Paper presented at the 11th International Seminar on Numerical Analysis of Weldability
Graz, Austria, Sept. 27-30, 2015

Analytical modeling of material flow in friction stir welding

A. Tongne[1], C. Desrayaud[2], M. Jahazi[3], E. Feulvarch[1]

[1] *Univ Lyon, ENISE, LTDS, UMR 5513 CNRS, 58 rue Jean Parot, 42023 Saint-Etienne cedex 02, France*
[2] *École des Mines de Saint-Etienne, LGF UMR 5307 CNRS, 158 Cours Fauriel, 42023 Saint-Etienne, France*
[3] *École de Technologie Supérieure, 1100 Rue Notre-Dame Ouest, Montréal, QC H3C 1K3, Canada*

Abstract

An analytical model is proposed for describing material flow during friction Stir Welding (FSW). The origin of the banded structure is clearly correlated to the cutting phenomenon which produces void defects at the retreating side of the weld.

Keywords: *Friction Stir Welding, Analytical modeling, banded structure, onion rings.*

1. Introduction

Numerical simulation of friction stir welding process is a great deal since high time consuming problems are to be solved. Indeed the process is non-linear because of friction condition at tool/workpieces interface and mainly the nonlinear constitutive laws required to describe the elastic and the viscoplastic material far and close to the pin, respectively. The high strain rate generated by the rotating tool involves mesh refining and a strong remeshing rule to solve mesh distortion problems.

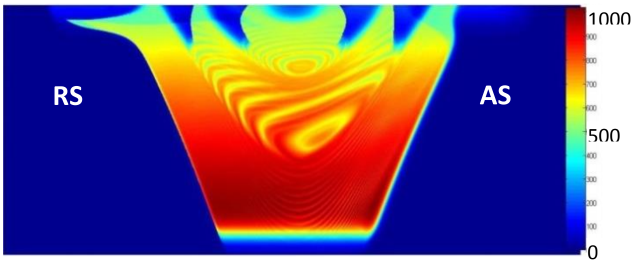
Moreover, FSW joints strength are related to the various features in the weld seam as the onion rings which form the weld nugget. Onion rings are formed by the periodical deposited material layer which originates from transient conditions at the tool/workpieces interface ([1],[2]). Conventionally, the material layers observed in longitudinal and horizontal sections are called banded structure and onion rings in transversal section. Therefore, the use of transient FSW models is required for onion rings prediction as reported by [3]. To avoid high computation time, a thermofluid model has been proposed by [3]. In this model, the material flow is described by analytical formula based on the analysis of the weld microstructure. The model results are compared to experimental. However, the correlation of the model to the experimental is not fully completed because the ratio of contrast difference between bands is about 1.3. This ratio is not enough to change microstructural proprieties between bands. Ratio over 5 will be realistic. In this paper, the material flow formula is improved in order to increased contrast difference within onion rings bands [3].

2. Material flow modification and results

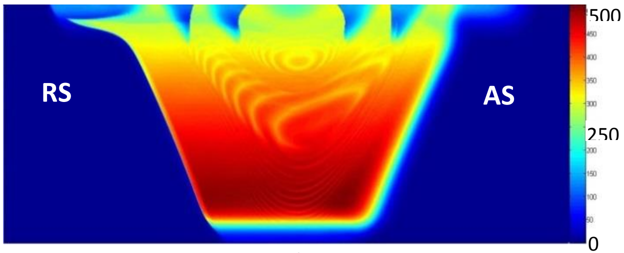
The material velocity field developed by [3] is given by:

$$\vec{v} = \left\{ \begin{array}{l} v_x = \overbrace{V_a \left(1 - r_p^2 \frac{(x^2 - y^2)}{(x^2 + y^2)}\, a_{pco}\right)}^{circumvention} - \overbrace{C_{ep}\, \omega_{Tool}\, a_{pci}\, \frac{y}{(x^2 + y^2)}}^{circulation} \\ \qquad \overbrace{- C_{ee}\, \omega_{tool}\, a_{atorr}\, a_{atorz}\, \frac{y}{(x^2 + y^2)}}^{torsion} \\ v_y = V_a \left(1 - 2\, r_p^2 \frac{x\, y}{(x^2 + y^2)}\, a_{pco}\right) + C_{ep}\, \omega_{Tool}\, a_{pci}\, \frac{x}{(x^2 + y^2)} \\ \qquad + C_{ee}\, \omega_{tool}\, a_{atorr}\, a_{atorz}\, \frac{x}{(x^2 + y^2)} \\ v_z = 0 \end{array} \right.$$

Figure 1 shows the experimental onion rings and the strain rate value compute from the velocity field for high and low strain rate. The ratio of strain rate value between bands is not high, mainly for the bands at the root of the weld.



a) Maximal strain rate for high velocity gradient.



b) Maximal strain rate for low velocity gradient.

c) Optical microscopy showing onion rings in the weld.

Figure 1: Maximal strain rate distribution (s^{-1}) compare to experimental onion rings.

Moreover, an experimental weld in [3] exhibits void defect which are located to the retreating side (Figure 2). This means that the material located to advancing side (which forms the banded structure) was separated to the bulk material during the process. I.e. the material is cut in front of the tool and forced to be deposited when reaching the advancing side hall at the rear of the tool.

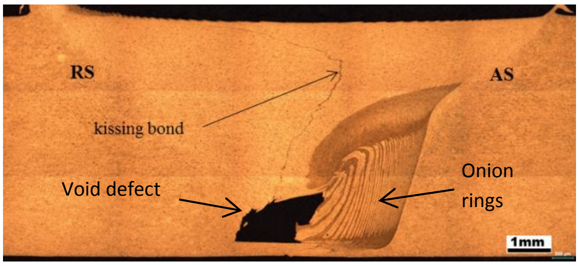


Figure 2: Void defect sample

Therefore, the material close to the tool interface is highly deformed. Indeed, the interaction tool/material in [3] model is based on friction. The model is then limited to predict void defects at the retreating side of the weld. Hence, full modeling of the trigonal tool which takes into account the cutting phenomenon in 2D (horizontal section) is proposed. The velocity field is defined as:

$$\vec{v} = \begin{cases} v_r = -V_p \sin(tta) + V_e \sin(tta) \\ v_t = V_p \cos(tta) + V_e \sin(tta) \\ v_z = 0 \end{cases}$$

Where $V_e$is the velocity normal to the tool edge avoiding material penetration into the tool. V_p is the tangential velocity which is also referred to as extrusion velocity caused by pressure. $V_e$and V_p contain an attenuation function which ensure the velocity gradient, mainly, the cutting phenomenon.

Figure 3 shows the particles identified as nodes which form the weld. The maximal strain rate reach by any of these particles is plots on Figure (5). The ratio of the contrast difference between bands is beyond 5.

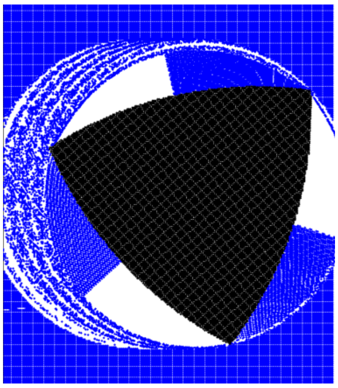


Figure 3: Particles (nodes) around the trigonal tool

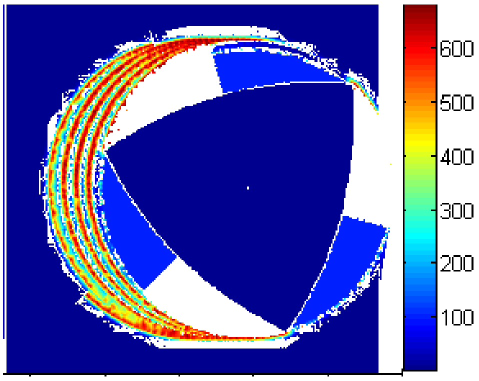


Figure 4: Maximal strain rate distribution

Conclusion

The analytical material flow shows that experimental onion rings can be related the above discussed cutting phenomenon. In coupled thermomechanical models, it’s quite difficult to introduce cutting phenomenon even worse, ships have no meaningful stresses in cutting models. The only available means is analytical modeling. Therefore, a study is ongoing to evolve this analytical material flow model to three dimensional.

References

[1] K.N. Krishnan, On the formation of onion rings in friction stir welds, Mater. Sci. Eng. A. 327 (2002) 246–251. doi:10.1016/S0921-5093(01)01474-5.

[2] F. Gratecap, M. Girard, S. Marya, G. Racineux, Exploring material flow in friction stir welding: Tool eccentricity and formation of banded structures, … J. Mater. Form. 5 (2011) 99–107. doi:10.1007/s12289-010-1008-5.

[3] A. Tongne, M. Jahazi, E. Feulvarch, C. Desrayaud, Banded Structures in Friction Stir Welded Al Alloys, J. Mater. Process. Technol. (2015). doi:10.1016/j.jmatprotec.2015.02.020.