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Coupled computational models of the arc plasma and the metal in wire-arc additive manufacturing

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Wire–arc additive manufacturing (WAAM) is a form of metal 3D printing in which an arc plasma melts a wire, depositing metal layer-by-layer [1]. WAAM is used to produce large parts with dimensions up to 1 m or more. Computational modelling of WAAM is challenging because of the many physical processes involved and the large difference between the part's dimensions and those of the arc and melt pool. The most widely adopted approach is to solve the heat transfer equation in the solid metal using finite element analysis (FEA). An artificial heat source is used to approximate the influence of the arc and the melt pool. While this approach is straightforward, calibration of the heat source requires costly experiments for every significant change in process parameters (e.g., arc current, travel speed, metal alloy); the heat source also changes from layer to layer. In addition, the height and width of each layer have to be estimated.

We present two multiscale approaches that substantially reduce the requirements for experimental calibration. In both approaches, we use a three-dimensional magnetohydrodynamic (MHD) model of the wire, arc and melt pool to calculate the heat transfer to the workpiece. The MHD model can also predict the shape of each added layer and the size and temperature of the metal droplets produced when the arc melts the wire. The model is an extension of a previously developed MIG/MAG welding model [2] and is run in steady-state mode to reduce computational time.

In the first approach, the heat flux and layer geometry predicted by the MHD model are coupled to an FEA model that calculates the heat transfer and residual stress in the workpiece. An example of the heat flux is shown in Figure 1, and an example of the residual stress is given in Figure 2. Combining the MHD and FEA approaches allows time-dependent modelling of the production of large parts.

In the second approach, the heat flux and the droplet size and temperature are used as the input to a smoothed particle hydrodynamics (SPH) model of the melt pool and workpiece. SPH can simulate the time-dependent impact of the droplet on the melt pool, and the flow dynamics and solidification of the molten metal.

The benefits of each approach will be assessed, and the predictions will be compared with experimental results in the literature.

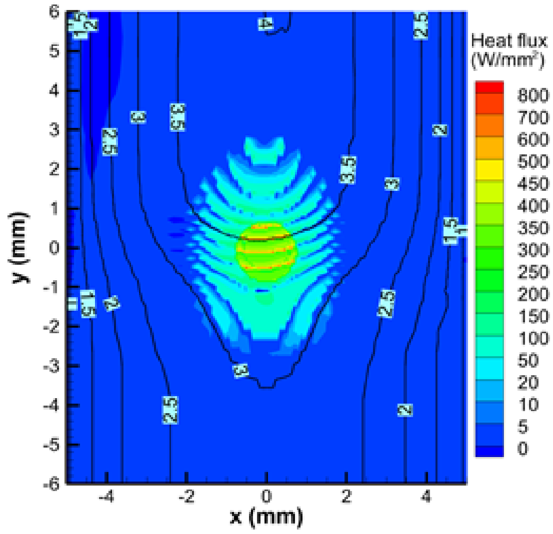

Figure 1: Calculated distribution of the heat flux to the workpiece surface during deposition of the fourth layer for the parameters of Zhao et al. [3]. The contour lines indicate the build height above the original substrate surface in mm. The arc is moving in the –y direction.

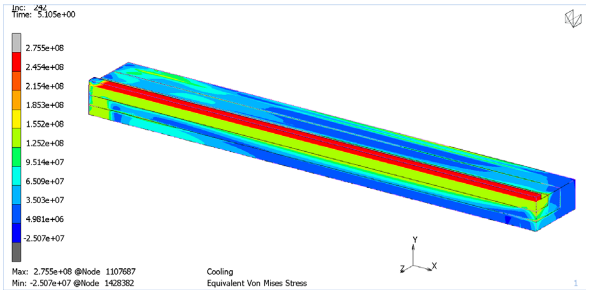

Figure 2: Von Mises stress distributions predicted by the coupled MHD-FEA model after deposition of the first layer. The scale is from 0 to 270 MPa in 27 MPa increments. The substrate is 51 mm long × 21 mm half-width × 6 mm thick.

References
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