Rationalizing Machining Tolerances for Laser Weld Fit-up*

G.A. Knorovsky, J.T. Norris, R.A. Roach, E.A. Holm, C.V. Robino
Sandia National Laboratories, Albuquerque, NM 87185

Introduction

We attempt to rationalize fit-up tolerances for laser welds, including edge, butt and lap geometries. Considered are the effects of gap, edge radius, vertical offset and parallelism. Both first principles concepts: energy absorption, volume conservation, surface energy minimization, dynamic motion of the molten zone, and practical considerations are incorporated.

Technical Approach

After summarizing available recommendations from LIA, AWS and ISO, we perform simple calculations on mass conservation, and energy absorption to see what amount of material and laser energy is lost because of less-than-perfect fit-up. We report on some systematic experiments investigating how the resulting welds vary with fitup, and high speed video observations of spot welds that show how weld coalescence and sometimes de-coalescence occur because of the dynamics of weld pool motion. We also report some numerical simulations that show the effect of surface energy.

Results/Discussion

We found that the three major laser welding standards-writing organizations are not in agreement over their fit-up tolerance recommendations. By combining first principles and established practice, we try to justify which limits may be relaxed, and which may not. Simple geometrical calculations of the material not present or the energy not absorbed due to gaps and edge rounding suggest requirements for these tolerances. The effect of surface tension can be thought of as having both static and dynamic effects. In the static case, the liquid ligament which links the maximal fusion zone extent on each part being joined must contain a minimum volume or separation will occur because of surface tension driving it to minimal surface area. However, because of dyamic effects, this criterion can be modified in both positive and negative ways. For example, "sloshing" driven by evaporative recoil pressure may help coalescence across wide gaps. However, "sloshing" may also result in the separation of coalesced gaps as well. Finally, the effects of Marangoni flows are also shown by level-set based numerical computations.

Conclusions

Considerations of molten zone volume, which is related to energy absorption, are used to show functional dependences of gap bridging on the critical machining tolerances. Allowable edge radii and gap recommendations are made which relate to the expected weld size and shape. Edge radii, in particular are much less restricted than usual practice except for very small welds. Finally, in addition to static criteria for gap bridging stability, dynamic considerations are also found significant.

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000