dimensional object, and thus has depth, a typical microscopic image will only show the area focused on while the damaged area behind or in front will be out of focus. Thus a digital microscope with montage capabilities is preferable. This function allows the microscope to take multiple microscopic photos at varying focal distances and merge them into one photo such that all items within the photo are in focus. This allows the investigator to photographically document the contaminant in situ such that the photograph will accurately reflect the contaminant's location in reference to other points within the cell.

Figure 10 - Contaminant Found During Cell Disassembly

Figure 10 shows a contaminant that has penetrated the separator. However, we need to identify the contaminant to determine if it is conductive and its likely origin.

Figure 11 - Closer View of Contaminant

A SEM or Scanning Electron Microscope is another tool we use in Li-ion battery analysis as well as many other investigations. We use the SEM/EDX to identify and document particles and their makeup. For example, if we find a contaminant within a cell, we can document this particle with the SEM and determine the metal or metals that make up this particle. Figure 12 is a sample result of SEM/EDX analysis that found a particle to be iron.

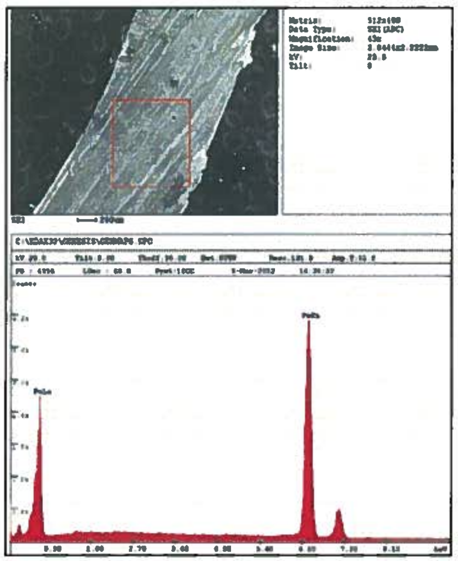

Figure 12 – SEM/EDX Results of Iron Particle

FUELS IGNITED

The primary and secondary fuels ignited are items every investigator should identify to determine fire cause. If a Li-ion cell fault occurs and we can make this determination to a reasonable certainty, then we have an ignition source. A cause and an ignition source are not one in the same. A cause is an ignition source, primary fuel ignited, and secondary fuel ignited. So once we have established a likely ignition source, the responsible investigator will determine the primary and secondary fuels ignited.

Temperatures of a failed cell can cause ignition of nearby combustibles. Such temperatures exist for a short duration. If a cell should fail exothermically, there is a chance that the heat generated by the failed cell will melt the separator in one or more adjacent cells. There may be a chain reaction where this occurs in each cell until all cells have exothermically reacted. Each event may reach high temperatures but each being short lived. If the event has multiple short duration events, even this level of heat may not be sufficient to ignite nearby combustibles. For example, the enclosures of many electronics products from reputable manufacturers have plastic enclosures with flammability rating of V-1 or better. These plastics typically melt at relatively low temperatures. While V-1 or better plastics will burn, they will not self-sustain a flame without an external flame source.

By definition, a V-1 rated plastic must self-extinguish within 30 seconds (V-0 within 10 seconds) of removal of flame and cannot drip flaming particles5. Since a plastic rated at V-1 or better requires some duration of heat and/or flame to maintain combustion, heat produced by a failed battery may not last long enough to ignite this plastic such that combustion continues. If the plastics with such a low melting point melt away from the heat rather than combust, the explosive pressure from a cell may force the cell from the pack where flame may contact fuels outside the product's enclosure. These fuels may be more likely to combust than the enclosure. If this is the secondary fuel ignited, it may seemingly place the origin of the fire a few inches to several feet away from the battery pack. Not only can a failure be difficult to determine, it may make the origin more difficult to determine.

SUMMATION

Lithium based batteries provide the energy required of today's portable products; thus they have become a necessity powering our world. Recognizing the potential volatility of these cells, safety protections have been designed and implemented to prevent failure. While battery failures are uncommon, they are not impossible. For the fire investigator or engineer to determine chicken or egg, internal short or fire attack, is as difficult as the expression is old. Retaining the proper expert for battery analysis and using the proper equipment is critical to the success of the investigation.

continued on page 22

ABOUT THE AUTHOR

Jonathan Jordan is a Consulting Engineer at Goodson Engineering. He received his BSEE from The University of Texas at Austin in 2001, and holds a CFEI certification. Mr. Jordan specializes in electrical engineering issues and addresses issues related to failure analysis of a wide array of products and components including but not limited to electronics, printed circuit boards, appliances, HVAC/R, residential and commercial wiring, motors, power supplies, and battery failure analysis with an emphasis on Li-Ion battery technology.

Mr. Jordan has performed numerous fire investigations involving electrical cause or alleged electrical cause. His experience includes evaluation of electronics products and their failure modes for adherence to safety standards such as Underwriters Laboratories (UL) and the Canadian Standards Association (CSA) as well as structural wiring compliance to the National Electric Code (NEC). Mr. Jordan has performed multiple projects regarding product safety failure analysis resulting in design changes, ODM changes, and recalls. Mr. Jordan holds two Li-ion battery patents.

jonathan@goodsonengineering.com
940-765-8986

REFERENCES

[1] "Electrochem - Battery Academy." Electrochem - Battery Academy. Web. 08 May 2012. <http://www.electrochemsolutions.com/battery/comparisons.aspx>.

[2] Anderson, David. "Sage Supplier: Lowering Costs of Lithium-ion Batteries for EV Power Trains." - Green Manufacturer Green Manufacturer. Fabricators and Manufacturers Association, International, 1 Oct. 2010. Web. 01 June 2012. <http://www.greenmanufacturer.net/article/tc/sage-supplier-lowering-costs-of-lithium-ion-batteries-for-ev-power-trains>.

[3] Arora, Pankaj, and Zhengming (John) Zhang. "Battery Separators." Chemical Reviews (ACS Publications). Chemical Reviews (ACS Publications), 13 Oct. 2004. Web. 21 May 2012. <http://pubs.acs.org/journals/chreay/index.html>.

[4] Yoshida, Masaru, and Nikkei Monozukuri. "Global Li-ion Battery Market Will Grow to $37Bln." Tech-On! Tech & Industry Analysis from Asia. Web. 08 May 2012. <http://techon.nikkeibp.co.jp/english/NEWS_EN/20111216/202689/>.

[5] UL 94: Tests for Flammability of Plastic Materials for Parts in Devices and Appliances (June 2, 2006) Northbrook, IL: Underwriters Laboratories Inc. (UL)