NUMERICAL MODELING OF FRICTION STIR WELDING: A COMPARISON OF ALEGRA AND FORGE3

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Objective

This research will focus on the application of two well established industrial codes, ALEGRA and Forge3, for numerical modeling of Friction Stir Welding. Both of these codes excel in various areas of modeling. ALEGRA utilizes the Arbitrary Lagrangian Eulerian (ALE) approach to modeling, while Forge3 focuses on the Lagrangian scheme, relying on the complete remeshing of the domain to handle high deformation events. This author will examine the viability of both codes to produce an experimentally validated, fully transient model of Friction Stir Welding in Aluminum 7075-T7.

Background

A preliminary list of requirements for a FSW analysis code may include the following:

1. Rotational Boundary Condition
    - The code must have a method of rotating the tool at a prescribed angular velocity.
2. Frictional Contact Algorithms.
    - To capture the frictional contact and heat generation between the tool and the work piece, the analysis code must employ frictional contact algorithms.
3. Support very high levels of deformation
    - Because of the nature of FSW, the code must employ some method of handling high deformation of materials.
4. Elastic-Plastic or Elastic-Viscoplastic Material Models
    - This requirement comes from the desire to model the FSW event as a solid-state model, rather than a viscous fluid.
5. Support for complex geometry
    - It is desirable to model FSW tools that incorporate threaded pin designs, and thus complex geometry.

Experimental Approach

The author will create a model of FSW in ALEGRA, evaluate the outputs against experimentally measured values, and modify the inputs as necessary. A similar model will be created in Forge3 and evaluated in the same manner.

This researcher will also be instrumenting FSW process with thermocouples in the tool, and the weld material. Outputs from this experimental approach will include: quantification of the forces involved, and temperature profiles in the tool and weld material. These data will then be compared against the numerical results from ALEGRA and Forge3.

Preliminary Results and Discussion

This two dimensional transient FSW slice, shown in the left image in Figure 1, was analyzed to test the viability of using ALEGRA to model FSW in a completely Eulerian formulation. This fully Eulerian scheme is the only approach that produced promising results. However, the model represented in Figure 1, both the two and three dimensional, echoes the most fatal flaw of ALEGRA as it pertains to FSW modeling. The reader should notice that the time shown in this figure is 3.535 milliseconds. This result was obtained at a computational clock time of 102 hours, because the largest stable time step ALEGRA could utilize was 1.86e-11 seconds. This time step issue was the primary deterrent from a viable FSW model in ALEGRA. Similar results, shown in Figure 1, of three dimensional models were also obtained at a computational expense of a few weeks.

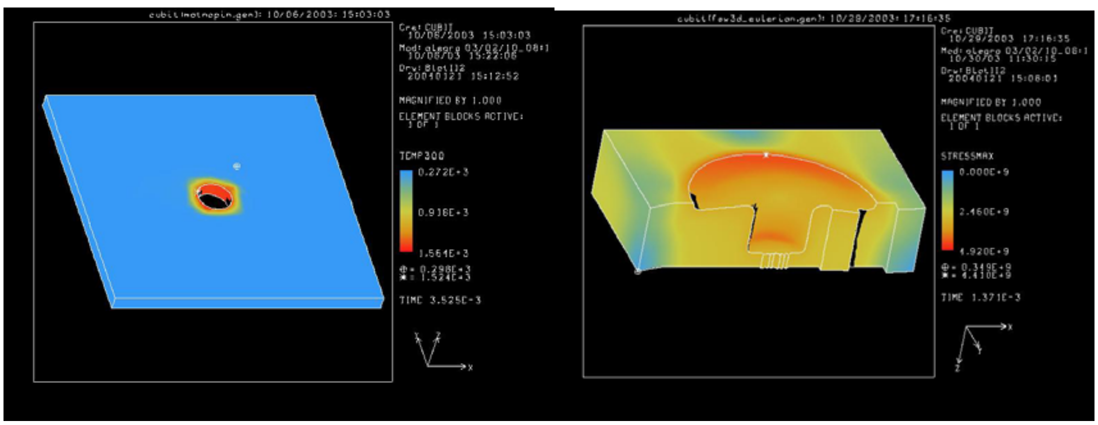

Figure 1—A two-dimensional slice, shown at the left, of the temperature distribution during the FSW process at t=3.535 ms, modeled with a prescribed rotational boundary surface representing the tool. A cut away view, shown at the right, of the three-dimensional Von-Mises stress distribution of an Eulerian model, with a prescribed rotational condition on the surface representing the tool. Total time elapsed 1.37 ms.

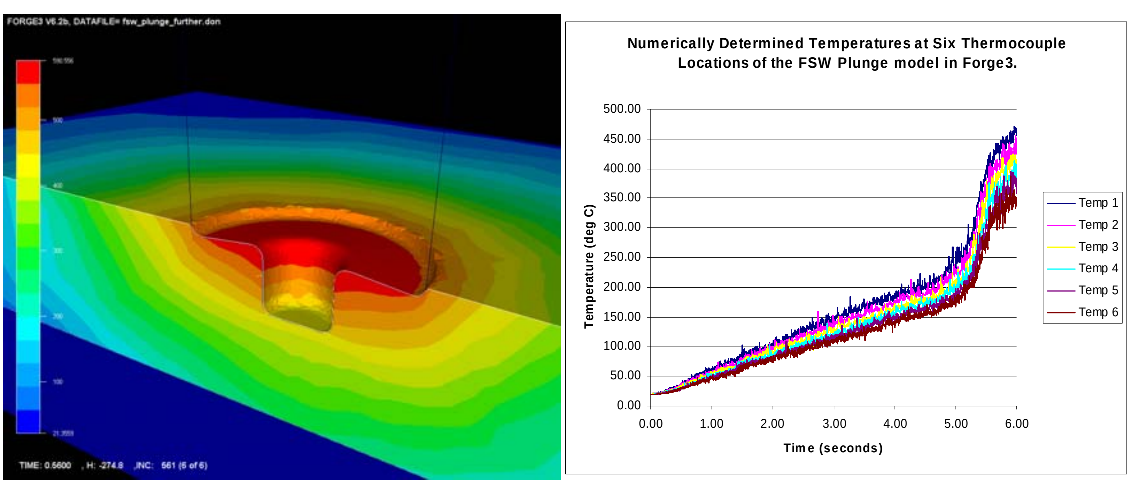

Figure 2—A cut plane view, left, of the Forge3 model of the temperature profiles at 6 seconds. The tool has been removed to allow the reader to view the shoulder

temperatures. Temperature range: 20-590 deg C. A plot of the numerically determined temperature histories at 6 thermocouple locations within the weld material.

Figure 2 above shows the temperature profiles calculated in the Forge3 numerical model, and also the temperature histories at the sensors placed in locations identical to the thermocouple positions in the validation experiment. This analysis was computed with an adiabatic heat transfer condition between the tool, the workpiece, and the backing plate. The numbered temperatures in the right plot, in ascending order, represent the thermocouple positions in increasing radii from the center of the pin. The reader will notice that each temperature profile “parallels” its neighbor temperature, with the highest temperatures closest to the pin. This is intuitively sound, and compares well to the measured experimental data.