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The G. S. Yuasa-Boeing 787 Li-ion Battery: Test It at a Low Temperature and Keep It Warm in Flight

Growth of dendrites is possible upon overcharging an anode of a Li-ion battery, particularly a Li-carbon anode, where the Li plating (deposition) potential is close to that of elemental Li. Dendrites, electrically shorting the electrodes of a battery, and creating a combustible mixture of $LiCoO_2$ and electrically disconnected metallic Li particles, are recognized causes of battery fires.

The likelihood of growth of a Li dendrite, a fine metallic Li fiber, and the likelihood of its survival and the survival of disconnected metallic Li particles at the $LiCoO_2$ cathode in the electrolytic solution, is inversely temperature dependent, *i.e.*, both increase at low temperature. Placing the battery in a compartment maintained at about 25°C could reduce the likelihood of a fire; and the battery should be tested by its repeated overcharging at the lowest temperature at which it is specified to be charged on a Boeing 787.

Electroplaters know the conditions for plating a smooth and shiny metal, and the opposite conditions, under which the plated metal consists of thin, fibrous dendrites, often of black appearance. The prime requirement for plating a smooth and shiny metal layer is fast transport of the plated ion to the slowly plated electrode. The condition for plating dendrites is the opposite—slow transport of the plated ion to the rapidly-plated electrode. Fast transport means, in the context of a Li^+ ion battery, transport that is fast enough to reduce the thickness of the solution layer in which Li^+ ions are depleted to much less than the distance between the anode and the cathode, for example to less than 1/100th of this distance. Conditions for avoidance of depletion include: (1) a low enough plating current density; (2) a high enough free and mobile Li^+ ion concentration; (3) fast enough diffusion of the Li^+ ion; and (4) stirring, mixing, flow of the electrolyte, whenever possible. Usually these are difficult in a battery, unless its electrolyte is circulated.

When a battery is cooled, the concentration of the plated Li^+ ion may decrease because of lesser solubility of the Li^+ salt serving as the electrolyte and, more importantly, because of pairing with the counter-ion, *i.e.*, the anion of the electrolyte. Furthermore, when the battery is cooled, the diffusion of Li^+ is slowed, because the cooled electrolytic solution is more viscous. The lesser solubility, greater ion pairing, and the slower diffusion in the more viscous electrolyte all enhance the growth of dendrites when the battery is rapidly charged at a low temperature and particularly when it is rapidly overcharged at a low temperature.

While slow transport of the plated Li^+ ion at low temperature is by itself a severe problem, an even greater problem is that at the low temperature, a growing dendrite, a fine Li fiber, and the electrically disconnected metallic Li particles formed upon partial corrosion of the dendrite that would not survive at ambient temperature, does survive. Lithium ions residing in an electrolytic solution are necessarily coated with a thin insulating film, known to corrosion chemists as a passivating layer, and to battery experts as an SEI (Solid Electrolyte Interface). The film, formed by reaction of the metal and the electrolytic solution, *i.e.*, by partial corrosive consumption of the metal, prevents further reaction with the electrolytic solution. In the absence of this film, a high surface-to-volume ratio metallic dendrite would be rapidly consumed—it would turn into a non-shorting insulator.

The thickness of the corrosion passivating layer is steeply temperature-dependent. While at a low temperature, a very thin film can prevent corrosion, at a high temperature only a thick passivating film will protect against corrosion and all of the metal of a fine Li fiber may be consumed before its protective film grows to its final thickness. A fire can result from the accumulation of fine metallic dendrites and their fragments when these are protected against corrosion by a passivating film that, at a low temperature, is too thin. Their corrosive digestion by reaction with the electrolyte can be enhanced, and the likelihood of an uncontrolled thermal reaction with the oxidant of the battery can be reduced, by keeping the battery warm.

So not only the passengers, but also the Li-ion battery of the Boeing 787 should be kept comfortably warm when the plane flies at an altitude of 40,000 feet, where the outside temperature is below -60°C.

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