Technical Note: Effect of Weld Pool Configuration on Heat-Affected Zone Shape

BY S. S. GLICKSTEIN AND E. FRIEDMAN

ABSTRACT. Irregular weld bead configurations resulting from the gas tungsten arc welding process have been observed and reported in the past for many different welding conditions. Although it would be expected that the outer boundary of the heat-affected zone would also have an irregular shape if that boundary were in close proximity to the weld metal, it has been observed that for stationary arc welds with alloy 600 material that the heat-affected zone consistently has a regular ellipsoidal shape.

A finite element heat conduction model was employed to demonstrate that the mechanism of conduction heat transfer is sufficient to completely damp out the effect of the weld bead irregularity on the shape of the isotherm representing the boundary of the heat-affected zone. An anomaly that has existed for some time has, therefore, been rationalized with the aid of computer modeling of the welding process.

Introduction

In the course of performing stationary gas tungsten arc welds on Inconel alloy 600 plates, irregularly shaped weld bead heat-affected zone interfaces were observed from photomicrographs of weld cross sections. Typical weld bead and heat-affected zone configurations are presented in Fig. 1. The irregularly shaped interface was unexpected and paradoxical. The shape of the interface is in conflict with results obtained from a heat conduction analysis used to calculate isotherms in the weldments and to predict the shape of the molten weld pool during stationary gas tungsten arc welding.1

In the first reference, it was conjectured that weld pool motion (in particular the circulation of two weld puddles3-4) during the stationary arc welding of alloy 600 may be the cause of
the "humped" configuration of the boundary between the weld bead and the heat-affected zone shown in Fig. 1. It is also believed that this irregularly shaped boundary denotes the farthest extent of the melting isotherm during welding. For alloy 600, the melting temperature is between 1355 and 1400°C (2471 and 2552°F). Most recently Savage et al. have reported similar observations and have associated this "humped" weld bead with the effect of arc pressure.

Regardless of the cause of such a peculiar bead shape, it is intuitively not apparent why the boundary between the heat-affected zone and the base metal is not irregularly shaped as well, since it is located a short distance from the irregularly shaped weld metal/heat-affected zone interface (Fig. 1) and would, therefore, be expected to be affected by the humped weld bead configuration. However, photomicrographs of stationary arc welds in alloy 600 plates show a smooth, ellipsoidal contour outlining the heat-affected zone. This is clearly illustrated in Fig. 1. Informal discussions of these observations at recent technical meetings have produced no definitive explanations as to why the heat-affected zone boundary is ellipsoidal.

To help explain this anomaly and thus provide a basis for understanding the observations, thermal calculations designed to simulate conduction heat flow conditions in the base metal and heat-affected zones of an alloy 600 weldment were performed. The results of these calculations are consistent with the observations of an ellipsoidal boundary demarcating the outer region of the heat-affected zone and provide a rational explanation for such observations. This brief note summarizes these results.

**Calculational Model**

A finite element analysis computer code was employed to calculate the heat flow in the heat-affected zone and base metal region of an alloy 600 weld plate. Heat input boundary conditions representing the existence of an irregularly shaped molten weld pool boundary resulting from a stationary heat source were used. The heat conduction equation for the axisymmetric temperature distribution $T(r,z,t)$ is given by:

$$\frac{\partial^2 T}{\partial r^2} + \frac{\partial^2 T}{\partial z^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

where $\alpha$ is the thermal diffusivity of the material.
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Weldability and Fracture Toughness of 5% Ni Steel

Part 1: Weld Simulation Testing

by A. Dhooge, K. Ostyn, W. Provost, and A. Vinckier

This paper describes an investigation on the weldability of a double normalized and tempered 5% Ni steel using weld simulation to estimate the heat-affected zone (HAZ) ductility at cryogenic temperatures. Charpy V- specimens were subjected to various weld simulation cycles and heat treatments and subsequently broken at a range of cryogenic temperatures.

Part 2: Wide Plate Testing

by A. Dhooge, W. Provost, and A. Vinckier

This paper describes the results of wide plate tensile tests on 25 mm thick welded 5% Ni steel plates in double normalized and tempered condition. The base metal and welded test specimens, containing 6 to 30 mm long through-thickness notches, were tested at temperatures ranging from -90°C to -165°C.

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