Simulation and Visualisation of Shielding Gas Flows During Wire-Arc Additive Manufacture

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Abstract

One of the challenges associated with the wire-arc additive manufacture (WAAM) of metals is to provide adequate inert gas shielding, not only for the molten pool, but also for the long reactive metal surface that follows it. For Ti-6Al-4V, it has been shown that increased levels of porosity, a direct consequence of air contamination, result in reduced structural properties, lower fatigue strength and a reduced threshold for crack initiation. We present magneto-hydrodynamic (MHD) flow modelling of plasma arc welding (PAW) in the context of WAAM to analyse the local shielding conditions.

A 2D axisymmetric geometry is used to represent the PAW torch, printed wall and Ar/air gas. By nature, MHD is a multiphysics phenomenon which requires an interlinked set of equations to be solved simultaneously. The Heat Transfer Module is therefore coupled with the Turbulent Flow, (SST) physics interface of the CFD Module, which allows non-isothermal flow modelling of the plasma jet, accurately capturing conductive, convective and radiative phenomena. Through the AC/DC Module, the electric currents interface is used to solve for the current in the plasma and electrodes, giving input to the Magnetic Fields physics interface, which calculates the self-induced magnetic field. The electromagnetic problem is coupled with the non-isothermal flow through domain contributions of electromagnetic heating and Lorentz forces.

The properties in the Ar/air gas domain, treated as a multicomponent plasma in local thermodynamic equilibrium (LTE), are input as a function of temperature and mass fraction. The above modules are therefore implicitly coupled with the species transport interface, which allows the calculation of air concentration in the gas domains.

Steady state solutions were generated using the double dogleg solver, which is well suited for this highly nonlinear set of equations. The model was utilised to characterise the effect process settings have on the printing conditions and Ar coverage of the part. It was shown that with the increase of arc current and plasma gas flowrate, apart from a non-linear response in temperature, velocity and pressure, higher Lorentz forces develop in the plasma jet which lead to higher air mass fractions in the jet. The amount of air entrainment in the plasma jet was determined for different part geometries. The model showed that during the deposition of wall structures, the stagnation of the main jet flow resulted in side jet formation at the edges of the build. Increased air mass fractions near the melt pool were predicted as a result of flow recirculation and turbulence build-up at the sides of the walls. Simulation of multilayer walls of increasing width showed that flow

separation occurs at different angles, potentially affecting the convective heat transfer in the part.

Visualisations of the shielding gas flow from a PAW torch in a WAAM setting through schlieren imaging are presented, used as a method of validation for the model. The observed side jet inclinations, flow features and turbulence levels show good agreement between experiment and simulation. The predicted variables in the MHD model promote process understanding and allow meaningful interpretation of the imaged refractive index gradients.

Figures used in the abstract

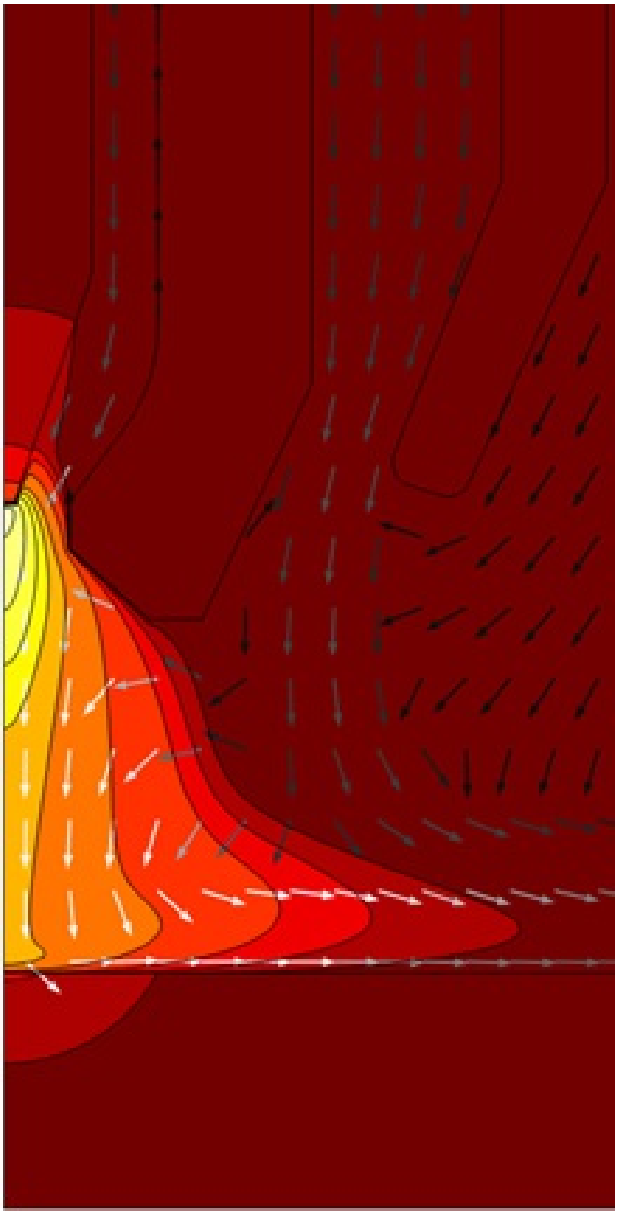

Figure 1: 2D axisymmetric temperature profile and shield gas velocity vectors from plasma arc welding torch during wire-arc additive manufacture.