

D. Liquid Metal Expulsion and Alloying Element Vaporization during Microjoining of Stainless Steel with Short Laser Pulse

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Introduction

Laser micro-joining is characterized by its small length scale, fairly short pulse duration, highly transient nature and very high heating and cooling rates. Because of the high power density used, the weld metal is rapidly heated to very high temperatures that often exceed the boiling points of materials. In such situations, the equilibrium pressure on the weld pool surface becomes higher than the atmospheric pressure and the escaping vapor exerts a large recoil force on the weld pool surface. As a consequence, the molten metal may be expelled from the weld pool. Vaporization and liquid metal expulsion are the two main mechanisms of material loss during laser micro-joining. Various factors that affect liquid metal expulsion and alloying element vaporization during microjoining of 304 stainless steel with short Nd-YAG laser pulses were investigated experimentally and theoretically.

Technical Approach

The laser spot welding experiments of 304 stainless steel were performed at the Sandia National Laboratories, with a pulsed Nd:YAG laser with varying pulse energies from 2.1 to 5.5 J. The weld pool geometry, concentration of various alloying elements in the fusion zone and the initiation of liquid metal expulsion were examined both experimentally and theoretically. During experiments, vaporized materials and ejected metal droplets were collected on the inner surface of an open ended quartz tube which was mounted perpendicular to the sample surface and co-axial with the laser beam. The material deposited on the interior wall of the quartz tube was analysed after the weld experiments. In the computational work, the temperature fields used to simulate the loss of materials were obtained from a well-tested comprehensive three-dimensional transient heat transfer and fluid flow model. The time necessary for the initiation of liquid metal expulsion from weld pool surface was determined by comparing the vapor recoil force with the surface tension force at the periphery of the liquid pool.

Results and Discussion

The computational model was validated by comparing the experimental and calculated results of weld pool geometry, mass loss and composition change under different spot welding conditions. In some cases, the computed temperatures at the weld pool surface were found to be higher than the boiling point of 304 stainless steel. The laser power density and pulse duration were found to be the two most important parameters for liquid metal expulsion. The larger laser power density and longer pulse duration increased the tendency of liquid metal expulsion. The sizes of ejected droplets ranged from tens of micrometers to several hundred micrometers. Increase of power density resulted in a larger droplet size.

The conditions necessary for the initiation of liquid metal expulsion could be determined by balancing the vapor recoil force with the surface tension force at the periphery of the liquid pool. The free surface profile of the weld pool was calculated by minimizing the total surface energy. The depression of the mid-region of the weld pool under the recoil force of the vapor stream was correlated with liquid metal expulsion.

Conclusions

The calculated fusion zone geometry, mass loss and composition change produced by laser spot welding of 304 stainless steel under various welding conditions showed fair agreement with the corresponding experimental results. The ejection of metal droplets was predicted by computations and verified by experiments. The conditions necessary for the initiation of liquid metal expulsion was determined by balancing the vapor recoil force with the surface tension force at the periphery of the liquid pool. The expulsion of liquid metal drops increased with the increase in both laser power density and pulse duration. Higher power density also resulted in the ejection of larger droplets.