Mathematical Modeling of Macroporosity Formation during Laser Welding of Aluminum Alloy 5182

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Introduction

Recent applications of transport phenomena in fusion welding have led to better understanding of the evolution of weld metal geometry in both stationary and linear welds. In addition, weld metal composition changes owing to both evaporation of alloying elements and dissolution of gases can now be understood from scientific principles. Applications of transport phenomena to quantitatively understand the phase composition, grain structure and the inclusion structure in welds of relatively simple alloys are now emerging. While most of these advances focused on the composition, macrostructure and microstructure of weldments, structurally sound welds of desirable weld metal composition often contain defects that make them unsuitable for service. We seek to present new computational and experimental results that demonstrate that applications of transport phenomena can lead to better understanding of the formation and prevention of macro porosity during laser welding of aluminum alloy 5182.

Approach

The modeling approach is based on the fact that during laser welding of thin plates of aluminum alloys, macroporosity is formed when the beam intensity is just above the threshold value for keyhole formation, where the keyhole is unstable. Macroporosity does not form during welding in either conduction mode or in keyhole mode. In the modeling, the keyhole profile was calculated based on point-by-point energy balance on the keyhole wall where the temperature was assumed to be equal to the boiling point of the alloy. The three-dimensional temperature field of the weld pool was calculated based on principles of thermal conduction. A key feature of this model is its ability to determine geometric stability of the keyhole for a given set of welding parameters. The model was used to determine the operating window of welding parameters where a stable keyhole can be formed and macroporosity could be avoided. The model predictions of the stability of the keyhole and weld pool geometry were compared with the experimental data to validate the model. Formation of macroporosity was then linked to lack of stability of the keyhole.

Results

The model was used to predict the stability and geometry the keyhole and the weld pool temperature field during laser beam welding of aluminum alloy 5182. The calculated results of keyhole stability and fusion zone geometry agreed with the corresponding experimental results. The calculation showed that the keyhole was asymmetric during high speed welding. The heat transfer rate at the front keyhole wall was higher than on the rear wall since cooler material was fed into the front wall. Such a difference caused the front wall to be more inclined than the rear wall so that more beam energy was absorbed on the front wall.

When the beam defocusing increased, the welding mode changed from stable keyhole mode to conduction mode. Macroporosity formed in the transition region between the keyhole and conduction mode of welding, where the keyhole was unstable. The predicted welding mode for different beam defocusing agreed with the corresponding experimental results. The model also correctly predicted the different welding characteristics using positive and negative beam defocusing. It was found that the transition from keyhole to conduction mode was more abrupt and the weld pool was deeper for negative beam defocusing than for positive beam defocusing.

Conclusions

A transport phenomena based model has been developed to predict the shape and size of the keyhole and the fusion zone. The model was applied to understand the effects of welding variables on the formation of macroporosity during keyhole mode of welding of aluminum alloy 5182. The calculated keyhole profile was asymmetric with the rear wall being steeper than the front wall. The front wall was more inclined so that more beam energy could be intercepted and absorbed. Negative beam defocusing resulted in deeper keyhole than that obtained with positive beam defocusing. The model can be used to predict the formation of macroporosity during for keyhole mode laser welding of aluminum alloy 5182.