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Heat Source Models in Simulation of Heat Flow in Friction Stir Welding

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ABSTRACT

The objective of the present paper is to investigate the effect of including the tool probe and the material flow in the numerical modelling of heat flow in friction stir welding (FSW). The contact condition at the interface between the tool and workpiece controls the heat transfer mechanisms. The convective heat transfer due to the material flow affects the temperature fields. Models presented previously in the literature allow the heat to flow through the probe volume, and the majority neglects the influence of the contact condition as the sliding condition is assumed. In this work, a number of cases is established. Each case represents a combination of a contact condition, i.e. sliding and sticking, and a stage of refinement regarding the heat source distribution. In the most detailed models, the heat flow is forced around the probe volume by prescribing a velocity field in shear layers at the tool/work piece interface. This results in a nonsymmetrical temperature field that depends not only on the total heat generation, tool/work piece geometry and thermal properties, but also on the contact condition, the tool's rotational speed and the assumed shear layer thicknesses. The models are implemented in FEMLAB and configured in terms of the heat source as: shoulder contribution only; shoulder and probe contribution, the latter as a volume heat source distributed in the probe volume; and shoulder and probe contribution distributed at the contact interface, i.e. as a surface flux in the case of sliding and as a volume flux in the shear layers in the case of sticking.

INTRODUCTION

When modelling the heat transfer in friction stir welding (FSW) it has previously been assumed that the heat generation from the tool probe has little or no effect on the temperature fields. The heat generation from the shoulder has been used as the only heat source in initial models presented by Chao and Qi (1999), Frigaard, Grong and Midling (1999), and Russel and Shercliff (1999). More recently, the heat generation from the probe has been included in the models by Colegrove (2000), Song and Kovacevic (2003), Chen and Kovacevic (2003), Shi, Dickerson and Shercliff (2003), and Khandkar and Khan (2001, 2003). Common to these models is the application of the probe heat generation in that particular volume of the work piece which would have been displaced by the tool probe. However, the probe volume has, in the real FSW process, thermal properties of the tool material, i.e. tool steel, but the models shown in the literature which include the probe heat effect do not distinguish between work piece and probe material properties for the probe volume. Further, the material flow around the probe affects the heat flow, hence the temperature field. The convective heat transfer in the deformation zone has previously been neglected, but recent studies by Khandkar and Khan (2001), Schmidt, Hattel and Wert (2004), and Schmidt and Hattel (2003) suggest that the convective heat transfer, due to the contact condition, affects the local temperature distribution close to the tool/matrix interface.

The level of refinement of the heat source model depends on the purpose of the thermal analysis. For modelling residual stresses/distortions, a rough heat source model has proven sufficient for estimating correct temperatures some distance away from the heat source (tool), e.g. Shi, Dickerson and Shercliff (2003) and Chao and Qi (1999). The thermal fields used as input for microstructure evolution models have previously been modelled with some rather rough heat sources, e.g. Russel and Shercliff (1999), who used a combined point/line source, solving the temperature fields by a modified analytical Rosenthal solution; and Frigard, Grong and Midling (2001), who used a uniform (constant) heat source distributed on several square-shaped sheets (Fig. 4). However, with a refined heat source model, using the whole tool/matrix contact interface for distribution of a radially dependent heat source, it is possible to obtain detailed transient thermal results, which cannot be simulated using less detailed heat source models. The estimation of temperatures close to the tool/matrix interface is of special interest, because experimental temperatures in the highly deformed zone are difficult to measure. Apart from being of more general interest for the FSW process itself, the temperature fields control the residual stresses and distortions, and in that respect they serve as an important input for any thermomechanical calculation.

This work shows 6 models (cases) for describing the heat source. Each case is configured to verify the effect of refining the model regarding the description of the probe and the effect of the contact condition. The refinements of the heat source have 3 stages: shoulder heat source only; shoulder and probe heat source, the latter as a volume flux in the matrix volume displaced by the probe; and shoulder heat source and probe heat source distributed at the probe/matrix interface. The volume displaced by the probe is removed, thus avoiding heat transfer through the probe volume.

Each refinement stage is configured for the 2 extreme contact conditions: full sliding and full sticking, which are termed a) and b), respectively.

Based on these 6 configurations it is possible to evaluate the influence of the heat flow around the tool probe, as compared to allowing heat transfer through the probe region.

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KEY WORDS: Friction stir welding, tool probe, contact condition, material flow, heat generation.