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Method to detect foil discontinuities in pouch battery cells using deformation-based x-ray radiography

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ABSTRACT
Inline and fast-offline nondestructive techniques for electric vehicle lithium-ion battery cell manufacturing play a crucial role in ensuring defective and non-conforming parts do not make it into a vehicle. Electrode foil discontinuities must be detected to avoid the potential for internal shorts. A nondestructive method to enhance foil discontinuity detectability in lithium-ion pouch cells via x-ray is presented. Detection via traditional x-ray radiographic approaches is difficult due to the very low contrast between the discontinuity and surrounding region. In this manuscript, x-ray direct radiography was applied to cells with induced foil discontinuities. Contrast enhancement post-processing techniques were employed. Additionally, a deformation-based approach was taken to verify the interpretation of cases where suspected discontinuities appeared as subtle linear indications. Results are presented and discussed.

Keywords: direct radiography, foil tears, battery cells, manufacturing

INTRODUCTION
Lithium-ion (Li-ion) battery cells required for electric vehicles (EV) generally have higher energy density, capacity, and use more materials compared to cells for consumer electronics. As production of EV battery cells scales up, it has become increasingly important to ensure high first-time quality, since the potential safety and cost consequences of a defective cell in an EV can be considerable [1]. Inline and fast-offline nondestructive techniques for quality verification play a crucial role in providing the necessary feedback for controlling the manufacturing process and ensuring defective and non-conforming parts do not make it downstream and into an eventual product [2].

The Li-ion cell is comprised of many layers of anodes, cathodes, separators, and electrolyte. The number of anode and cathode foils can vary depending on the application, e.g.,15 to 50 layers. Once stacked, external leads (tabs) are welded to the layered stack at the bare portions of the current collectors (i.e., foil tabs) for both anode and cathode, as shown in Figure 1. One important defect to inspect for is the presence of foil tab discontinuities in this region. Such discontinuities can be precipitated by a flaw in the manufacturing process or excessively rough handling. It is important to catch this type of defect early to allow for process corrections and scrap reduction. Further downstream, detection is still necessary to prevent a defective cell from being assembled into a battery module / pack and eventually a vehicle.

The line speed requirements in high volume battery cell manufacturing necessitate that any inline nondestructive technique must conform to low cycle time requirements (e.g., < 5s[1]). This requirement rules out techniques such as x-ray computed tomography. Traditional vision is quick; however, inspection is confined to outer layers and cannot observe inner-layer discontinuities. Furthermore, it is highly susceptible to reflections. Once the electrode stack is placed into the pouch, the visual accessibility is removed. X-ray can penetrate the pouch; however, it is difficult to detect these foil tears using direct radiography due to low "contrast resolution." This is primarily due to the very small attenuation differences observed between a torn and untorn foil region. For example, if one foil is torn among 30, a 1/30 difference must be detectable. For ~10um thick copper foils, this may result in an observed gray scale difference of < 2%. This difficulty is increased for the cathode aluminum foils, which are very low density. Note, x-ray attenuation is a complex topic, as a start the reader is referred to the following: [3,4]

[1] The actual cycle time requirements depend on where in the manufacturing line the NDE solution is implemented

A method is presented to enable detection of foil discontinuities via x-ray direct radiography. In this technique, detectability is increased by combining technique optimization and post-processing. In certain cases, a slight deformation may be applied to the cell. Deformation serves one of two purposes, either: (1) to "open" the foil tear faces to reveal or verify interpretation, or (2) reveal discontinuities that would otherwise be hidden by other features. Examples are presented and discussed for cells of various discontinuity types.

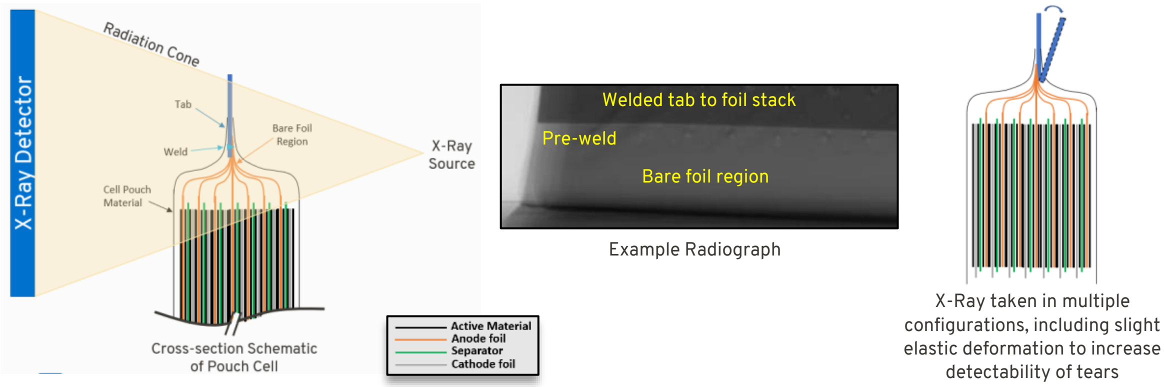

Figure 1. Schematic of direct radiography of pouch battery cell (left) and with slight deformation (right)

SAMPLES, EXPERIMENTAL SETUP, AND RADIOGRAPH POST-PROCESSING

Discontinuities were introduced to foils in Li-ion pouch cells having two different types of welds in this study. A North Star Imaging X5000 (XRayWorX 225 kV microfocus tube and Perkin Elmer 1620/1621 detector) was used to image the samples by maximizing contrast through the foil tab region, as shown in Figure 1. Geometric magnification and NSI's "subPix" acquisition method was used to increase resolution. No physical filter was used in this study. Cells were radiographed in three different conditions: (1) "as-is", (2) minor tab deformation toward the source, and (3) minor tab deformation away from the source. Tab deformation was achieved by sliding a custom 3D printed apparatus over the cell.

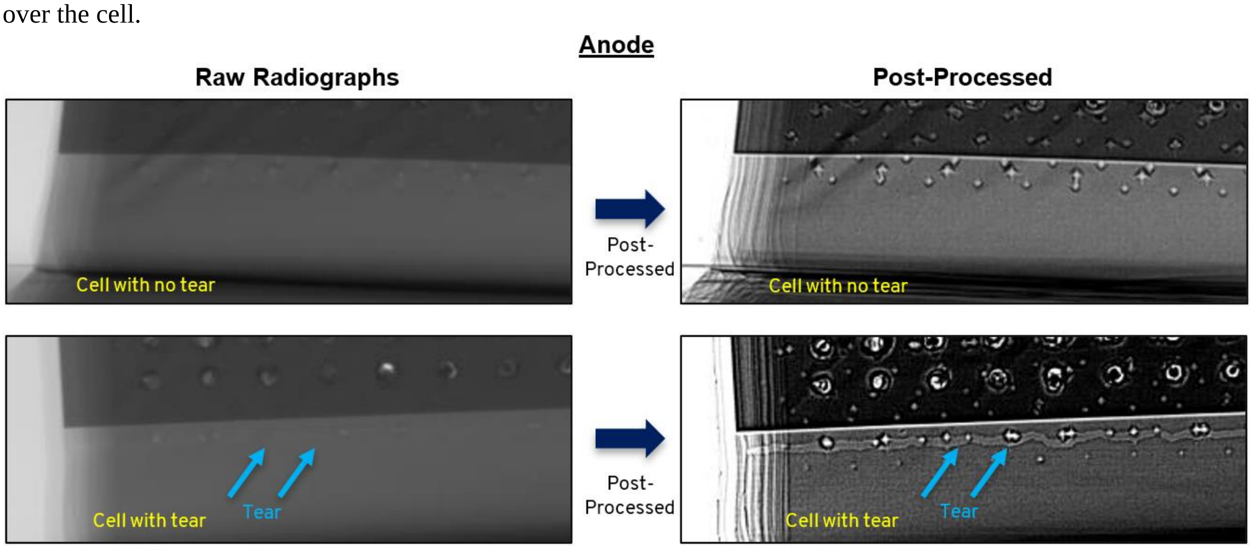

Figure 2. Raw (left) and post-processed (right) radiographs for a reference cell without a tear (top) and a reference cell with a tear (bottom) on the anode.

RESULTS

As previously mentioned, foil discontinuities are difficult to detect in "raw" unfiltered radiographs. It was therefore necessary to post-process the images in the form of window leveling, sharpening, and locally adaptive contrast enhancement. Upon filtering, the discontinuity becomes clear. See Figures 2 and 3 for anode and cathode examples, respectively. The presence of discontinuities was verified with a teardown.

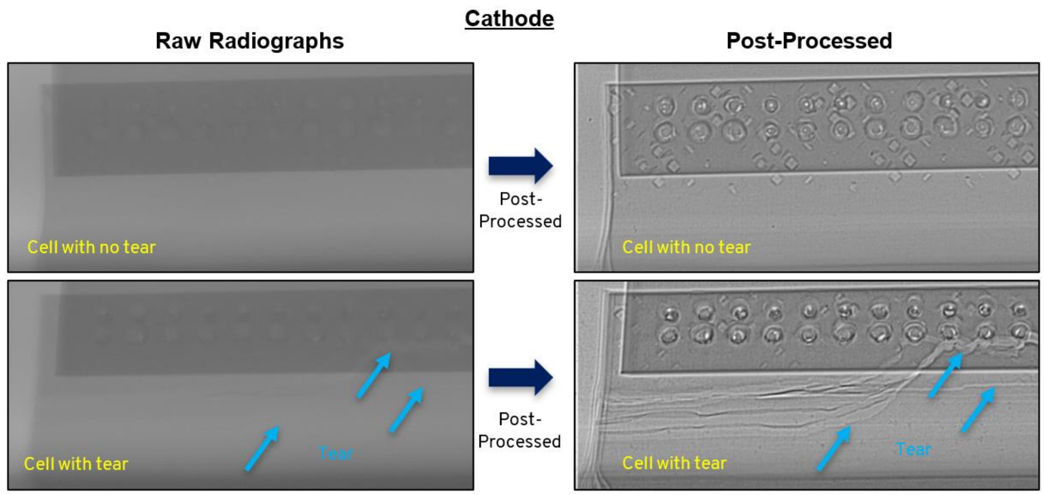

Figure 3. Raw (left) and post-processed (right) radiographs for a reference cell without a tear (top) and a reference cell with a tear (bottom) on the cathode.

If there is thinning in the foil from excessive creasing, it can be difficult to distinguish between a stress concentrator from thinning and a tear. In these cases, a slight elastic deformation was applied to the tab to open the tear and verify the presence. Figure 4 shows an example of a subtle linear indicator, which was verified to be a tear as it opened upon deformation. In other cases, the tear can be closed or obscured by other features, such as the pre-weld or external tab. Figure 5 shows the case where the tear is obscured by the pre-welds, partially obscured by the tab, and closed. Without deformation or post-processing, it is nearly undetectable. The low density of aluminum means that detectability is even more challenging for cathodes as can be seen by comparing the cathode radiographs (Figures 3 and 4) to anode radiographs (2 and 5) [5,6]. At times, deformation reveals that what initially appears to be a discontinuity is not, as in Figure 6, where a crease is resolved upon deformation.

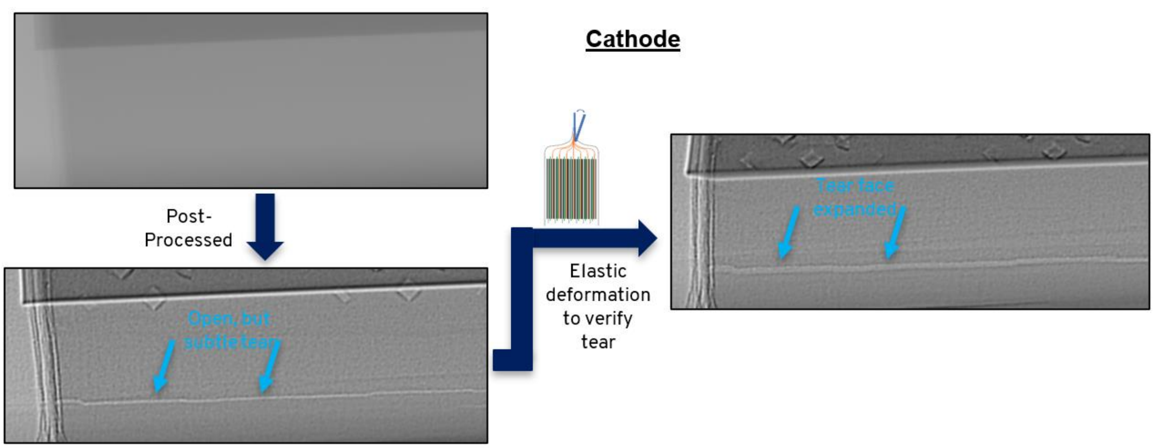

Figure 4. Examples of subtle linear indicators verified as tears by imposing minor deformation in a cathode.

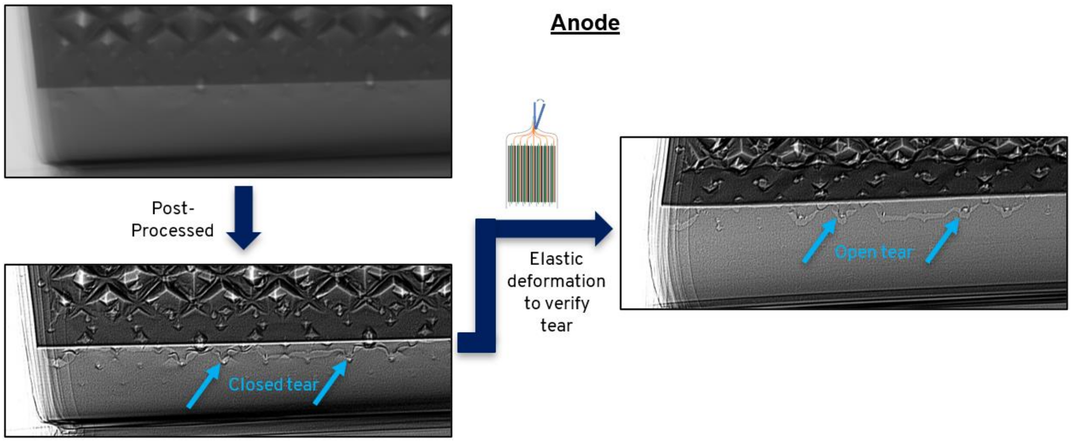

Figure 5. Examples of subtle linear indicators verified as tears by imposing minor deformation in an anode.

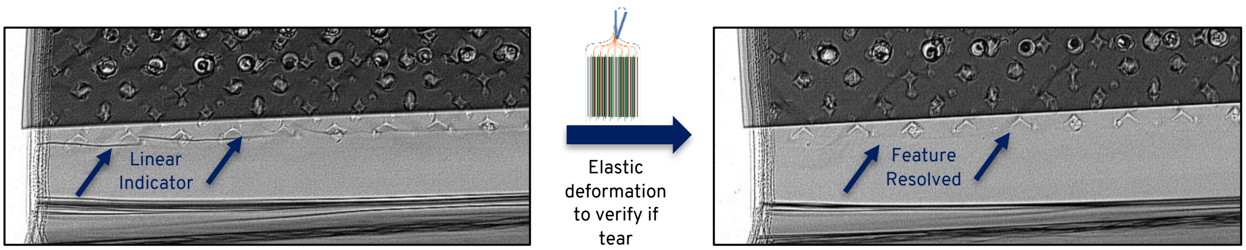

Figure 6. Examples of linear indicators revealed to be a crease, rather than a tear, after deformation.

CONCLUSIONS AND FUTURE WORK

A novel method was presented to increase the detectability of low "contrast resolution" foil discontinuities. Future work will be geared towards increasing the manufacturing readiness, including automating radiograph interpretation via machine learning, designing and building a fast system, and optimizing parameters to achieve quickest scan while still maintaining detectability. Trade-offs between cycle time and image quality / detectability will be explored.

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