

Weld Pool Geometry and Alloying Element Vaporization during Laser Spot Welding of 304 Stainless Steel

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Introduction

During laser beam welding of many important engineering alloys, selective vaporization of volatile alloying elements takes place from the weld pool surface when the weld pool temperatures are very high. As a result, the composition of the solidified weld pool often differs significantly from that of the alloy being welded. The loss of alloying elements affects the weldment properties. The resulting composition change is especially pronounced in the welding of thin sheets where a small weld pool with large surface to volume ratio is formed. This problem is particularly important since lasers are most commonly used for the welding of thin sheets. Therefore, quantitative understanding of the evaporation rate and composition change is very important in the welding of stainless steels.

The goal of this investigation was to quantitatively understand the effects of laser spot welding variables on the fusion zone geometry, vaporization rate of alloying elements and the resulting composition change of stainless steel from experiments and theoretical modeling.

Approach

The evaporation rate of alloying elements and composition change during laser spot welding of 304 stainless steel was studied experimentally and theoretically. The experiments were performed at the Sandia National Laboratories. A pulsed Nd:YAG laser was used for laser spot welding with varying pulse energies from 1 to 5.5 J, and pulse durations of 2.2 and 7.0 ms. The effects of laser beam power and pulse duration on the weld pool depth, width and the mass loss were investigated. A three-dimensional heat transfer and fluid flow model based on the solution of the equations of conservation of mass, momentum and energy in the weld pool was used to calculate the temperature and velocity fields and the geometry of weld pool. Another model for the calculation of

evaporation rate and composition change was developed based on principles of transport phenomena, kinetics, and thermodynamics. The rate of evaporation and condensation were both considered in the program. The temperature distribution on the weld pool surface obtained from the transient heat transfer and fluid flow model was used in the evaporation model to calculate the vaporization rates of alloying elements driven by both total pressure and concentration gradients. The effects of laser beam power and pulse duration on the weld pool geometry, temperature and velocity fields, and the mass loss were calculated. The experimentally determined fusion zone geometry and the mass loss were compared with the corresponding theoretically calculated values.

Results and Conclusions

The power intensity and the pulse duration were the most important variables in determining the geometry of the fusion zone. The fusion zone geometry produced by the laser spot welding of 304 stainless steel could be predicted from the transient heat transfer and fluid flow model under a wide variety of spot welding conditions. The ratio of the heat transported by convection and conduction, i.e., the Peclet number for heat transfer increased with power density and the duration of the laser pulse. The peak temperature and velocities increased significantly with the deposited power. Depending on the welding conditions, computed temperatures at the weld pool surface were found to be higher than the boiling point of 304 stainless steel. As a result, evaporation of alloying elements was contributed by both the total pressure and concentration gradients. Manganese and iron were the dominant species in the vapor phase. The calculations showed that the vaporization was concentrated in a small region under the laser beam where the temperature was very high. During the heating cycle, the evaporation rate increased significantly with time as the pulse progressed. The computed vaporization rates under all welding conditions were found to be much lower than that of the measured values, perhaps because of the ejection of the tiny metal droplets owing to the recoil force exerted by the metal vapors.