C. The Role of Pressure in Welding (and Cutting) Processes*

by G.A. Knorovsky and D.O. MacCallum, Sandia National Laboratories, Albuquerque, NM 87185

Introduction

While not having been considered to be a primary factor in the past, the role of pressure induced by heat sources in welding is becoming more appreciated as an influence on the fusion zone shape and size. This is particularly evident in high energy density processes such as laser or e-beam, or plasma arc welding or cutting. In this work we will evaluate from theoretical sources and experimental results the range of magnitude of force causing fusion zone geometry modification and compare it with resisting forces such as surface tension, applied forces and gravity, for a variety of welding processes.

Technical Approach

We examine various welding processes, including RW, OFW, consumable and non-consumable arc (GTAW, GMAW, PAW, PEW), LBW, and EBW to determine the physical sources of and magnitudes of pressure generated by the process. We then compare these with the resisting forces that act to keep the fusion zone as a compact volume. This comparison is then used to evaluate conventional wisdom about how important the effect of heat source-induced force is in modifying the final fusion zone shape and size. Pulsed (or AC) vs continuous (or DC) process variants are compared where appropriate. Alloys of low and high vapor pressure are also compared, as are different size regimes of fusion zones (macro vs microwelding).

Results/Discussion

For high energy density processes such as pulsed and cw laser or EB welding and cutting, it is now known that non-equilibrium (i.e. unbalanced) recoil-pressure driven metal flow caused by the high rate of evaporation under intense beam irradiation is the most predominant modifier of the fusion zone, creating deep keyholes, which particularly for the laser process, enhance laser energy absorption by creating a black-body-like cavity which directs energy directly to the bottom of the cavity, enhancing its ability to penetrate. The magnitude of the pressure which can be created by this effect is up to several atmospheres, as compared with the few psi which can be created by surface tension or metallostatic heads. However, when extrapolations of the process are examined, such as welds of a few microns extent, the balance between the interacting forces can be substantially changed, with surface energy playing a much larger role. Other issues include pulse rate vs natural period of the fusion zone, and spatial modulation of the beam. A further consideration will be the propensity of the heat source-induced pressure to form weld discontinuities. Particularly interesting scenarios include "spiking" in EB or laser deep penetration welds, and spatter in consumable arc, RW and PEW processes.

Conclusions

While the effect of heat source-induced pressure on the fusion zone has become increasingly appreciated with respect to high-energy-density beam processes, we examine how important the effect is in a variety of other common welding and cutting processes relative to pressure-retaining phenomena and how it may affect fusion zone final geometry and defects.

* 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