Visualization of fluid flow and heat transfer in resistance spot weld nugget†

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KEY WORDS: (Resistance Spot Welding) (fluid Flow) (Heat Transfer) (Electromagnetic Stirring) (Modeling) (Magnetofluidodynamics)

1. Introduction

Resistance spot welding (RSW) process has been widely used in sheet metal joining, especially in automotive BIW (body in white) assembly. During RSW, a large welding current flows through electrode caps and sheet metals. The current not only produces resistance heat which can melt the sheet metal to form a nugget, but also induces a large magnetic field to stir molten metal in the nugget. Traditional electro-thermal models have been widely used to predict the nugget growth and heat transfer during RSW, however, these models could not reveal forced fluid flow and its effect on heat transfer in the nugget. There is still a lack of in-depth understanding of the physical behavior in the weld nugget.

In this paper, the fluid flow and heat transfer in RSW are a magneto-hydro-dynamic (MHD) finite element (FE) model, which couples the electric field, thermal field, flow field, magnetic field, and is used to investigate the electromagnetic phenomena in RSW and its effects on the nugget formation.

2. Numerical Model

A standard RWMA CLASS II electrode (MPE-25Z CMW® 328) with a flat end surface was utilized in this work. The material to be welded was 1.6mm thick mild steel sheet, the welding current was 10,200 ampere, the welding time was 12 cycles (0.2 s), the ambient temperature was 21℃, and the temperature of cooling water was 17.8℃.

In order to reduce the complexity of the coupled multi-physics process, the molten metal in the nugget was assumed to be incompressible, viscous, laminar, and with Newtonian fluid. Gravity's effect on fluid flow was ignored [1]. The electromagnetic field was viewed as quasi-stable for low-frequency welding current [2, 3].

The governing equations, boundary conditions, material models and numerical method are given and validated in our previous papers [4, 5]. ANSYS/Multiphysics and its parametric design language were used to realize the coupling of the electric, magnetic, thermal and flow fields.

3. Results and Discussion

Figure 1 showed the flow field in the nugget at the end of welding cycles. Obviously, the liquid metal makes rotational motion in four quarters, and in each quarter of the nugget, the molten metal flows out of the nugget along the faying surface and flows back into the nugget along the edge of the nugget. Thus, a small dead zone is formed at the center of the nugget. Moreover, the maximum flow velocity appears at the faying surface away from the weld nugget.
The flow of the molten metal will definitely affect the heat transfer behavior in the nugget. For traditional models, which can not consider the fluid flow in the nugget, the temperature gradient consists of a series of concentric ellipses and is large in any direction because of the consistent cooling, as shown in **Fig. 2**. However, for the model with magnetic field considered, the strong flow substantially disturbs the regular thermal conduction and mixes the hot and cold metal through mechanical stirring, and greatly reduces the temperature gradient in the nugget, especially in the width direction, as shown in **Fig. 3**.

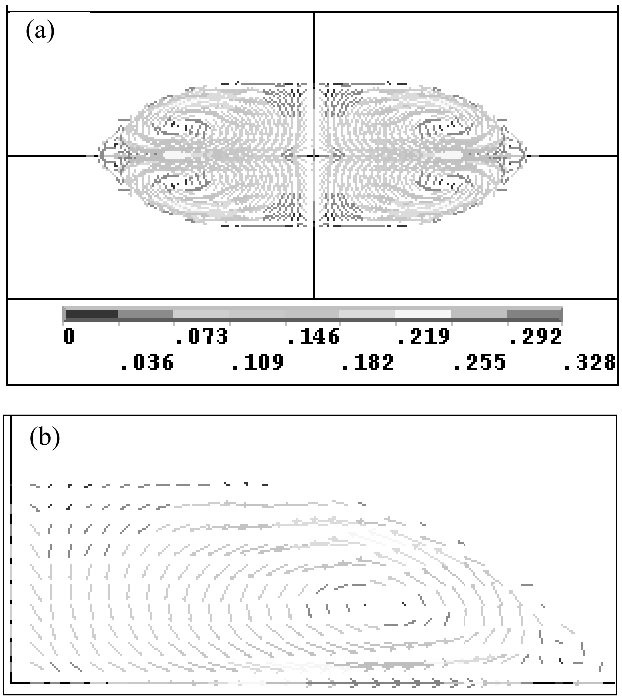

Fig. 1 Calculated flow field in the nugget. The unit is m/s. (a) overall view; (b) close-up view of the first quarter.

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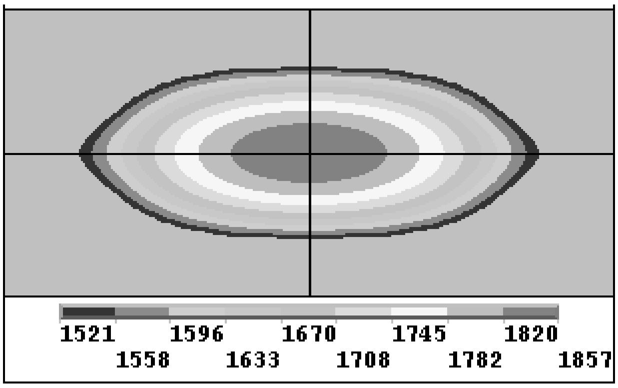

Fig. 2 Calculated nugget with traditional electro-thermal model.

Figure 4 showed the evolution of maximum temperature in the nugget throughout the welding process. Obviously, the maximum temperature evolution below the liquidus is totally the same. Once there is molten metal in the nugget, temperature differences will appear. For traditional models, the maximum temperature increases almost linearly with time, however, for the model with magnetic field considered, after about 0.18s, the maximum temperature does not increase obviously and only makes slight fluctuations with the alternating welding current.

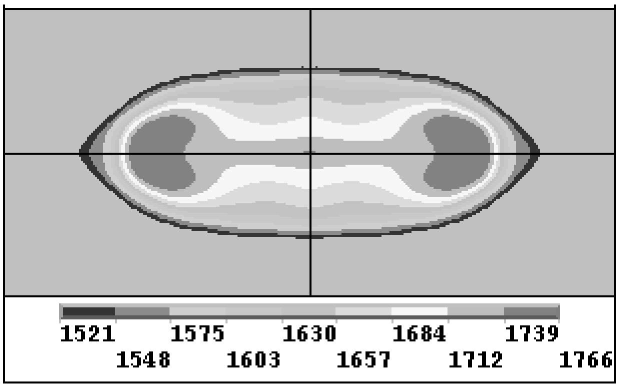

Fig. 3 Calculated nugget with the MHD model.

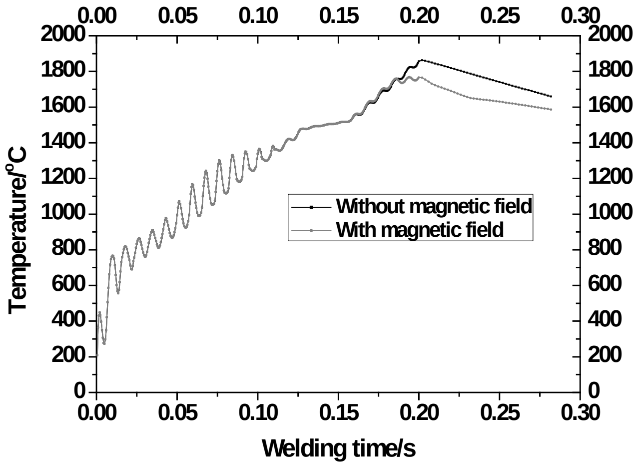

Fig. 4 This unit is maximum temperature evolutions for both kinds of models.

4. Conclusions

A multi-physics FE model is used to model the electromagnetic phenomena in RSW. Researches showed that the magnetic force field, which is produced by the welding current and the induced magnetic field, is very regular, and causes the molten metal in the nugget to make regular flow in four cores at high velocity. The flow dramatically changes the heat transfer in the weld nugget, and results in a different temperature gradient in the nugget, which will surely affect the crystallization process of the liquid nugget.

Acknowledgement

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