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HEAT FLOW IN VARAIBLE POLARITY PLASMA ARC WELDS

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INTRODUCTION

The space shuttle external tank and the space station Freedom are fabricated by the variable polarity plasma arc (VPPA) welding. Heat sink effects (taper) are observed when there are irregularities in the work-piece configuration especially if these irregularities are close to the weld bead (1). These heat sinks affect the geometry of the weld bead, and in extreme cases they could cause defects such as incomplete fusion. Also, different fixtures seem to have varying heat sink effects.

The objective of the previous (1), present and consecutive research studies is to investigate the effect of irregularities in the work-piece configuration and fixture differences on the weld bead geometry with the ultimate objective to compensate automatically for the heat sink effects and achieve a perfect weld.

TAPER DURING WELDING

By taper is meant the convergence or divergence of weld diameter. In the present situation, both the crown and the root diameters, are taken to diverge or converge simultaneously.

When welding conditions are set constant, taper is particularly observed when there are irregularities close to the weld bead. Measurements of weld beads of plates with ridges, protuberances and step close to the weld beads showed decreases in weld diameters sometimes as much as 23.5% (1).

It had been thought that as welding progresses, the work piece effective ambient temperature (measurable at the edge of the plate on the same horizontal line as the power source) would rise, thus raising the temperature with respect to melting at the weld and pushing out the melting isotherm to create taper (divergence in weld bead). But taper was not observed (1) on weld beads on quarter inch flat plates, insulated except for the edges and the torch path. Taper was not detected even for the narrowest plate, where weld diameters were measured with a microscope (1). Thus, to fully understand the mechanisms of heat flow during welding, the following experiments were performed.

EXPERIMENTS

One pass, bead on plate welds were performed on two vertical plate configurations. The first configuration is flat plate 61 x 20.3 x 0.64 cm (24 x 8 x 0.25 in). A matrix

RESULTS AND DISCUSSION

The temperature profile in the vicinity of the torch, i.e. from the start of melting through the width of the plate is shown in Figure 1. The location of the liquidus point (643 C) and the solidus point (543 C), were determined by examining macroscopically treated specimens under the microscope.

Figure 2 a, b, c, and d shows the raw data, for the first configuration, for the bottom, middle front (facing the torch), middle back, and the top rows of data, respectively. Figure 2 represents the temperature rise from the start of welding to the end for each thermocouple, i.e. it shows the temperature rise for stationary locations as the torch moves. Examining the locations aligned parallel, close to the bead, it is observed that before the torch approaches any one of these locations there is a very small temperature rise. But as the torch becomes almost in the vicinity of that location there is a sudden sharp temperature rise which drops less abruptly as the torch moves away and levels up giving an average temperature higher than the initial plate temperature. The thermocouples were scanned once every 10 s, i.e. every 4.65 cm (1.83 in). This did not allow recording the thermocouple reading when the distance between it and the torch was the shortest. But, the bottom thermocouple (TC 1) recorded a temperature reading when the torch passed it with 0.254 cm (0.1 in), and this was the highest reading recorded for any thermocouple location as you can see comparing Figure 2 a, b, c, and d. Examining the locations parallel and farther from the weld, a gradual increase in temperature is noticed before it levels off.

As mentioned in the previous paragraph abrupt elevation in temperatures are observed only in the close proximity of the torch. This was also supported by thermography as seen in Figure 3, where the temperature isotherms have an elliptic shape.

The scatter in the power estimates made using the moving line source were within the expected order of magnitude behind and in the immediate vicinity of the torch. A power transfer efficiency of 39 % was obtained in the vicinity of the torch. Care should be exercised in estimating the power from the temperature field in front of the power source (torch) as these are very sensitive to uncertainties in physical properties and temperature measurement errors. Some of these locations ahead of the power source recorded a rise in temperature of 2.5 C, while the measurement error limit is 2.2 C. To illustrate the sensitivity to physical properties a decrease of 15 % in the thermal diffusivity at a location 1.5 cm beside the weld center and 1.4 cm. ahead of the power source shows an increase of 13 % in power, while for the same conditions if the distance ahead of the center of the power source was 2.8 cm. an increase of 95 % in the power calculated. But estimating the temperature field using the moving line source equation for a power absorption of 1.65 kW gave similar temperature field to that determined experimentally.

Rough estimates of natural convective losses, and thermal radiation from the plate are not large, e.g. natural convection at a constant plate temperature of 127 C is less than 10 % of the power absorbed by the work piece.

CONCLUSIONS

The average temperature rise of the work-piece was contained in the temperature hump behind the torch. The temperature field of a VPPA weld on a one pass bead on flat plate is similar to that for a moving point source on an infinite plane.

There was negligible change in the effective ambient temperature of a flat plate. Consequently, there is no measurable taper in weld width.

Power estimates made using the moving point source solution are reasonable in the vicinity of the power source, although power estimates from the temperature field in front of the power source are too sensitive to uncertainties in physical properties and temperature error to yield useful value.

Natural convection and thermal radiation losses from the work-piece outside the puddle are not large (according to rough estimates).

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