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Simulation of a Gas Tungsten Arc Welding Process in COMSOL

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Abstract

The purpose of this project is to model the transport phenomena (heat transfer, fluid flow, and current flow) in a gas tungsten arc welding (GTAW) process using COMSOL Multiphysics. The model development will start with developing two separate models – an arc model and a weld pool model and end with an integrated arc – weld pool model to simulate the interaction between the arc and the weld pool. The integrated arc-weld pool model will be used to study the effects of some welding process parameters, such as the anode materials, the arc length, and the shielding gas, on the final weld quality.

Introduction

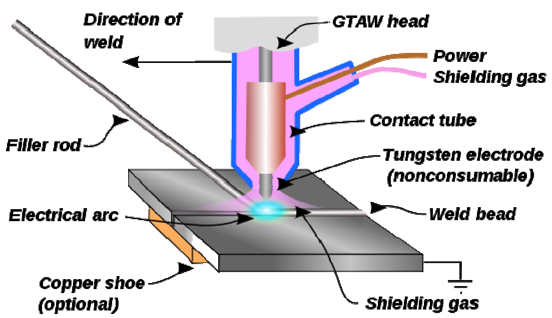

Fig. 1. A schematic sketch of a GTAW process [Wikipedia].

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas (usually an inert gas such as argon), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma. It is widely used in aerospace and other industries to join thin metals and repair tools and dies.

GTAW is a very complex process, involving many welding process parameters, such as welding voltage and current, electrode size and electrode tip shape, shielding gas nozzle size and gas flow rate, material properties, arc length, etc. Therefore, a component design and its material selection and assembly often rely on the previous experience of engineers; the process is long and expensive due to its trial-and-error nature. With pressure to reduce product development time and production costs and, at the same time, improve weld quality and lower energy consumption, aerospace companies are resorting to welding simulation tools to predict the effects of the welding process on components and to optimize and control the welding process.

Mathematical Formulation of Arc Model

Electromagnetism

The current density $\vec{j}$ and the electrical field $\vec{E}$ are calculated from the electrical potential V and magnetic potential $\vec{A}$ using the following relations:

$$\vec{E} = -\nabla V - \frac{\partial \vec{A}}{\partial t} \qquad \vec{j} = \sigma \vec{E} \qquad \vec{B} = \nabla \times \vec{A}$$

Fluid Flow

Conservation of mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

Conservation of momentum

$$\rho\left(\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v}\right) = -\nabla p + \mu \nabla \cdot (\nabla \vec{v} + {}^{t}\nabla \vec{v}) + \vec{j} \times \vec{B} + \rho_0 \vec{g} + w_p \rho_0 \beta (T - T_{ref}) \vec{g}$$

Heat Transfer in Fluid

Energy conservation

$$\rho C_p^{eq}\left(\frac{\partial T}{\partial t} + \vec{v} \cdot \nabla T\right) = \nabla \cdot (\lambda \nabla T) + \vec{j} \cdot \vec{E} + \frac{5 k_B}{2e} \vec{j} \cdot \nabla T - (1 - w_{p)}) \cdot 4\pi \varepsilon_N$$

Computational Domain and Sample Result

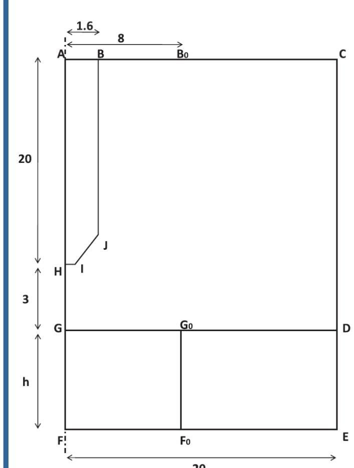

Fig. 2. Computational Domain (top) and sample result (bottom) [Traidia and Roger].

A. Traidia and F. Roger, Numerical and experimental study of arc and weld pool behaviour for pulsed current GTA welding, International Journal of Heat and Mass Transfer, 54 (2011) 2163-2179.