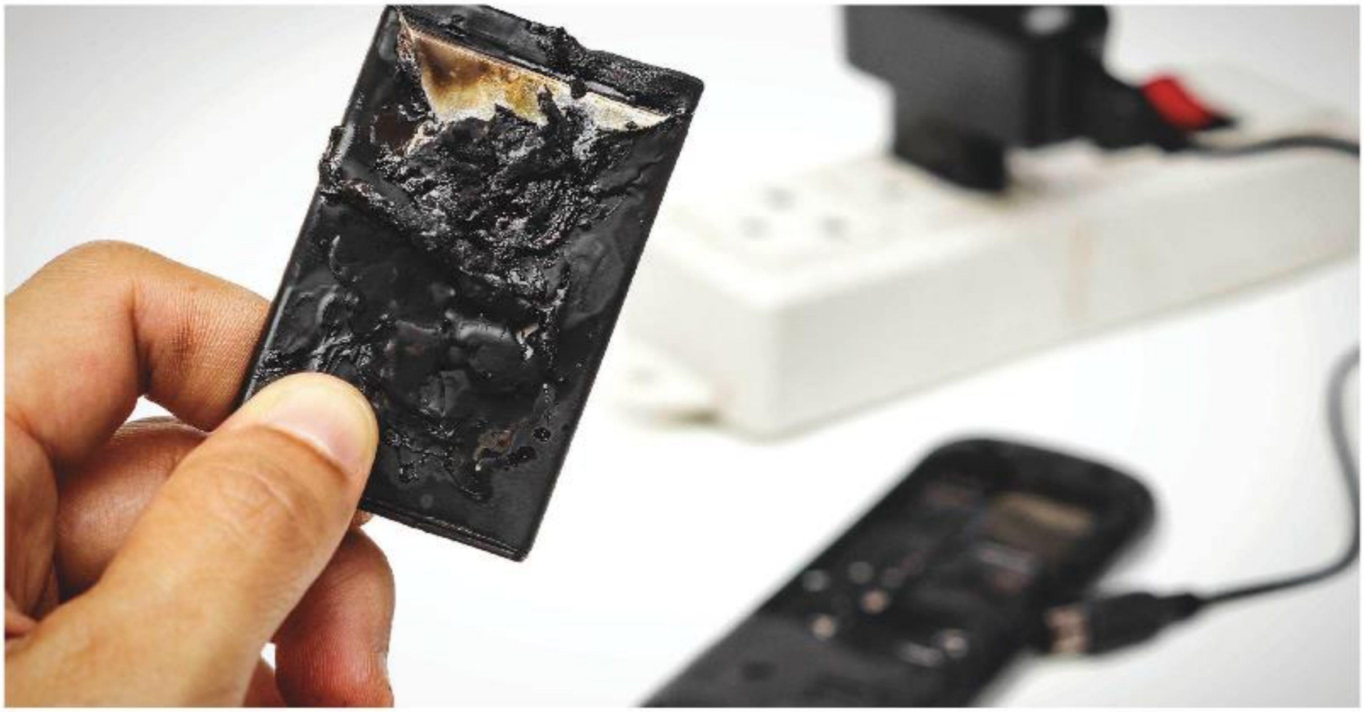

ANATOMY OF FAILURE

Understanding the Causes of Lithium-Ion Battery Fires

By Michael Stichter

Lithium-ion batteries are used in many devices like cordless power tools, hoverboards, e-cigarettes, and cell phones, and they have an increasing presence in electric automobiles, too. Most of us know this because we've read in the news about the fires and explosions that have occurred with some of these devices, whether they were in use or not, and the causes have been attributed to overcharging, product design, manufacturing defects, and mechanical damage. The fire hazards associated with these devices have the potential for significant personal injuries and property damage.

As the use of these batteries continues to rise, technologies to increase energy density (more amp-hours) and output (maximum and sustained amps) will continue to be developed. But these improved output specifications are balanced with safety concerns. As electrical capabilities increase, there also is an increased concern for rapid energy release in the form of a fire or explosion.

In a lithium-ion battery, the material that separates the anode (graphite) and cathode (various lithium-ion chemistries including manganese and cobalt) is very important in controlling the electrochemistry inside the battery cell. In normal conditions, these ions pass through the membrane separator in a controlled manner. However, lithium-ion batteries are susceptible to mechanical damage via puncture, crush, or impact; electrical short-circuiting; and high temperatures, all of which can cause permanent failure of the batteries.

Electrical short-circuiting of the positive and negative electrodes causes internal heating of the battery as high currents are drawn. This internal heating increases the temperature of the battery, and at approximately 130 degrees Celsius, polymer-based separator materials begin to break down. This allows additional contact of the anode and cathode materials, leading to increased heating that can quickly turn into thermal runaway in which the internal heat generated is more than the heat dissipated by the outside surface of the battery. Also, under certain circumstances, the rapid release of energy

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when anode and cathode materials come in contact can cause high temperature gases to be released. In any case, once thermal runaway is achieved, failure is assured, but protection mechanisms may reduce the likelihood of propagation to components and persons in proximity.

PROTECTION

Battery packs contain multiple cells, which are required by IEC, ANSI, and UL standards to have protection. Battery cells designed for use in battery packs often are not individually protected; instead, the battery pack itself has the protections built in. Whether on the pack or on the cell, an electrical circuit is included to protect the cell from overcharge, over-discharge, and over-temperature due to current flow. Individual cells include mechanical methods to release gases before the pressure can build to a level that would cause an explosion.

Mechanical damage protection is provided by the casing materials used at the cell and pack level. Common cylindrical and prismatic battery cells have metal or plastic cases that protect the anode, cathode, and separation materials inside. The mechanical protection in pouch-style cells is not as robust, and external structural details are necessary to protect them from damage.

In order to substantially reduce risks associated with handling batteries, the warnings and guidelines supplied with the batteries should be followed. Bare batteries especially should not be allowed to short-circuit or come into contact with high temperatures.

FORENSICS OF FAILURE

Lithium-ion batteries often are part of a complex system that includes charging circuitry, a battery management unit, a thermal management system, and the electrical circuit of the system. Each relevant system component needs to be investigated by an expert to determine its role in a fire.

The materials of construction have a significant effect on the extent of destruction in a fire. Internal components in a battery cell, such as the membrane separator, will chemically and physically change when they see relatively low temperatures of around 130 degrees Celsius, which is much lower than any flame achieved in a fire. That means destruction of these components will happen rapidly.

Computer and power tool battery packs generally are found encased in plastic that will melt or burn. The location of melting on these packs can indicate higher temperatures and/or longer duration of radiation, origin, or heat flux. The design of the case can be critical to the long-term health of the battery. Heat transfer away from the battery cells and battery pack during charge and discharge requires design consideration so that heat buildup does not become excessive. Analysis of the design of a battery pack for sufficient conduction and convection of heat away from sensitive components can be important in determining cause, and can open battery manufacturers and/or battery integrators to liability.

As in any fire, the extent of destruction that has occurred will affect the investigation process.

When searching for a cause, the battery should be looked at in context with the whole system, including the charging system and discharge circuitry. When attempting to capture the full context, X-ray imaging can be a powerful tool in determining the status of wiring interconnections and identifying areas of focus for further investigation.

Multiple layers of inspection are needed when investigating lithium-ion battery fires. Test methods may include, but are not limited to, characterization of the charging system by measurement of voltage and current profiles supplied to the battery cell over time; measurement of the current demanded from the battery; and X-ray imaging and/or computed tomography (CT) scans of damaged cells.

Battery cells that have seen overcharge and over-discharge cycling often exhibit localized deposition of anode and/or cathode materials, which can lead to mechanical damage to separator materials. This mechanical damage is difficult to detect without destructive examination of the battery cell. A battery fire can make these forensics difficult to observe, complicating the investigation. However, the failure mechanism can often be determined by other methods. ■