HAL
open science

Numerical Simulation of Friction Stir Welding Processes

Icíar Alfaro, François Gratecap, Arnaud Poitou, Elías Cueto, Francisco Chinesta

To cite this version:

Icíar Alfaro, François Gratecap, Arnaud Poitou, Elías Cueto, Francisco Chinesta. Numerical Simulation of Friction Stir Welding Processes. XXII ICTAM - International Conference of Theoretical and Applied Mechanics, Aug 2008, Adelaide, Australia. pp.25-29. hal-01008564

HAL Id: hal-01008564

https://hal.science/hal-01008564

Submitted on 22 May 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

NUMERICAL SIMULATION OF FRICTION STIR WELDING PROCESSES

Icíar Alfaro*, François Gratecap**, Arnaud Poitou**, Elías Cueto* & Francisco Chinesta***
*Aragón Institute of Engineering Research. University of Zaragoza, Spain
**GeM, Ecole Centrale de Nantes, France
*** LMSP, UMR 8106 CNRS-ENSAM-ESEM. Paris, France.

Summary In this paper we present a numerical model for the simulation of Friction Stir Welding (FSW) processes. FSW is a solid-state welding process based upon the mixing provoked by a rotating pin that is forced to move between the pieces to join (usually plates). The model employs the Natural Element Method (NEM), a member of the vast family of meshless methods, to perform simulations in an updated Lagrangian approach. This avoids the burden associated with remeshing in traditional Eulerian or Arbitrary Lagrangian-Eulerian (ALE) approaches to this same problem. The method allows to understand the flow patterns that lead to the formation of layers during the welding. Experimental results that confirm the presence of chaotic flow will also presented.

INTRODUCTION

Friction stir welding (FSW) is a process that, although in its development stage, has been successfully used to join pieces of materials with poor weldability. Briefly speaking, it achieves welding of the pieces by employing a rotating ping that provokes both extremely high plastic deformation and also a high heat generation. It is represented in Fig. 1.

In FSW, two pieces of sheet or thin plate are joined by inserting a specially designed rotating pin into the adjoining edges of the sheets to be welded and then moving it all along the seam. At first, the sheets or plates are abutted along edge to be welded and the rotating pin is sunken into the sheets/plates until the tool shoulder is in full contact with the sheets or plates surface. Once the pin is completely inserted, it is moved with a small nuting angle in the welding direction. Due to the advancing and rotating effect of the pin and shoulder of the tool along the seam, an advancing side and a retreating side are formed and the softened and heated material flows around the pin to its backside where the material is consolidated to create a high-quality, solid-state weld.

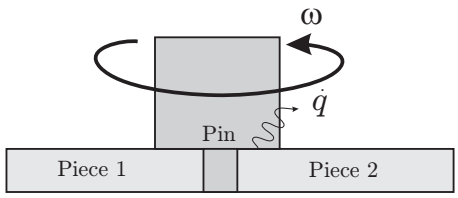

Figure 1. Schematic representation of the FSW process.

From the numerical point of view, such a process presents several challenging difficulties. First of all, the extremely large deformation present during the process always introduces numerical problems. Second, there is a strong coupling between these large deformation and heat generation, that in turn affects the behavior of the material.

Meshless methods allow for a Lagrangian description of the motion, while avoiding the need for remeshing. Thus, the nodes, that in our implementation transport all the variables linked to material's history, remain the same throughout the simulation. Mappings between old and new meshes are not necessary and hence the avoidance of numerical diffusion.

Among the many meshless methods available nowadays, we have chosen the Natural Element Method (NEM)[1]. It possesses some noteworthy advantages over other meshless methods that will be described shortly.

THE NATURAL ELEMENT METHOD

The Natural Element Method is a meshless method that employs natural neighbour interpolation in a Galerkin framework to solve the weak form of the problem. Consider a model composed by a cloud of points $\mathbf{N} = \{n_1, n_2, \ldots, n_m\} \subset \mathbb{R}^d$, for which there is a unique decomposition of the space into regions (the Voronoi diagram) such that each point within these regions is closer to the node to which the region is associated than to any other in the cloud (see figure 2): $T_I = \{\mathbf{x} \in \mathbb{R}^d : d(\mathbf{x}, \mathbf{x}_I) < d(\mathbf{x}, \mathbf{x}_J)\ \forall\ J \neq I\}$, where $d(\cdot,\cdot)$ is the Euclidean distance function.

The dual structure of the Voronoi diagram is the Delaunay triangulation. Two nodes sharing a facet of their Voronoi cell are called *natural neighbours* and hence the name of the technique. Equivalently, the second-order Voronoi diagram of the cloud is defined as $T_{IJ} = \{\mathbf{x} \in \mathbb{R}^d : d(\mathbf{x}, \mathbf{x}_I) < d(\mathbf{x}, \mathbf{x}_J) < d(\mathbf{x}, \mathbf{x}_K)\ \forall\ J \neq I \neq K\}$.

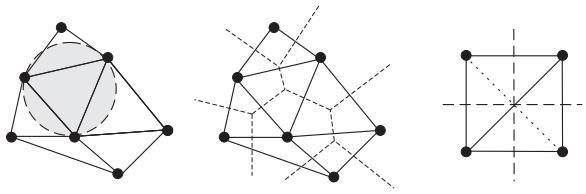

Figure 2. Delaunay triangulation and Voronoi diagram of a cloud of points. On the right, an example of degenrate (non-unique) triangulation.

The most extended natural neighbour interpolation method is the Sibson interpolant [2]. Consider the introduction of the point $\mathbf{x}$ in the cloud of nodes. Due to this introduction, the Voronoi diagram will be altered. Sibson [2] defined the natural neighbour coordinates of a point $\mathbf{x}$ with respect to one of its neighbours I as the ratio of the cell T_I that is transferred to T_x when adding $\mathbf{x}$ to the initial cloud of points to the total volume of T_x. In other words, if $\kappa(\mathbf{x})$ and $\kappa_I(\mathbf{x})$ are the Lebesgue measures of T_x and T_{xI} respectively, the natural neighbour coordinates of $\mathbf{x}$ with respect to the node I is defined as $\phi_I(\mathbf{x}) = \frac{\kappa_I(\mathbf{x})}{\kappa(\mathbf{x})}$.

CONSTITUTIVE MODELLING

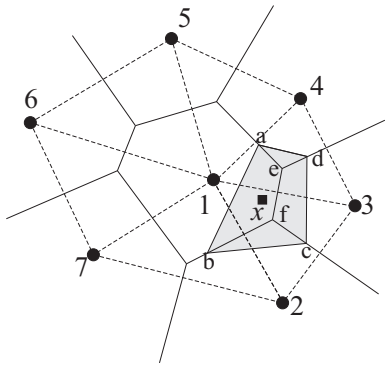

Figure 3. Definition of the Natural Neighbour coordinates of a point $\mathbf{x}$.

FSW processes involve large deformation and high velocities of the rotating pin that make the elastic strains to be negligible. Although an elastic recovery exists, it is obvious negligible as a first approximation. The obvious advantage of this assumption is that the material can then be modelled as a non-newtonian (rigid-visco-plastic) fluid. This assumption is known as the *flow formulation* in the forming processes community. Thus, the essential variables of the problem will be velocities and pressures.

From the numerical point of view, such a process presents several challenging difficulties. First of all, the extremely large deformation present during the process always introduces numerical problems. Second, there is a strong coupling between these large deformation and heat generation, that in turn affects the behavior of the material. A fully coupled thermo-mechanical formulation has been considered by means of a Picard algorithm in order to take into account this great amount of heat generated in the process.

Meshless methods allow for a Lagrangian description of the motion, while avoiding the need for remeshing. Thus, the nodes, that in our implementation transport all the variables linked to material's history, remain the same throughout the simulation. Mappings between old and new meshes are not necessary and hence the avoidance of numerical diffusion.

Among the many meshless methods available nowadays, we have chosen the Natural Element Method (NEM) [1]. It possesses some noteworthy advantages over other meshless methods that can be found in the before mentioned references.

NUMERICAL RESULTS

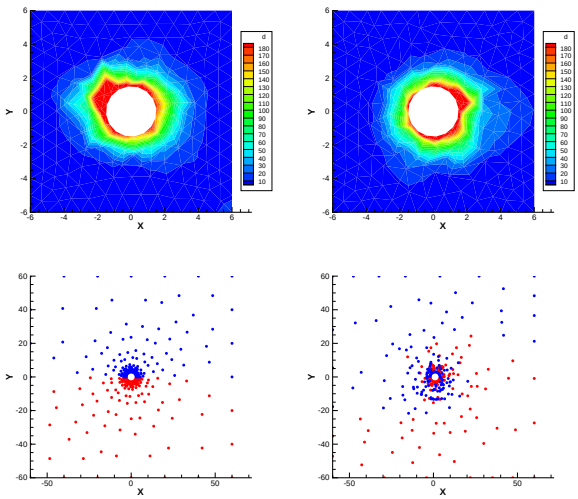

Figure 4. Top: Evolution of the equivalent strain rate during the beginning of the rotation. 10th and 90th time steps. Bottom: Evolution of the phases through the welding process.

We consider here a very simplified two-dimensional, plane stress, model of the union of two plates. The model is composed by 240 nodes whose Delaunay triangulation is re-computed at each time-step. This is very fast process, which actually consumes only a few time, if compared with the equilibrium iterations. The pin is assumed to rotate at 1000 rev/min and to advance at $1mm/s$. Despite that the usual friction coefficient between the pin and the sheet has been established to be around 0.5 we have considered here perfect adhesion between them. This will overestimate the strain produced by the pin rotation. The time increment chosen was 10^{-4} seconds. In Fig. 4 (top) the equivalent strain rate is depicted.

But the most interesting feature of the method, if compared to Eulerian or ALE formulations is, in our opinion, the possibility of tracking the flow of the material. This is shown in Fig. 4 (bottom). The formation of layers, also experimentally seen, is also found in this simulation. These layers suggest the presence of chaotic flow during the welding process.

CONCLUSIONS

A novel model has been constructed for the simulation of FSW processes based on the use of the Natural Element Method in an updated Lagrangian framework. This allowed us to track the layers of material during the process. The obtained flow patterns, also confirmed by experimental evidence, suggested the presence of chaotic flow during the process.

References

[1] E. Cueto, N. Sukumar, B. Calvo, M. A. Martínez, J. Cegoñino, and M. Doblaré. Overview and recent advances in Natural Neighbour Galerkin methods. *Archives of Computational Methods in Engineering*, 10(4):307–384, 2003.

[2] R. Sibson. A Vector Identity for the Dirichlet Tesselation. *Mathematical Proceedings of the Cambridge Philosophical Society*, 87:151–155, 1980.