NDT Methods to determine the integrity of ultrasonic welds for Lithium – ion battery tabs

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Abstract

Lithium ion batteries are predominantly used in electric-mobility solutions. Ultrasonic welding is an additive manufacturing technique that is a vital process during the manufacturing of Lithium ion batteries. During ultrasonic welding, high frequency ultrasonic energy generates a shear force at the interface between the sonotrode and metal sheets to produce solid state bonds clamped under normal compressive force. The advantages of this process include, but not limited to, joining dissimilar metals that could be highly conductive, no melting of workpieces, low energy consumption, etc. The heat generated during the ultrasonic welding process creates residual stresses on the sub surface layers of copper and aluminum tabs, which are used in making the lithium ion batteries. However, the effect of thermal and mechanical inputs on the battery tabs affect the quality of the welding and consequently the performance of the battery. The various methods include non-destructive testing techniques such as Thermography and X-Ray Computed Tomography were employed to study the effect of the processing parameters (thermal and mechanical inputs) on the quality of the ultrasonic welds.

Keywords: Ultrasonic Welding, Thermography, X-Ray Computed Tomography, Lithium ion Battery Tabs, Additive Manufacturing, Fatigue Testing

1 Introduction

Batteries play a significant role in energy storage and energy conservation. Over the years, lithium ion batteries have occupied an important space in aerospace and automotive applications. There have been lots of development in lithium ion batteries in recent years due to it’s inherent advantages such as high energy density, minimal maintenance and availability of huge varieties. However, suggested evidences in recent researchs revealed a few disadvantages of lithium ion batteries to be limited protection, high cost, transportation issues and ageing due to frequent charging and discharging. In this paper, the motivation to find the integrity of ultrasonic welding in lithium ion battery tabs stem from the fact that these batteries have safety issues due to ageing. We are going to consider the effect of ultrasonic welding on Aluminum – Nickel and Copper – Nickel battery tabs, which are frequently used in lithium ion batteries’s protective casings. Non-destructive evaluation methods such as X ray computed tomography and thermography are employed to fatigue tested samples to determine the integrity of ultrasonic welds.
1.1 Brief Introduction: X RayComputed Tomography

Computed tomography method is an imaging procedure to detect abnormalities in a wide variety of materials ranging from low dense body tissues to high dense steel. X rays are employed in such methods to penetrate through the materials. X rays are electro–magnetic rays which are produced in two types: Bremsstrahlung and Characteristic radiation. It is produced in an X ray tube where accelerated electrons hit the anode and the resulting slowed down electrons are converted into the two types of radiation. Generally, Bremsstrahlung consists of 70% of the X rays and the remaining 30% are Characteristic radiation. X rays travel in straight paths and are not deviated in electric or magnetic or combined fields. The main property of X rays is that it either gets absorbed or dispersed or transmitted. It follows the Lambert’s law of absorption. These transmitted or dispersed X rays are caught by the photo diodes employed in the detector to obtain the grey scale value over an array of pixels. These pixels, arranged according to grey scale values, are then converted into a greyscale image. X ray computed tomography used in this work pertains to GE Phoenix vtomexs of 240kV/320W range.

1.2 Brief Introduction: Thermography

Thermography is one of the several non–destructive evaluation techniques which employs the infrared rays of the electro–magnetic spectrum to capture a thermal image of a heat radiating body. It follows the basic idea that all objects with temperatures above the absolute mean temperature (0 Kelvin) emits heat into the surrounding environment. This radiation is captured by an infrared photo detector, i.e., the camera. The physics associated with this technique are: First Law and Second Law of Thermodynamics. We employ this technique during fatigue testing to capture any thermal spike due to bond dislocation or for any such defects. Thermal management of lithium ion batteries is a critical reliability assessment factor [1]. Hence, thermography plays an important in capturing the thermal effect of fatigue cycles on such battery tabs.

2 Materials Used and Test Matrix

Over the years, many welding techniques are employed to join materials. However, most of the methods concentrated on joining only two or more materials of the same type. Joining dissimilar metals was a real world practical problem. Innovations using ultrasonic vibrations brought about a new welding technique called as ultrasonic welding. It employs ultra high frequency acoustic vibrations, which are passed through a sonotrode onto the materials to be welded. It is a solid-state weld devoid of soldering material or adhesives to create the bond. In this work, we take two varied materials usually employed as the lithium ion battery casings. Nickel 201 grade material acts as the base. Over it, 50 foils of each copper and aluminium (25 on each side of the Nickel 201 grade sheet) act as the secondary materials. Any welder would know that aluminium is a difficult metal to weld due to it’s high thermal
conductivity. But in our case, aluminium poses no such problem because it is a soft metal where solid state ultrasonic weld is easier to achieve. Since no material is melted, it could be safe to assume there is minimum or negligible thermal residual stress.

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Aluminium – Nickel Tabs</th>
<th>Copper – Nickel Tabs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude (%)</td>
<td>Welding Time (s)</td>
</tr>
<tr>
<td>1</td>
<td>70</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>9</td>
<td>80</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Table 1: Test Matrix for Aluminium – Nickel and Copper – Nickel tabs

3 Experimental Procedure

Initially, the samples were checked for any improper welds such as cross welds, incomplete welds, etc. Before fatigue testing began, we employed X-ray Computed Tomography to scan the samples for any internal defects. Only perfectly welded samples were taken into consideration. To determine the maximum load that could be withstood during fatigue testing, one sample was tested in tensile testing configuration. The maximum load was found to be 1.5kN. Moreover, in order to determine the maximum frequency that the weld could withstand, samples were fatigue tested at 20Hz, 15Hz and 5Hz. It was determined that at 5Hz the samples lasted more than 1000 cycles of 0 to 1.5kN fatigue range. Moreover, the samples were fatigue tested using an Instron machine at 250, 1000, 1500 cycles and till breakage. The X-ray computed tomography of the samples were conducted after each cycle iteration. Furthermore, the thermography was conducted during the fatigue test to detect any thermographic spike. Hence, the parameters were fixed according to Table 2 description. Thus, the samples were tested for Constant Load and Constant Frequency.
Frequency  | Maximum Load (N) | Minimum Load (N)  
--- | --- | ---  
5  | 1500  | 0

Table 2: Parameters for Fatigue Test

4 Results

During ultrasonic welding, the vibrations pass through the material to form a shearing force. It causes the weld shocks to pass through the clamped workpieces, where the heat forms resistance at the contact surfaces which causes stresses. The ultrasonic welding of aluminium – nickel and copper nickel tabs which acts as a casing for battery packs have high stress concentration factors, indicated by the circular holes, acting on the bottom edge of the ultrasonic welds. It was reported in the literature that ultrasonic weld failures occurred predominantly by Mode III through thickness fracture [2].

![Figure 1: X ray computed tomography for top, front and side views of copper nickel tabs before fatigue cycle](image1)

![Figure 2: X ray computed tomography for top, front and side views of copper nickel tabs during 1000th cycle](image2)
Figure 3: Thermography of copper nickel tabs during 1000th cycle

Figure 4: X ray computed tomography for front, top and side views of copper nickel tabs during broken cycle
From what could be inferred from the above figures are that the fatigue cracks propagate along the slip planes. The cracks start from high stress concentration factors areas near the weld zones. During the fatigue testing, the thermography cameras were set up. The temperature spike indicates the heat release caused by fatigue crack propagation. At the time of complete breaking, the thermal spikes increase by at least 100% to indicate brittle failure of the welds. Moreover, from figure 4, we could infer that delaminations occur during higher fatigue cycles as well.
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Figure 7: Themography of aluminium nickel (70.1.5) after 250th cycle

Figure 8: X ray computed tomography for front, side and top views of aluminum nickel tabs during 1000th cycle

Figure 9: Themography of aluminium nickel (70.1.5) after 1000th cycle
From the first and second law of thermodynamics, we know that any body at a temperature above 0K would emit heat. Heat dissipation could be described as a process where internal energy or kinetic energy could be transformed into mechanical energy. It could inferred that as heat flows from higher gradient to lower gradient, energy conversion happens in the form of transforming mechanical energy.
into heat energy. From figure 2, we could determine that copper nickel tabs had undergone delamination. It was precisely recorded through a thermal spike by the thermography camera, as indicated by figure 3. The inter connected ultrasonic welding between copper and nickel made the material fail through tearing and dissipating heat in this process. Similarly, from figure 6 and 7, we could infer that aluminium nickel tabs underwent delamination, thereby, dissipating heat in this process. Moreover, the two samples of aluminium nickel tabs failed at lower fatigue cycles (Sample 70.1.5 at 1100th cycle and sample 75.1.6 at 500th cycle) whereas, copper nickel withstood higher fatigue cycles (more than 1500 cycles each). It proves that copper nickel tabs were more stable mechanically and thermodynamically than aluminium nickel tabs. Hence, we could conclude that the integrity of copper nickel and aluminium nickel tabs were determined by NDT methods.

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References
