WELDING CHARACTERISTICS AND MODELING OF LITHIUM-POLYMER BATTERY FOR ELECTRIC VEHICLE

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Paper Number 13-0143

ABSTRACT

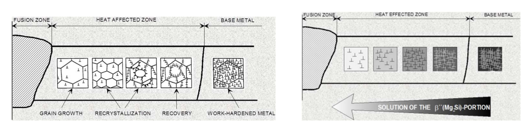
The fatigue life is a major issue of weld joints due to a severe thermal exposure during the welding process. Welded joints experience highly localized heating and cooling from welding processes. As a result, the material properties around the welding joints can be in significant variations after welding. The prediction of fatigue life and crack propagation in welding parts of pouch cell type lithium polymer battery is the main objectives of this study. The series spot welding and laser welding processes between different electrode materials (Cu and Al) were virtually processed using a finite element method and validated against the metallography of welding specimen.

INTRODUCTION

Lithum-polymer battery is mainly used for Rechargeable Energy Storage System(RESS), the main energy source for electrical vehicles. In this study, weld characteristics of spot welded connections between lithium-polymer battery pouch cells for electric vehicles are investigated with finite element modeling. The final objective of welding simulation is to determine fatigue lifecycle at the welding area. In general, fatigue lifecycle at the welding area is vulnerable due to a phase transformation and residual stress induced by thermal effects. [1] In this study, the series spot welding process is used for welding between electrodes materials of pouch cells and virtually processed using a finite element method. The welding characteristics such as material properties and residual stress can be used as initial conditions for fatigue life cycle assessment or crack propagation analysis.

MATERIAL PROPERTIES

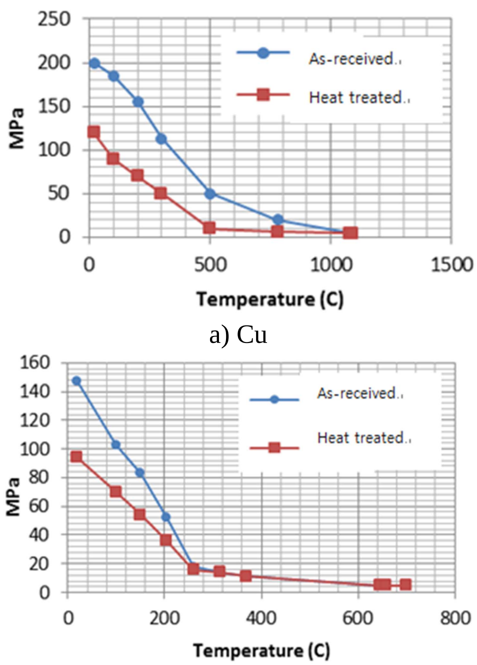
Spot welding is a resistance welding process welded by a contact resistance between sheets and electrodes and a resistance of material to apply current between two electrodes. [2] Sheets are held together under pressure exerted by electrodes. A large amount of heat can be delivered to a very small area and therefore welding occurs without excessive heating to remainder part of components. But heat affected area and molten area are exposed to inhomogeneous heating and cooling process and this thermal cyclic loading brings a metallurgical change such as a phase transformation, recrystallization, re-solution of precipitation. These metallurgical changes effect on mechanical characteristics on the welding area. In case of Cu and Al, typical metals used for electrodes of lithium-polymer battery, a softening due to a recrystallization and re-solution occurs at the heat affected and molten area.[3](See Figure 1)



a) Recrystallization b) Re-solution

Figure 1. Schematic illustrations for recrystallization and precipitation kinetics in Al and Cu alloys during the welding process.

To capture the softening material properties at heat affected and molten zone, specimens of Cu and Al are heat-treated at 500°C and 300°C then cooled in furnace. Tensile coupon test for intact and heat-treated specimens were performed at room and elavated temperature conditions. Yield strength of intact and heat-treated Cu and Al specimens at various temperatures are shown in Figure 2.



a) Cu

b) Al

Figure 2. Comparison of yield strength for intact and heat treated Cu and Al with temperature.

FINITE ELEMENT MODELING OF SERIES SPOT WELDING PROCESS

Schematic diagram for series spot welding process is shown in Figure 3. Electrodes are located in parallel and each contact area can be welded simultaneously with one electrical circuit in a series spot welding process. Unlike a vertical electrical current movement in a conventional direct spot welding process, the electrical current flows through the longitudinal direction of plates in a series spot welding process.

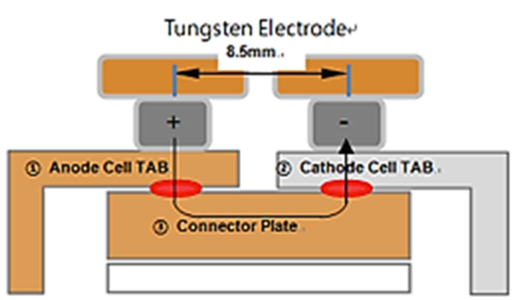


Figure 3. Schematic diagram of electrode for series spot welding.

The thicknesses of Cu and Al sheets are 0.3mm and 0.64mm, respectively. Tungsten electrode with 4mm tip diameter and a DC inverter type with a current profile as shown in Figure 4 which is employed in this study.

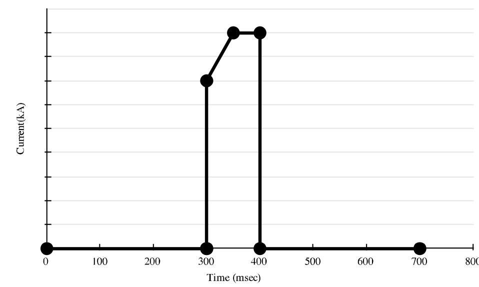


Figure 4. Current profile for Cu-Al welding process.

The spot welding wizard module in SYSWELD [4], which supports a full coupling computation between Electro-Thermo-Metallurgical-Mechanical processes for conventional direct spot welding process, was modified and applied to construct a modeling of series spot welding. Due to a complexity of coupling process between Electro-Thermo-Metallurgical-Mechanical processes of spot welding process, a 2D axisymmetric FE model was assumed and a dummy electrode was introduced to reproduce an electrical current flow in series spot welding process as shown in Figure 5.

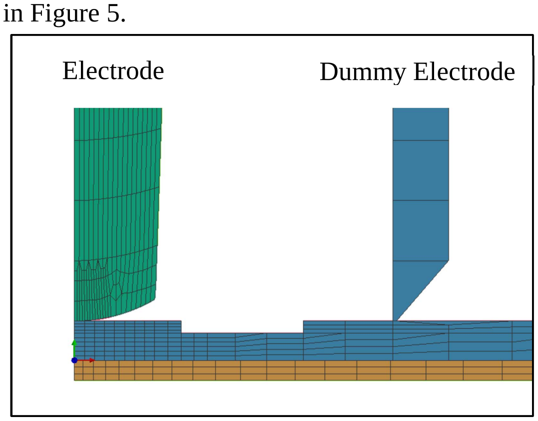


Figure 5. 2D axisymmetric mesh model for series spot welding process.

The main tungsten electrode is modeled at the center of axisymmetric mesh model while a dummy electrode reproducing electrical current flow is placed at the right side. The tip shape of dummy electrode is modified to make same contact area by comparing real and dummy electrodes.

Electrical and mechanical boundary conditions are shown in Figure 6. Electrical current from process condition is applied at the top surface of the electrode and squeezing force is applied at the same surface where the electrical current is applied. For the dummy electrode, an exit of electrical current condition is given on the top surface of and squeezing force is also applied. The thermal and electrical contact resistance is assigned to the interface between electrodes and sheets. Regarding the mechanical contact, a sliding contact method is initially applied to the interface between sheets and electrodes. When temperatures of nodes at the interface exceed the melting point of alloys, the contact method automatically changes from a sliding into a sticking. [5]

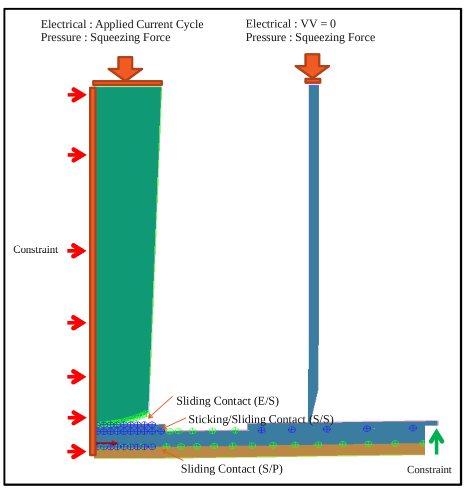


Figure 6. Applied boundary conditions.

RESULTS AND DISCUSSIONS

Validation against experimental results

Electrical potential distribution of a series spot welding process is shown in Figure 7. Electrical potential difference between electrodes is predicted about 1.508V, which is in good agreement with measured range which is between 1.5 and 1.6V.

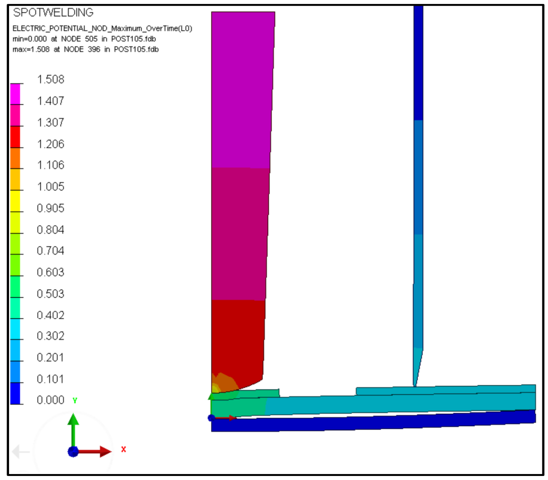


Figure 7. Electrical potential distribution in a series spot welding process.

To verify series spot welding simulation, maximum temperature distribution of whole spot welding cycle is compared with experimental results. The sectioned series spot welding specimen is grinded and polished. To reveal grain structures, the polished surface is etched by a nitric acid solution and analyzed by an optical microscope. (See in Figure 8.) [6]

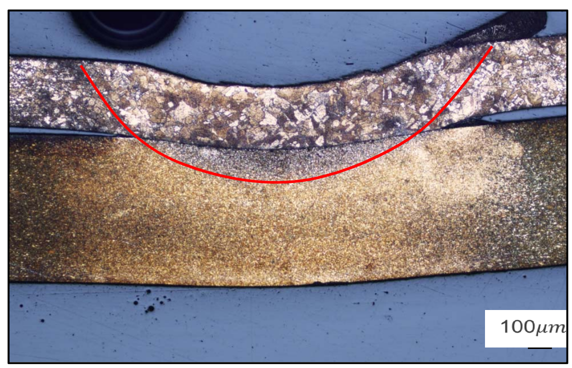


Figure 8. A micrograph of Cu-Cu series spot welding specimen.

More heat is induced at the upper sheet due to a high electrical resistance between tungsten electrode and sheet interface. Therefore the recrystallization and grain growth is observed at the upper Cu sheet. Molten zone shape is displayed with red line in Figure 8.

Predicted maximum temperature distribution of Cu-Cu series spot welding process is shown in Figure 9.

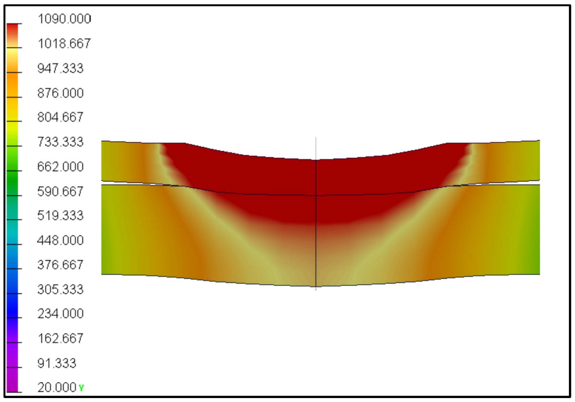


Figure 9. Maximum temperature distribution.

Temperature above melting temperature during welding process is depicted as a red region in Figure 9 and the comparison with micrograph of a specimen Figure 8 is in good agreement.

Series spot welding simulation results

Series spot welding simulations are conducted for 4 welding process conditions of Cu and Al electrode in lithium polymer battery pouch. Phase distribution results are shown in Figure 10 for Cu-Cu-Cu welding process.

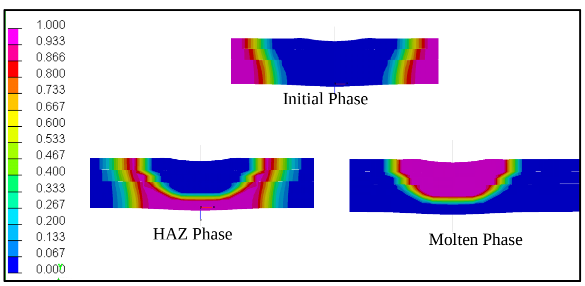


Figure 10. Phase distribution after welding for Cu-Cu-Cu sheet.

Molten zone is created across 3 sheets which ensure that applied electrical current is enough to weld 3 sheets simultaneously. Predicted yield strengths are shown in Figure 11 for Cu-Cu-Cu sheet.

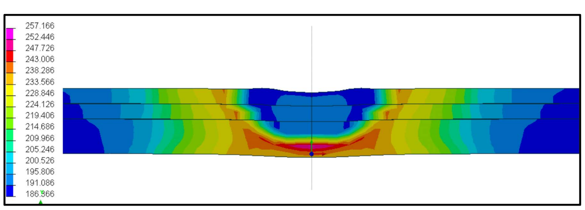


Figure 11. Yield strength distribution after welding for Cu-Cu-Cu sheet.

Because of re-melting and recrystallization in the molten zone, yield strength decreased. But yield strength increased in the heat affected zone due to work hardening effect. Residual stress distributions quantified by Von-mises and longitudinal stress of Cu-Cu-Cu sheet are shown in Figure 12.

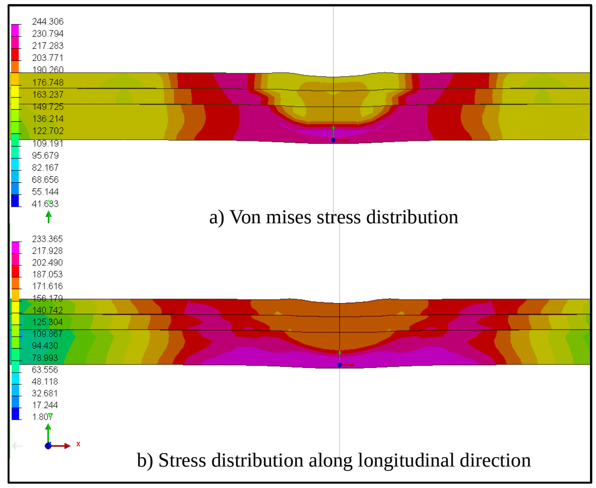


Figure 12. Von-mises stress distribution and stress distribution along longitudinal direction (x) after welding for Cu-Cu-Cu sheet.

A deformation that occurred during welding process from squeezing forces by electrodes and the thermal gradient in heat affected zone is constrained therefore tensile residual stress is observed at longitudinal direction. These material changes occurred at molten and heat affected zone would influence on fatigue life and fracture properties of lithium polymer batteries in service.

CONCLUSIONS

2D axisymmetric finite element modeling method for series spot welding process is proposed. A dummy electrode method is used to simulate electrical current flow in a series spot welding process. Thermo-metallurgical and mechanical characteristics of weld joint between Cu and Al electrodes of Lithium-Polymer battery are computed and validated against experimentally measured electrical potential values, macrographs and hardness values. Computed values with the proposed 2D axisymmetric methods were in good agreement against the experimental results. Further studies to predict fatigue life of weld joint, which take account into welding effect based on this study, are scheduled as a following step.

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