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ORIGINAL PAPER

Thermal and fluid flow modeling of the molten pool behavior during TIG welding by stream vorticity method

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Abstract

The present paper deals with the numerical simulation of weld pool development in Tungsten Inert Gas (TIG) process. A mathematical model is developed in order to solve the Navier–Stokes equations expressed in the stream–vorticity formulation coupled with heat equation taking into account the liquid solid phase change. Using the stream–vorticity formulation in incompressible fluid flow, the same problem is solved with reducing the number of transport equations. Therefore, only one transport equation (vorticity) and one Poisson equation (stream) are considered in this model. The FORTRAN programming and the numerical simulation are then achieved using appropriate discretization that ensures the convergence of the numerical methods to solve a large and sparse linear algebraic systems. Furthermore, to solve the radiation phenomena during welding described by the Stefen law, another method is proposed. The obtained numerical results are discussed and validate with experimental.

Keywords Thermal and fluid modeling · TIG welding · Stream vorticity · 304L steel · Numerical simulation

1 Introduction

The TIG welding is an assembly process by an electric arc. During welding, several physical phenomena occur, such as heat transfer, hydrodynamics, metallurgical transformation and electromagnetic phenomena; these ones have great effect on the microstructure and the morphology of the weld pool zone which affect the weld quality. Indeed, during the TIG welding, the weld pool is the location of a strong thermal gradient where temperature variation is very large; this variation ranges between the melting temperature of the metal on the edges of the weld pool and under the vaporization temperature of the metal in the center of the weld pool. This creates weldability problems such as: cracking solidification, appearance of porosity and the effect of residual stresses [1, 2] due to the occurrence of risk zones, denoted the fusion zone (FZ) and the heat affected zone (HAZ), respectively. Lant et al. [1] indicated that the development of appropriate procedures is still an interest in weld repair, in order to extend the lifecycle of defective welded components beyond the temporary repair policies. Peng et al. [3] used a new image processing method to calculate and estimate the crack growth of an aluminum alloy weld. Therefore, through the development and improvement of technologies in order to solve welding problems, several tracks are followed; among them are predicted by mathematics and simulation.

Unfortunately, the mathematical models describing the physical phenomena are very hard to solve by an analytical way; consequently, it is the reason why numerical simulation have been used. Several research works as Varghese et al. [4] highlighted an increasing interest on numerical computation as a technique giving more knowledge and understanding of the welding processes and related the effects of the physical phenomena.

Thus, the simulation of the heat transfer and fluid flow in the weld pool has been the subject of various research works. In this work simulation results are compared with the ones presented below. Atthey [5] was one of the first to study the flow patterns in a hemispherical weld pool to determine the heat transfer during TIG welding process; by considering the electromagnetic force as the main

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