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ScienceDirect

Procedia Engineering 207 (2017) 580–585

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017, Cambridge, United Kingdom

Application of Adaptive Element-Free Galerkin Method to Simulate Friction Stir Welding of Aluminum

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Abstract

The modeling of friction stir welding (FSW) is challenging as severe plastic deformation is present. This is in particular the case as typical finite element methods are employed. In this study we use a meshfree technique to model the material flow during the FSW process. We employ the Element-Free Galerkin method (EFG) as approximation method. A mortar contact is used to account for the stirring effect and heat generation from the frictional contact. A two-way adaptive method (rh-adaptive) during the coupled thermomechanical process is used to overcome potential numerical problems arising from the extensive mesh distortion and material deformation. This means, the mesh is globally refined with perusing an anisotropic tetrahedral mesh (h-adaptive). At the same time, a completely new mesh is built based on the old mesh (r-adaptive). Finally, we perform the simulation method on an aluminum sheet with a cylindrical tool to exemplarily show the applicability of the adaptive Element-Free Galerkin method. In future work, the obtainable deformation and temperature history from the thermomechanical simulation will be used to predict the final micro-structure after the welding process.

Keywords: Friction Stir Welding, Meshfree Methods, Adaptivity

Nomenclature

FSW Friction Stir Welding

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10.1016/j.proeng.2017.10.1024

EFG	Element-Free Galerkin Method
ALE	Arbitrary Lagrangian Eulerian
$\boldsymbol{X}$	position vector
Φ_I	shape function for node I
u_I	nodal displacement at location X_I
$\boldsymbol{p}$	linear basis functions vector
T	temperature
h	dilation parameter
W	weight function
ω	set of particles

1. Introduction

In order to design light weight structures for ever emerging demands, developing suitable joining processes are essential. Among many others, a solid state joining technique is Friction Stir Welding (FSW). FSW was first invented at the Welding Institute (TWI), UK, in 1991 [1]. FSW has been proven to be effective in order to weld hard-to-weld materials as well as joining plates of different materials or thickness. During FSW, a rotating non-consumable tool with a shoulder is inserted into the edges of the workpieces which are joint, see Fig. 1 [2]. As the rotating is advancing into the workpieces, two phenomena are mainly responsible for generating heat. These are the frictional contact between the tool/shoulder and the workpiece as well as the plastic deformation of the workpiece. For a comprehensive overview on the FSW process, refer to the review article by Mishra and Ma [3].

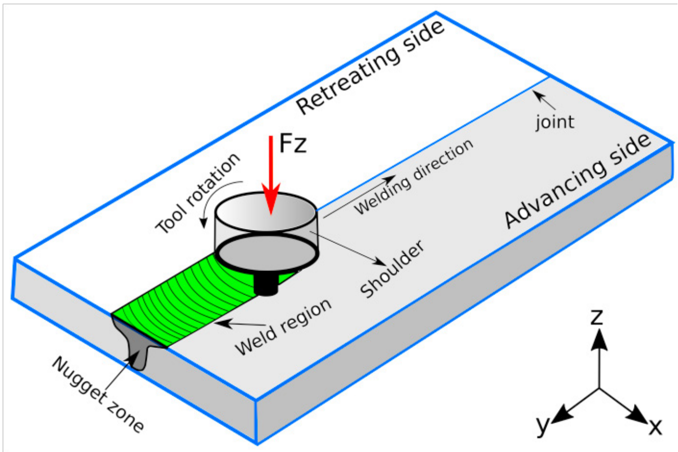

Fig. 1. Schematic illustration of the FSW process.

FSW is a rather 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 generation resulting from friction and plastic deformation. To achieve a stable process, leading to a successful weld and good final mechanical properties of the FSW joints, depends on multiple parameters. These parameters include the type of joining material(s), the geometry of the tool, the rotation speed of the tool, the welding speed and the downward force applied to tool among others. Moreover, due to the non-linear coupled thermo-mechanical behavior of the system, it is difficult to predict for different parameter combinations the final mechanical properties of the joints. Since experimental tests are costly and time consuming, many researchers opted to use numerical simulations to model the FSW process.