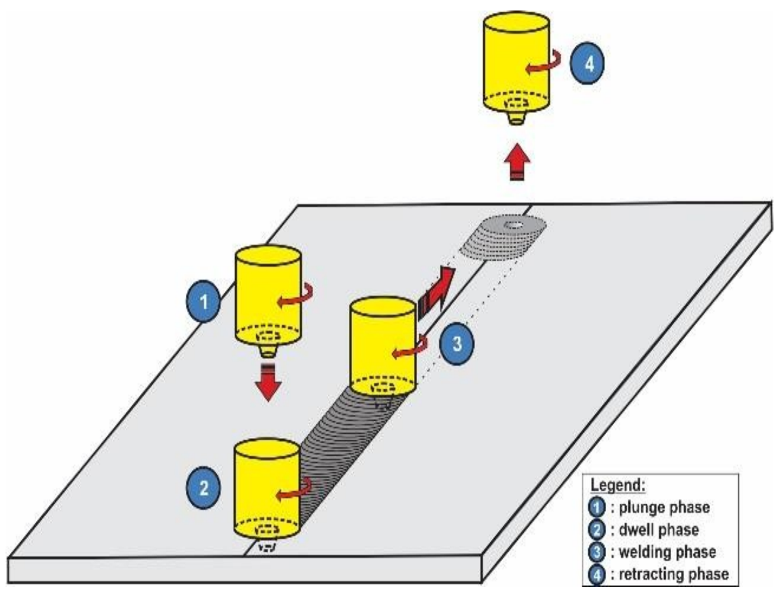
Optimization of the Friction Stir Welding Process of Aluminum Alloys

submitted by Kirk Fraser and François Nadeau (National Research Council Canada)

Background

In many industries, joining aluminum alloys together can be accomplished via various approaches (such as adhesive bonding, fastening, welding, etc.). Recently, a new approach has surfaced called friction stir welding (FSW). In this process, a hardened steel tool rotates and presses into the aluminum plates to be welded. As the tool rubs on the aluminum, heat is generated due to friction at the interface. This frictional heating softens the aluminum and renders it malleable. Once the temperature in the weld zone attains 80% to 90% of the melting temperature, the aluminum plates mechanically mix and a solid state joint is created. The process is depicted schematically below [1].



The FSW process is quickly becoming one of the major joining techniques for aluminum alloys in various industries such as the aerospace, automotive, rail, and marine industries. The ultimate goal for any industry is to create sufficient quality welds as quickly as possible in order to maximize profits and minimize time to market. One of the difficulties currently associated with the FSW process is that the speed at which the weld is created has a strong impact on the quality of the weld. Ideally the weld would be created as fast as possible. If the weld is carried out too quickly, however, defects will be present in the weld. When a defect is found in an industrial weld, the part is rejected, causing unwarranted downtime. This is undesirable and should be avoided.

One approach for determining the fastest welding speed is to carry out a numerical simulation of the process. Because of the enormous level of plastic deformation occurring during the process, conventional finite element methods (FEM) cannot be used: indeed the mesh becomes highly distorted (the mapping between the computational and geometric domains breaks down) and the calculation fails before any meaningful data can be acquired.

The problem

The NRC works closely with a number of major players in the automotive and rail industry. We are involved in many projects where we must determine the optimal welding parameters that will not cause defects in the welded joint. At this point in time we use a meshfree method called Smoothed Particle Hydrodynamics (SPH) to simulate the welding process (see Fraser et al. [2] for details). Although the meshfree method is well suited for large deformation problems, it is computationally expensive and leads to computing times that are unduly long.

Our industrial partners require a simulation approach that is able to provide optimal process parameters as quickly as possible. The prospect of having to wait a number of days or even weeks to find optimal process parameters is undesirable. Thus a more efficient approach is required to serve the industry in a better way.

The Challenge

The goal of the team will be to develop a computationally efficient model to predict the presence of defects in an FSW joint. The following elements play an important role in the FSW process.

1. Large plastic deformation

2. Material mixing

3. Heat generation due to plastic deformation and friction

4. Heat transfer within the aluminum

5. Heat transfer to the FSW tool and support structure

6. Microstructure evolution in the weld zone

The following experimental data is available to validate the results of the team.

1. Temperature histories at various locations in the aluminum plates

2. Defect locations and sizes

3. Forces and torque on the welding tool

Once the approach is validated, it can be used to find optimal parameters that will not cause defects. An efficient optimization scheme should be used to minimize the number of iterations required to compute the optimal parameters. Our ultimate goal is to allow our industrial partners to determine quickly how fast a weld can be created. This will allow them to minimize costs and maximize productivity.

References

1. L. I. Kiss, L. St-Georges, and E. de Varennes, *Tool-material Interface in Friction Stir Welding*, 7th International Symposium on Friction Stir Welding, 2008.

2. K. Fraser, L. St-Georges, and L. I. Kiss, *A Mesh-free Solid-Mechanics Approach for Simulating the Friction Stir-Welding Process*, in Joining Technologies (M. Ishak, Éd.), Rijeka, Croatia : InTech, 2016, pp. 27-52.