International Journal of Heat and Mass Transfer 69 (2014) 473–480

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Determination of thermal contact conductance between thin metal sheets of battery tabs

Jian Chen [a,*], Wei Zhang [a,b], Zhili Feng [a], Wayne Cai [c]

[a] Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[b] Materials Science and Engineering, The Ohio State University, 1248 Arthur Adams Drive, Columbus, OH 43221, USA.
[c] Advanced Propulsion Manufacturing Research Group, Manufacturing Systems Research Lab, GM Global R&D, Mail Code: 480-106-224, 30500 Mound Rd, Warren, MI 48090-9055, USA

ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form 20 October 2013
Accepted 21 October 2013
Available online 16 November 2013

Keywords:
Thermal contact conductance
Thin metal sheets
Pulsed heating
Infrared thermography

ABSTRACT

A novel method combining experimental test and heat transfer modeling was developed to determine the thermal contact conductance (TCC) between thin metal sheets as a function of contact pressures. In the experiment, thin metal samples were sandwiched between one white light transparent and one infrared (IR) transparent glass disks pressed together under different pressure levels. The metal stack was then heated up from the white light transparent side by an intense short pulse of flash light. The temperature transient on the other side was measured by an IR camera. To obtain a value of TCC, two separate experiments having different layers of thin sheet materials were performed and the values of maximum temperature rise were measured. Numerical heat transfer modeling was used to calculate the temperature evolution in the stack-up comprised of metal layers sandwiched between two glass disks. The heat transfer calculation results showed that TCC had a strong correlation to the ratio of maximum temperature rise between the two experiment configurations, but it was insensitive to the variations of other thermal properties. Thus, for a given pair of metal sheets in contact, a unique correlation between the TCC and the ratio of temperature rise was established using the heat transfer calculation. Such correlation allows the direct determination of the TCC value from the ratio of the experimentally measured temperature rise. The TCC between three types of thin metal sheets (i.e., 0.2-mm-thick Al, 0.2-mm-thick Cu and 0.9-mm-thick Cu) were measured and compared with the available literature data.

Published by Elsevier Ltd.

1. Introduction

Hybrid and electric vehicles have been increasingly gaining interests in recent years. Battery packs, one of the most important components, are assembled by joining multiple battery electrode tabs. Ultrasonic and laser welding are the two most widely used techniques for battery joining. Many investigations including numerical simulations [1–7] have been conducted for better understanding and appropriate designing of the battery joining process. Thermal contact conductance (TCC) between battery tab sheets is an important thermal property involved in the ultrasonic and laser welding of multiple electrode tabs. As a function of a number of factors, including contact pressure, surface roughness, surface coating, stiffness and strength, values of TCC for battery tab materials are not available in the standard reference books. Therefore, it is necessary to measure the TCC for specific combinations of materials and pressure levels relevant to the welding of battery tabs.

There have been many theoretical and experimental studies on TCC measurement [8–13]. Most of the existing methods require the establishment of steady-state heat transfer testing conditions [14]. The major drawback of the steady-state measurement technique is its limitation to long (or thick) samples due to the requirement of embedding thermocouples and installing heat flux meters and heating/cooling devices. For thin solid samples, Ohsone et al. developed a dynamic optical method [15] to measure TCC between wafer-like samples. In their experiment, two rigid and flat optical glass disks were used to transmit contact pressures on to the samples. A modulated laser beam as a heating source was irradiated on one side of the samples and the TCC was deduced from the phase lag of the temperature profile on the other side. However, this method neglected the heat loss from solid samples to glasses, thus resulting in the deteriorated measurement accuracy. Moreover, the measurement apparatus was relatively complicated because of the use of modulated laser heating.

---

* Corresponding author. Tel.: +1 865 241 4905.
E-mail addresses: chenj2@ornl.gov (J. Chen), zhang.3978@osu.edu (W. Zhang), fengz@ornl.gov (Z. Feng), wayne.cai@gm.com (W. Cai).

0017-9310/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.10.042

The present work focused on measuring TCC between thin metal sheets, which were common to battery tabs, under various contact pressures. Since it was not practical to use steady state approach with thermocouples attached on such thin samples, a simple experimental system along with a novel and robust data reduction approach was developed. A special clamping system was used to apply predetermined contact pressure to the metal sheets. The sheets were heated up by an intense pulse of flash light from one side, and the surface temperature transient on the other side was recorded by an infrared (IR) camera. To deduce the TCC value from the measured temperature transient, a quantitative understanding of the temperature evolution during testing was needed. Due to the lack of available analytical solutions to such transient heat transfer problem across multiple metal layers with heat loss to the clamping fixtures, numerical finite element modeling was applied to assist the determination of TCC.

It is noted that one possible method to obtain the TCC value using the numerical model is the “inverse modeling” approach, which essentially relies on the trial-and-error iterations of tuning material properties to best match the simulation result with the experimental measurement data [16,17]. However, application of such inverse modeling to the new measurement system can be difficult due to the large number of unknown thermo-physical properties, especially the thermal contact heat loss to the clamping fixtures, which can significantly affect the determination of TCC at the interface of interest.

A new data reduction approach was developed in which two separate experiments having different layers of thin sheet materials were performed and the values of maximum temperature rise were measured. Through heat transfer simulation of temperature transient during measurement, a series of “Master Curves” – a set of theoretical curves that characteristically correlated TCC to peak temperature rises were established. Using the master curves, TCC between three types of thin metal sheets (i.e., 0.2-mm-thick Al, 0.2-mm-thick Cu and 0.9-mm-thick Cu) were measured for various contact pressures and compared with the available literature data. Moreover, the as-determined TCCs were applied back to the numerical model to simulate the transient temperature histories. The calculated temperature profiles were found to be consistent to the corresponding experimental measurements from IR camera.

2. Method and procedure

The novel experiment and master curve approach developed in this work is illustrated by a flowchart shown in Fig. 1. On the experimental side, the determination of TCC requires performing two separate measurements on two different test configurations, i.e. m layers vs. n layers of metal sheet stack-ups. By varying the applied pressure, the relationship between the $\Delta T_m/\Delta T_n$ ratio and contact pressure can be established, where ΔT_m and ΔT_n are average peak temperature rises near the sample center measured in the two separate experiments. For data analysis, finite element heat transfer simulations corresponding to the two experiments having different sample stack-up configurations are performed to calculate ΔT_m and ΔT_n. As discussed in details later, the heat transfer modeling results show that the value of $\Delta T_m/\Delta T_n$ strongly depends on the TCC and is insensitive to other thermo-physical properties. This finding makes it possible to simplify the data analysis procedure: master curves explicitly representing the relationship between $\Delta T_m/\Delta T_n$ and TCC can be derived systematically by varying the metal-to-metal TCC in the numerical analyses. Finally, combining the experimental measurements with the master curves, the final values of TCC as a function of the contact pressure are then deduced. Details of the experimental apparatus and finite element heat transfer model are described in the following sections.

2.1. Apparatus and experimentation

Fig. 2. depicts the experiment apparatus to measure TCC between thin sheets. Thin layered samples (20 mm in diameter) were sandwiched between an IR-transparent germanium glass and a white-light-transparent sapphire glass. The number of thin layers between the two optical glass disks was purposely varied in TCC measurement. A specially designed clamping device applied a predetermined load through the top and bottom fixtures to the two optical glasses to exert contact pressure onto the samples. The applied pressure was measured by a donut-shaped load cell as shown in the figure. An intense pulse of flash light (Elinchrom A3000 N) was delivered to the bottom side of the metal samples through the sapphire glass. For all the experiments, the same pulse energy was used. The temperature rise on the other side of the metal samples was recorded by an IR camera (FLIR SC655). The size of the orifices for the donut-shape load cell, top and bottom parts of the sample holders was all 10 mm in diameter. In order to increase the flash light energy absorption and the emissivity, the very bottom and very top surfaces of the metal sample(s) that were in contact with sapphire and germanium glasses were uniformly applied with a thin layer of black paint. The paint also minimized the variation of surface conditions to improve the consistency of the measurement results. It is noted that the surfaces on the metal–metal interface were not treated in order to preserve the original surface conditions of materials during the measurement as the TCC is a strong function of the surface conditions. In the experiments, it is assumed that the energy of flash light absorbed in the sapphire glass is negligible because the transmittance of the sapphire glass for the flash light is above 0.9 (Edmund Optics, part No. 43369). In addition, it is assumed that there is a negligible effect of

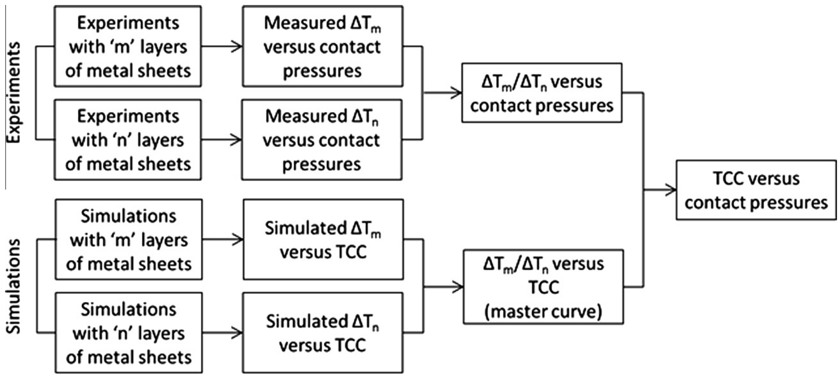

Fig. 1. Flowchart showing the procedure for determining TCC as a function of contact pressure.