Prediction of Brazed Joint Formation for Aluminum Compact Heat Exchanger Applications

F. Gao[¶], H. Zhao, D. P. Sekulic, Center for Robotics and Manufacturing Systems, University of Kentucky; and B. Zellmer, Department of Mechanical and Industrial Engineering, Marquette University, Milwaukee; [¶]Harbin Institute of Technology, Harbin

Introduction

Controlled Atmosphere Brazing (CAB) of aluminum brazing sheets is a process of choice in manufacturing of aluminum compact heat exchangers. Design of joints in CAB brazing, such as the ones between the manifold shell and tubes or between fins and tubes, has been a well-developed engineering art. However, such industrial applications still lack reliable predictive analytical/numerical tools for establishing *a priori* whether a good integrity of the joints would be accomplished. Such tools should be able to predict the outcome of the brazing process independently of trial-and-error empirical tests for a particular application.

This talk deals with a development of a set of deterministic links within the model of a brazing process aimed at *predicting* the required joint volume as a function of the following material/process parameters: (1) cladding ratio, (2) alloy composition, (3) joint configuration, (4) heating ramp rate, and (5) peak brazing temperature, all for a given brazing time, flux, background atmosphere and material temper. The theory behind the prediction is presented elsewhere. In this report, we present in outline form the software platform for joint formation by utilizing materials properties and process parameters.

Joint Formation Model

The basis for the approach was to focus on the amount of cladding which did not flow to the joint, rather then the amount which did. Subsequently, residue formation is linked to joint formation through a numerical modeling of the joint topology [1, 2]. The developed model of residue formation assumes presence of Si diffusion across the clad/core interface, and a near equilibrium, non-eutectic solidification of molten cladding during rapid quench. Silicon diffusion process is analyzed both in the joint zone and far from the joint where the residue has been formed [3]. The residue formation model is based on the description of known Si-depletion and core-metal Si-enrichment phenomena in the vicinity of the clad-core interface [4]. The joint formation model assumes existence of an equilibrium molten metal membrane at the onset of solidification and a negligible shrinkage during solidification. This model also infers surface tension as a dominant joint formation force, and negligible erosion and base metal dissolution. Verification of the model was conducted by performing a series of experiments in order to form both (1) the wedge-tee-shaped joints and (2) real fin-tube and tube-manifold joints for automotive applications, and by comparing these empirical findings with numerically determined joint formations, Fig. 1.

Numerical calculations are based on an in-house developed finite-element code. Experimental material included AA4343/AA3003 brazing sheets with cladding ratios between 5 and 10%. Brazing was accomplished in pure nitrogen using a non-corrosive potassium fluoraluminate flux.

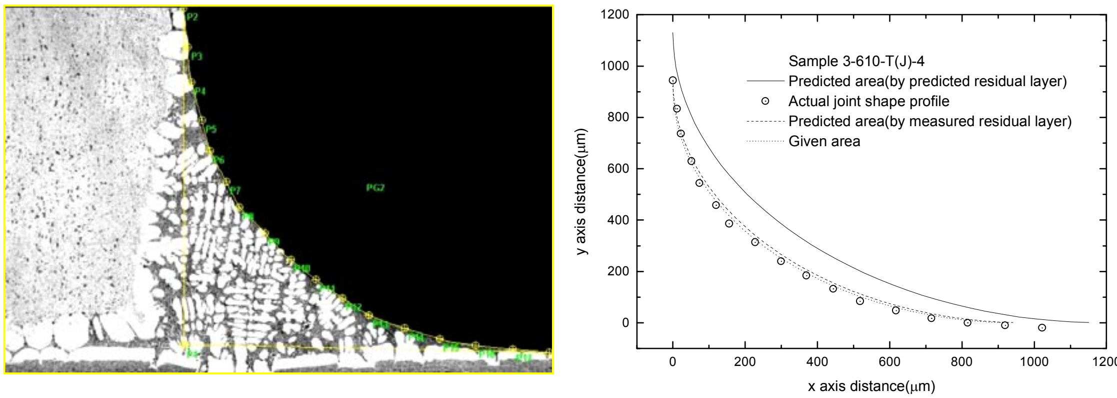

Fig. 1 Verification of the joint formation topology

Software Platform

Integration of the residue and joint formation models into a predictive tool was accomplished by developing an interactive software platform (see Fig. 2) that has the predicted joint topology after brazing as an ultimate output.

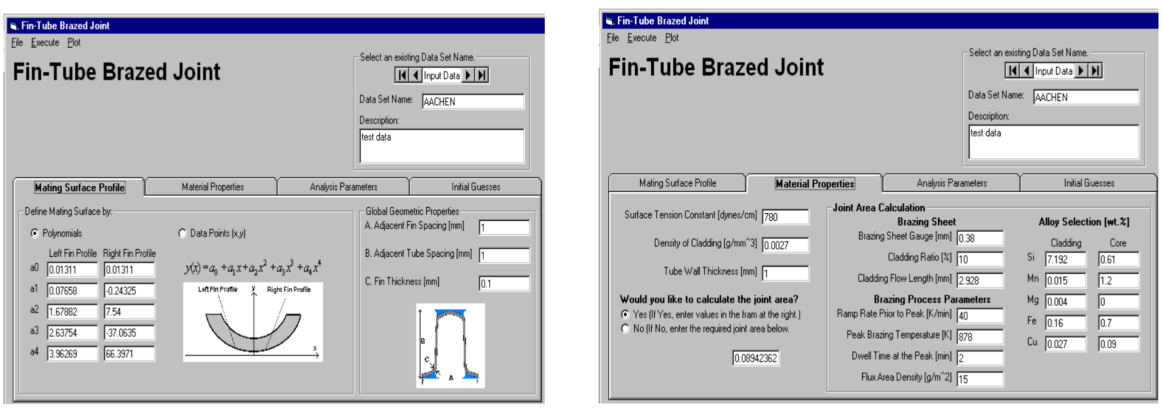

Fig. 2 Interactive software platform

Conclusion

This platform has been developed to support the engineering decision procedure that leads to manufacturing of good integrity joints during CAB aluminum brazing. The software is based on joint formation modeling that requires minimal empirical input, but it is verified by extensive experimentation.

References

[1] Sekulic, D.P., et al. (2001) *Model. Simul. Mater. Sci. Eng.*, Vol. 9, pp. 357-369.
[2] Zellmer, B., et al. (2001) *Model. Simul. Mater. Sci. Eng.*, Vol. 9, pp. 339-355.
[3] Gao, F., et al. (2002) *Mater. Sci. and Eng.*, Vol. A317, to appear.
[4] Sekulic, D.P. et al. (2001) *DVS – Berichte*, Vol. 212, pp. 204 – 219.