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A review of numerical analysis of friction stir welding

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ABSTRACT

Friction stir welding is a relatively new solid-state joining technique which is widely adopted in different industry fields to join different metallic alloys that are hard to weld by conventional fusion welding. Friction stir welding is a highly complex process comprising several highly coupled physical phenomena. The complex geometry of some kinds of joints and their three dimensional nature make it difficult to develop an overall system of governing equations for theoretical analyzing the behavior of the friction stir welded joints. The experiments are often time consuming and costly. To overcome these problems, numerical analysis has frequently been used since the 2000s. This paper reviews the latest developments in the numerical analysis of friction stir welding processes, microstructures of friction stir welded joints and the properties of friction stir welded structures. Some important numerical issues such as materials flow modeling, meshing procedure and failure criteria are discussed. Numerical analysis of friction stir welding will allow many different welding processes to be simulated in order to understand the effects of changes in different system parameters before physical testing, which would be time-consuming or prohibitively expensive in practice. The main methods used in numerical analysis of friction stir welding are discussed and illustrated with brief case studies. In addition, several important key problems and issues remain to be addressed about the numerical analysis of friction stir welding and opportunities for further research are identified.

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Contents

1. Introduction

There is an increasing need to design lightweight structures such as those in aircraft panels and vehicle body shells. Advanced joining technology is an integral part of the manufacturing processes of lightweight structures. Considerable effort has been expended to develop various joining processes and assess their suitability for use in lightweight structures [1–5].

Friction stir welding (FSW) is a solid-state joining technique which was invented at The Welding Institute (TWI), UK, in 1991 [6]. The FSW has been found to be effective for joining hard-to-weld metals and for joining plates with different thickness or different materials.

In the FSW process a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of workpieces to be joined and traversed along the line of the joint, as shown in Fig. 1 [7]. As the tool travels, heat is created by the contact friction between the shoulder and the workpiece, and by the plastic deformation of the materials in the stir zone. The high strain and heat energies experienced by the base metal during stirring causes dynamic recrystallization, which is the formation of new grains in the weld zone [6]. Although Fig. 1 shows a butt joint for illustration, other types of joints, as shown in Fig. 2, also can be fabricated by FSW [8].

FSW is often a preferred joining technique not only for aluminum alloys [e.g. 9,10] but also for other difficult-to-weld metals such as magnesium alloys [e.g. 11,12], titanium alloys [e.g. 13,14] and metal-matrix composites [e.g. 15,16], etc. The technique is now widely used in many industrial sectors such as marine, aerospace, railway, land transportation, etc. Some general information on the FSW is available from TWI [17].

FSW is a highly complex process comprising several highly coupled (and non-linear) physical phenomena. These phenomena include large plastic deformation, material flow, mechanical stirring, surface interaction between the tool and the workpiece, dynamic structural evolution and heat