Application of Advanced Manufacturing Technologies to Polymer Lithium Ion (PLI) Bi Cell Production Electrode Preparation / Assembly / Lamination

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Introduction

The manufacturing of PLI batteries requires several steps:

Step 1 – Mixing and coating of the electrode chemistry onto a web of expanded copper and aluminum mesh.

Step 2 – Assembly of one Anode, two Separators, and two Cathodes, then binding them together with a hot lamination process to create a bi cell.

Step 3 – Extraction of the plasticizers in the chemistry to leave a microporous structure for the electrolyte.

Step 4 – Assembly of numbers of bi cells to create the desired energy density, welding of tab materials for battery connections, typically with ultrasonics.

Step 5 – Activation of the cell with electrolyte.

Step 6 – Packaging of the battery in a hermetically sealed container.

Step 7 – Formation of the battery

Step 8 – Evacuation of gasses liberated during formation from the package, and final seal and trim cut of the package.

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Commercialization of lithium polymer batteries has been slower than anticipated, despite a number of companies with significant technical and financial resources participating in this new battery technology. The primary areas requiring extensive development have centered on the electrode and separator materials, the assembly of bi cells from those materials, and the final electrolyte activation and packaging of the battery. This paper will focus on the most critical step downstream of the materials mixing and coating – the bi cell assembly process.

1. Historical Perspective

Polymer Lithium Ion (PLI) patented battery technology was pioneered earlier in this decade by Bellcore, now Telcordia Technologies. Bellcore sought to commercialize this technology thru sale of licenses to existing battery manufacturers and others.

While the technology transfer package focused heavily on electrochemical and materials issues, it lacked a thorough treatment of the manufacturing technologies and techniques that were required to actually build the bi cells and the batteries. At that time, it appeared that these steps were relatively straightforward, and that the licensees could readily develop the tooling and equipment needed.

This did not, however, turn out to be the case. PLI commercialization has been hampered over the last several years by both the development of the electrode and separator materials to reach battery performances required both by the device manufacturers and competing battery technology pressures, as well as the manufacturing technologies required for full scale mass production with acceptable yields, high thruputs, and low costs.

In transferring technology, Bellcore demonstrated the application of the polymer chemistry of the anode and cathode electrode materials, and the chemical composition of the separator, along with certain processing steps required, eg; extraction . Bellcore also taught the lamination process either by pressing between flat plates at elevated temperature, or thru calendaring rollers at elevated temperature.

Many attempts at developing reliable manufacturing systems for the PLI battery were made, either by outsourcing to equipment vendors, or attempting in-house machinery development. Several system concepts have had design drawbacks that have not produced the production thruput, yields, and performance desired.

Initially, the bi cell design was based on the electrode dimensions and the separator dimensions being the same, that is, an edge to edge stack up. In practice, however, it has been demonstrated that this is not practicable. Reliable, burr free cutting is not achievable so that battery life degrades thru intercell and intracell short circuiting thru metallic contact, as well as metallic burrs shorting thru to the package material. Shorts also develop as crystal growth occurs around the exposed edges.

Many companies initiated the lamination process of these materials by using hot rollers, indeed, sample working cells were made with cheap "home office" style laminators. Roll lamination was, therefore, taken as a given for the bi cells.

2. Continuous Web vs. Discrete Components for Bi Cell Manufacture

Continuous Web Roll Lamination

The most basic method for making the bi cells is to form a continuous laminate of cathode, separator, anode, separator, cathode. This was readily done with standard or modified roll lamination systems that are commercially available. While widely used, this particular method has demonstrated several drawbacks.

The electrode materials are manufactured by directly coating or laminating a web of the electrochemistry onto a web of thin expanded metal or laminating a strip of material to the mesh - either copper or aluminum. Separator webs are coated on a carrier web, then this web is peeled away and the separator can be applied to the electrode.

In the continuous process these webs come thru a set of heated rollers that apply pressure to the web to fuse the layered structure together. Preheating of the materials prior to the pinchpoint is also performed. There are several factors that adversely effect roll lamination from being a reliable manufacturing process for this particular set of materials.

a) As the web or stack up of bi cell materials enter the rolls, pressure is applied. The pressure is a function of the thickness of the introduced materials relative to the gap setting of the rolls. Since coating thicknesses of the electrode materials can and do vary, the applied lamination pressure will vary. Indeed, if the materials run under tolerance, stack-up height can become less than the minimum gap setting, and no lamination will occur in these areas. Conversely, thicker areas will result in greater lamination pressure at those points, which can cause distortions in the materials.

b) As the web flows thru the rolls, the material is squeezed together - entering material is thicker than exiting material. This extrusion effect can induce stresses in the web, misregistration of cathode / anode / cathode, wrinkles, other material distortions, and in the end not produce uniform lamination of the layers.

c) The rollers are essentially in "instantaneous" contact with the web - point contact - as the web flows thru. This means that temperatures of the rollers can be high relative to the material's temperature limits to attempt reliable bonding, especially in a five layer structure. Since the time duration of applied pressure is so short, this is an unforgiving process, that can have non-repeatable lamination quality within the web and from web to web.

d) Accurate and repeatable temperature measurement and control of the contact surface of the rolls is difficult as the rolls are in continuous rotational motion.

Cutting Bi Cells from a Continuous Web

A complete web may contain up to eleven (11) layers of material – separator x 2, electrode x 6, and expanded metal x 3. Many attempts at different tooling to cut this material and leave burr free edges have been attempted. Crush cutting with dies, die punching, slitting, and knife cutting have all ended up with similar results. The tendency of the expanded metal is to elongate, stretching the metallic filaments into burrs that can intertwine causing shorted bi cells. It is very difficult to hold the metal filaments back by clamping it between so many layers of compressible materials.

Another failure mode for this bi cell design has been reported in the literature, that crystalline growth can occur at the edge interface as the battery is charged and discharged. Since these crystals are salts of the electrolyte and electrode chemistry they are conductive, and, therefore, cell short circuits can occur.

Discrete Bi cell Electrode Preparation

In this case, the bi cell is built with discrete anode, cathodes, and separators stacked up, then laminated. The cell exhibits a separator dimension a nominal 1 mm in excess of the anode dimension in both directions. Once this separator is laminated, it effectively seals the anode edges within. This design effectively insulates the electrode edges from crystal growth. It also tends to make the cell less susceptible to burrs from cutting, and isolates the edge of the battery from the packaging material. (Note that poor cutting tools and techniques that form substantial burrs will not be corrected by this design).

Several concepts that considered the extended separator were developed. These were basically divided into two efforts:

a) produce discrete anodes, cathodes, and separator parts, stacking one atop the other with fixturing means (one embodiment featured a fine mist spray of adhesive material), then delivering the stack to lamination.

b) produce discrete electrodes, apply heat to a separator web to energize the surface of the separator (make it "tacky or "sticky"), and apply the electrode to this heated web, eventually forming a stacked up cell, then delivering the stack to lamination.

Both approaches exhibited problems in execution. Concept a) particularly was difficult as the separator material is extremely thin and has no rigidity, so cutting and handling techniques are quite demanding. In addition, the necessity to spray on fixturing adhesive incurs the difficulties of maintaining repeatable dispensing, machine cleanliness, operator safety issues of fumes in the environment, and the necessity to remove evaporable materials in the adhesive from the assembled cell prior to further processing steps, as these materials can adversely effect cell performance.

Concept b) was a much improved process, but used traditional mechanical web transport devices that ignored the physical peculiarities inherent in the electrode materials. This made web tracking, web flatness, and web tensioning difficult to achieve, all which impact electrode dimensional tolerances. Advanced material handling techniques with servo motor controlled motion have addressed these issues, and can transport the electrode materials flat, wrinkle and stress free thru tooling stations while maintain better than +/- .1mm tolerances.

Preferred Technique / Electrode Preparation

A preferred method has been demonstrated, and includes a proprietary process, **ZEROcs**, wherein the single electrode webs are die punched as individual parts, either one or two at a time depending on machine thruput and coating area (or cell size), with a die punch toolset. This **ZEROcs** design has demonstrated planar shearing of the electrode coating with the expanded metal mesh, the control of the metallic filaments to prevent elongation, especially in the copper material, and the ability to run three shifts at high speeds for months between tool sharpenings.

This die punching method yields an extremely accurate and clean electrode. Advanced material handling then delivers the electrodes to the separator webs, where assembly and lamination occur with tight registration.

Discrete Bi cell Lamination

Again, roll lamination was originally attempted for the discrete bi cell design, but even demonstrated more difficulties as there was an interrupted stream of parts flowing thru the lamination system instead of a continuous web, which exaggerated the issues of deformation and non-uniform pressure application..

Flat Platen Lamination

Originally platen lamination was demonstrated by the use of heated metal plates either in an oven or in a heated press. But this process required improvements. Lamination uniformity suffers with the use of rigid press plates that cannot distribute forces evenly over single or multiple stacks of cell components of varying heights.

Additionally, flat platen lamination has typically been applied to the entire stack of five layers of the cell, requiring heat to travel thru the layers to reach the anode - thus inducing a temperature gradient across the stack, and requiring relatively higher temperatures to attain the short lamination dwell times necessary for a manufacturing process. Higher temperatures can cause bubbles to be entrapped in the laminate, again reducing yields.

Preferred Technique / Platen Lamination

Thru an evolutionary process, the lamination method of most promise to the bi cell assembly is flat platen lamination, now with several unique differences.

- Proprietary platen coatings, **CRS9940** , to distribute the heat uniformly, while conforming to the surface of the parts clamped so forces are evenly distributed over the surface of the part or parts being laminated.
- Separation of lamination into stages – laminate the separators to the anode fully, followed by lamination of the cathodes to the separator/anode web.
- Multiple, independently temperature and pressure controlled lamination substations, **THCPS**, within each lamination process.

Multiple lamination cycles gain thruput, reduce temperatures, control gas bubble formation, and insure complete uniform fusion across the surfaces of the bi cells. This process is critical for high thruput cellphone battery lines, and required for large format cells for notebook and laptop applications.

Summary

Technical advances in manufacturing techniques and applied technologies have been made for bi cell manufacture, and are currently being implemented in the areas of discrete electrode / bi cell assembly, and electrode / separator lamination.

Not only have improvements been noted in the reliability of the mechanical assembly and the increase in yields and decrease in costs, battery electrical performance has also been enhanced thru these assembly techniques. Evidence has been shown that the lamination techniques can influence porosity and electrolyte dispersion, and therefore electrical performance and long term reliability of the cells.