Three-dimensional computational modelling of MIG welding†

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1. Introduction

There are several difficulties involved in modelling of MIG (metal–inert-gas) welding. The motion of the wire and arc relative to the workpiece has to be taken into account. The geometry is three-dimensional, due to the motion of the arc. The flow in the molten weld pool, and in particular the deformation of the surface of the weld pool, require careful treatment. The transfer of droplets from the wire electrode to the weld pool also has to be considered.

Computational models of arc welding of varying degrees of sophistication have been developed, but no comprehensive treatment of MIG welding that addresses all the difficulties listed above has yet been developed. In this paper, I outline progress towards developing such a model and present representative results. I discuss in particular the influence of weld pool surface deformation and of droplets on the weld depth.

2. Methods

The equations of conservation of mass, momentum, energy and charge, together with Maxwell's equations, are solved in three-dimensional Cartesian geometry using a finite volume method. Motion of the wire anode and arc relative to the workpiece is taken into account using the method described in [1]. An equilibrium surface method [2] is used to treat the deformation of the surface of the weld pool due to the arc and droplet pressure and the addition of mass through droplet transfer. The mass and momentum transferred to the weld pool by droplets is calculated on a time-averaged basis. The temperature and velocity of the droplets are tracked from the initial detachment to the bottom of the weld pool [3].

Results are presented for steady-state calculations with an initially flat workpiece (i.e., bead-on-plate welding), argon shielding gas and aluminium alloy electrodes. The thermodynamic and transport properties of argon were taken from [4].

3. Influence of Molten Weld Pool and Droplets

To determine the shape of the weld pool, it is essential to take into account flow in the weld pool, deformation of the weld pool surface, and the influence of droplets. The results presented in this section have been obtained with all three phenomena included in the model. Calculations were performed for parameters typical of one-drop-per-pulse welding of aluminium, which are given in **Table 1**.

Figure 1 shows the temperature distribution in a cross-section through the electrode, arc and workpiece. The presence of a reinforcement of the weld pool due to droplets is clearly apparent. The arc tends to attach to the raised region, and thus this region is the hottest in the weld pool.

Table 1 Parameters used for the calculations

Parameter	Value
Arc current	95 A
Wire electrode radius	0.6 mm
Welding velocity	15 mm s^{-1} in negative *y* direction
Wire electrode feed rate	72 mm s^{-1}
Droplet frequency	93 Hz
Workpiece thickness	3 mm (on a 50 mm base)
Workpiece and wire composition	Aluminium alloy AA5754, melting temperature 875 K

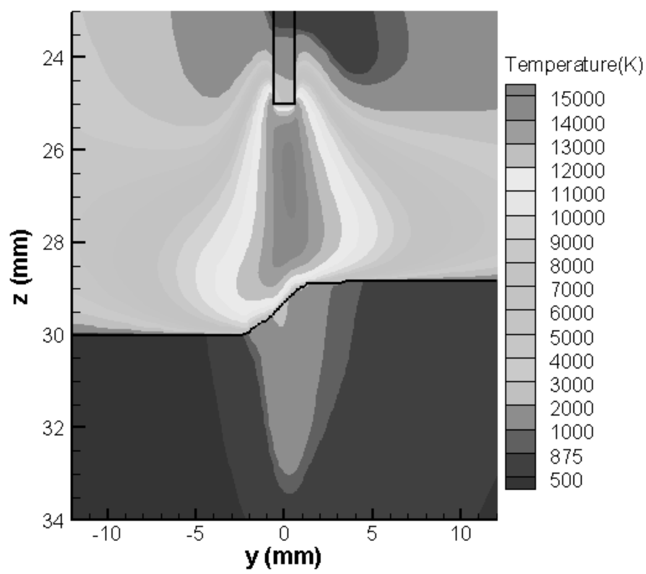

Fig. 1 Temperature distribution in the cross section at $x = 0$. The welding velocity is to the left.

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Figure 2 shows a more detailed view of the weld pool region of Fig. 1, including the flow vectors in the weld pool. The direction of flow is determined by many factors, including the Marangoni effect (the change in surface tension with temperature), the magnetic pinch force and buoyancy [5]. In this case, the influence of droplet momentum is dominant, driving flow downwards and leading to a relatively deep weld pool. This can be seen by comparing Fig. 2 with **Fig. 3**, which shows the time-averaged momentum transferred to the arc and weld pool by the droplets. Momentum is transferred to the droplet by the arc (due to the drag forces applied by the rapid plasma flow), but on reaching the weld pool, the droplet is rapidly slowed, thereby applying downward momentum to the molten metal.

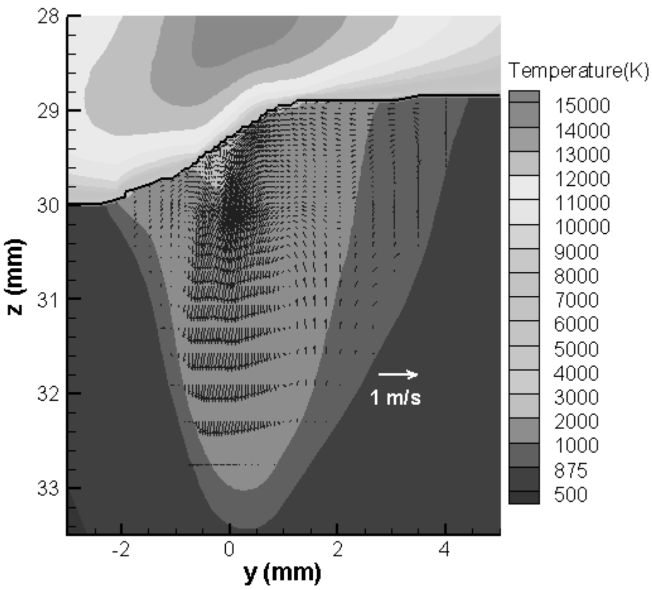

Fig. 2 Temperature distribution and velocity vectors in the weld pool in the cross section at $x = 0$. The welding velocity is to the left. The white arrow shows the scale of the velocity vectors.

4. Comparison with Experiment

The calculated weld profile is compared with a measured profile in **Fig. 4**. The width of the weld and the height and shape of the reinforcement predicted by the model are in good agreement with measurements, but the predicted depth of the weld is significantly larger. This is at least partly due to fact that the presence of metal vapour is neglected in the calculation. Metal vapour will cool the arc by increasing the radiative emission [6]. Further, vaporization of the molten section of the wire and of the droplet will cool the droplet and reduce its volume, thereby decreasing the energy and momentum transferred by the droplet to the weld pool. Both these changes will lead to a shallower weld pool.

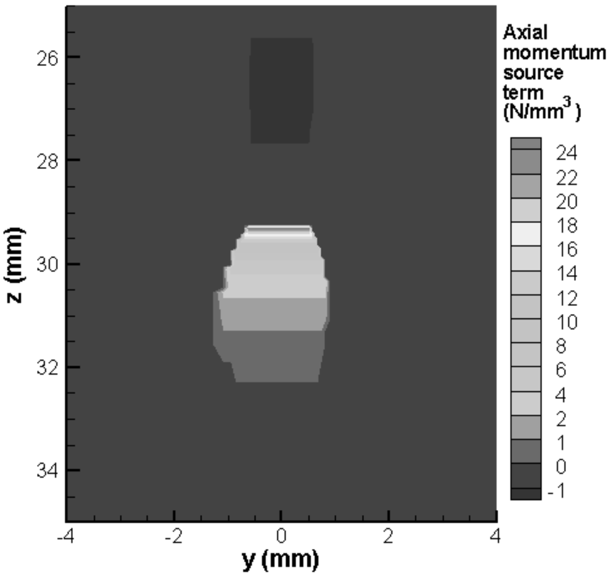

Fig. 3 Axial momentum source term applied to the arc and weld pool to take into account the effect of droplets, in the cross section at $x = 0$. The top of the weld pool is at $z = 29.3$ mm. The welding velocity is to the left.

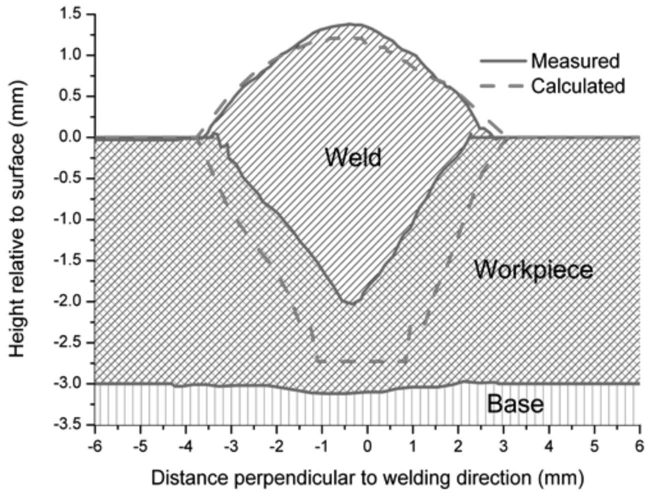

Fig. 4 Comparison of measured and calculated weld profiles. The welding direction is into the page.

5. Conclusions

A three-dimensional computational model of MIG welding that takes into account all important effects, except for the influence of metal vapour, has been developed. The model treats the wire electrode, arc and workpiece self-consistently, and allows the shape of the weld pool, including the surface deformation, to be predicted.

The importance of including the arc plasma in the computational domain (rather than just the workpiece, with the influence of the arc included through boundary conditions) should be emphasized. The influence of weld pool surface deformation on the location and size of the attachment region of the arc, and the momentum of the droplets and its effect on the weld pool, to give just two examples, can only be treated reliably by including the arc in the model.

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