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INVESTIGATION OF MACHINE DESIGN FOR FRICTION STIR WELDING

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Introduction

The process of joining two pieces of metal together has not significantly changed over the last few decades. The basic idea used is to bring the pieces together and apply enough heat to melt the metal at the interface. The molten metal mixes and after cooling forms a strong joint. This process is called the fusion process. The most significant difference between the many fusion processes is how the heat is generated and applied. The Welding Institute (TWI), in Great Britain, has recently patented an innovative application of mechanical friction. TWI designed a tool and process called Friction Stir Welding (FSW) that uses friction to heat the metal to within a few hundred degrees Fahrenheit of melting, just to the point of being plastic-like. The tool then stirs the plasticized metal together forming a joint that has been shown to be as good or better than an equivalent fusion joint. The FSW process is well suited for the joining of the aluminum alloys used in the aerospace industry. The relatively low melting point of aluminum eliminates the requirements for exotic materials for pin tool design. The FSW process has been successfully used to join alloys such as 7075 which were before considered "un-weldable", and aluminum-lithium 2195 which exhibits many problems when fusion welded.

The objective this summer was to investigate the design of a FSW system that could take this process from the laboratory to the manufacturing floor. In particular, it was the goal of my NASA colleague to develop a concept for applying the FSW process to the manufacturing of aluminum cryogenic oxygen and hydrogen tanks, of the sort used to make the Shuttle External Tank. Much more was accomplished this summer than was planned because of NASA's extreme interest is applying the friction process to the repair of small defects found in the fusion welds of the new Super Light Weight External Tank (SLWT). The SLWT is being made of 2195 which has presented many problems in weldability for initial welds and repair welds. It has been common with 2195 for small defects to turn into big defects after several attempts at traditional fusion repair methods. The fusion process combined with the 2195 alloy has led to problems with penetration, porosity, and residual stress. Preliminary tests have indicated that using the FSW process to repair through fusion welds leads to improved mechanical properties. For this purpose we traveled to the Michoud Assembly Facility near New Orleans Louisiana where the external tanks are manufactured by the Lockheed-Martin Aerospace Corporation. Our purpose there was to examine the actual welding tooling used on the tank to investigate the feasibility of using the FSW process. Our conclusion was that replacing fusion welding with FSW on existing welding fixtures was not going to be easy because of several issues: 1) the fixturing was designed to hold the parts together with zero forces exerted by the welding process, not the thousands of pounds of force due to the FSW process; 2) in most cases, sufficient room was not available on the backside of the welding area for the FSW backup tooling; and 3) in most cases, the modifications could not be made without impacting the regular operation of the tools. My goal after this point was to more accurately determine the FSW loads and if variation in the parameters could be used to reduce this load.

The Friction Stir Welding Facility at MSFC

To experiment with the FSW process you need a FSW pin tool, a CNC milling machine, or similar, capable of rotating the pin tool to at least 500 RPM and pushing in the axial direction with at least 8000 pounds of force, and a positioning device or holder robust enough to take the axial loads without significant flexing.

The Metals Process Development Branch in building 4711 has such a facility. Their system consists of a very robust Kearney&Trecker five-axis CNC milling machine and an automated data acquisition computer (ADAC), Figure 1.

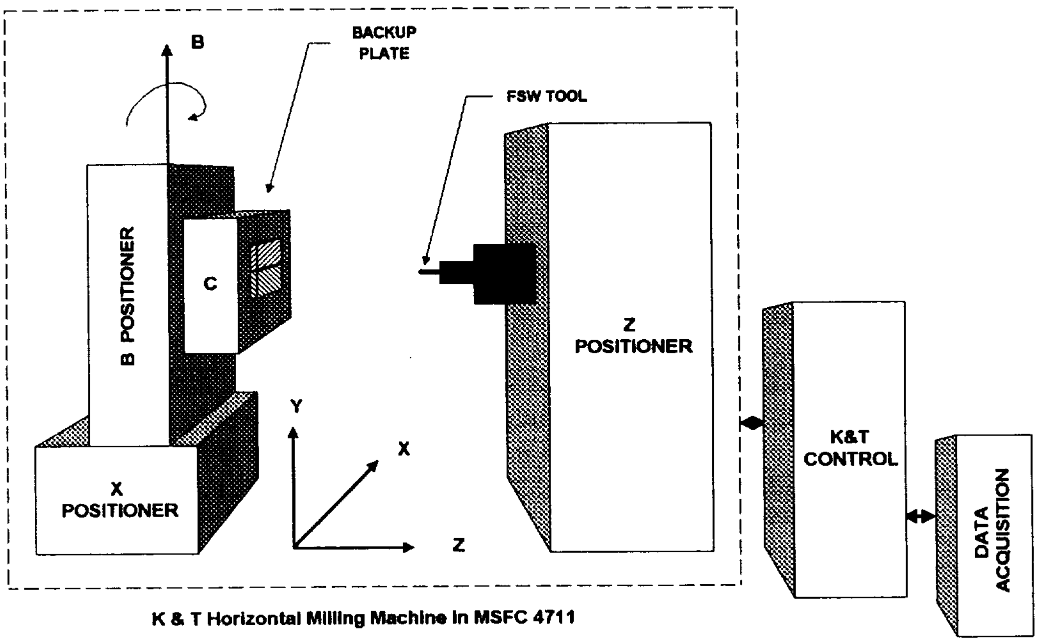

Figure 1. Friction Stir Welding System at MSFC.

The Initial Concept for a FSW System

I worked as part of a team consisting of my NASA colleagues Jeff Ding, Chip Jones, and Dr. Arthur Nunes; Peter Oelegetz with the Rocketdyne Corporation, and Dr. Glenn Adams from the University of Arkansas, a SFFP fellow. The approach taken this summer was to develop an initial skeleton of a concept for the FSW system and then fill in the details as we discovered and quantified the parameters associated with the FSW process. I started the SFFP program two weeks early, so I developed the first concept, Figure 2. It was the vision of my NASA colleague that Dr. Adams would then carry on the mechanical design of the FSW system and I would fill in the electrical portions (instrumentation and controls).

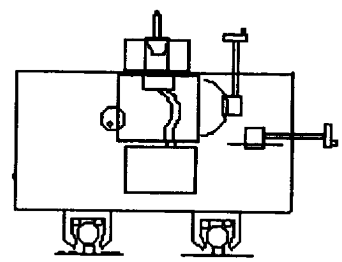

Figure 2. Initial Concept for a FSW Manufacturing System.

Modeling the Friction Stir Process

Because of the newness of the FSW process and the proprietary (profit) attitude of the companies developing it, very little is publicly known about the science of this process. For this purpose it became obvious that it would be appropriate for NASA to lead the effort to model this process. In order to do this it was first necessary to clarify the parameters of the FSW process, that is, what are the independent and dependent variables. The independent parameters include rotational speed (RPM), shoulder depth, pin-to-backup distance, lead angle, and travel speed. The dependent parameters include the axial load, transverse load, and temperature. Drs. Nunes and Adams developed an initial analytical model for the process. I designed and implemented a small DOE to try to obtain a large-scale view of how the FSW parameters interact.

In the experiment, I chose to collect data for RPM, axial load (Z), transverse load (X), fixture load (B), and the temperature of the weld. I chose to use four thermocouples spaced evenly along the 10-inch square butt joint. A typical plot of load and RPM is shown in Figure 3, and a typical thermocouple plot is shown in Figure 4.

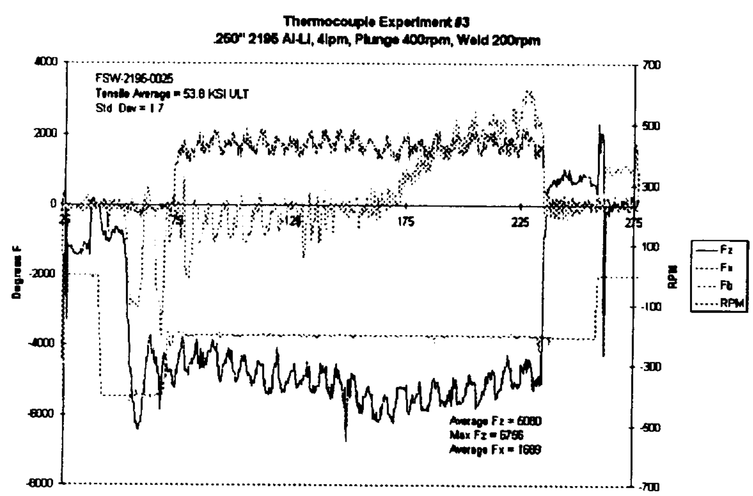

Figure 3. A typical plot of load and rotational speed.

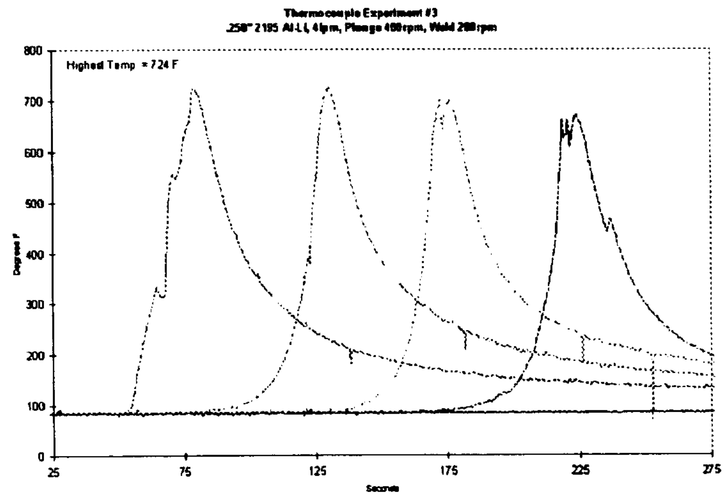

Figure 4. A typical plot of welding temperature.

Discovery of the Backside Relief

A significant discovery was made during the thermocouple experiment. Pete Olegetz had the idea to machine four notches in the back of one plate to pass the thermocouples through so that they could be consumed in the weld but not destroyed by the shoulder. Observations made by Dr. Adams, Pete Oelegetz, and myself of how the plasticized aluminum flowed nicely into the notches led to the V-groove backside relief experiment in which we intentionally produced a void on the backside of the butt joint. As in the thermocouple experiments, the plasticized aluminum flowed nicely into the V-groove filling it. The resulting weld did not exhibit the lack of penetration which commonly occurs in the FSW process when the pin is not sufficiently close to the backup, this can be seen in the microstructure of Figure 5. The resulting tensile fracture, elongation and variability of this data was significantly better than any other data collected at MSFC.

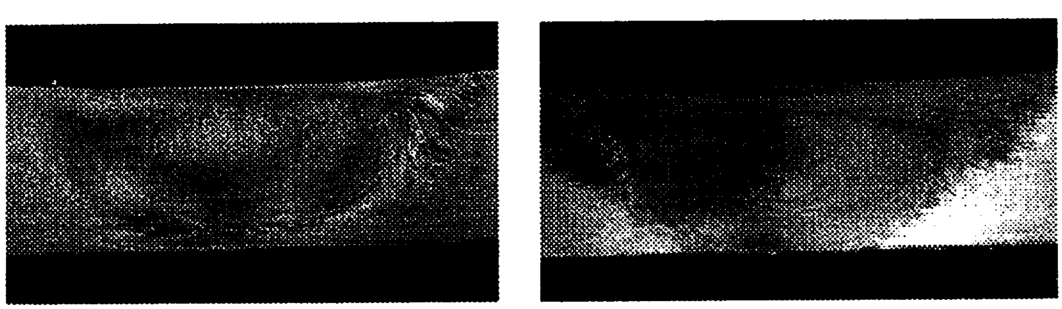

Figure 5. Microstructure without (left) and with (right) the V-groove backside relief.

Summary and Conclusion

The Friction Stir Welding process is sure to become a standard joining process for aluminum alloys, especially in the aerospace industry. The results of this summer have led to a better understanding of how variation of the parameters effects the loads, temperature, and resulting mechanical properties. It is strongly believed that using the FSW process for linear repairs is the superior technique for repairing defects in fusion welded aluminum-lithium. The backside relief is an obvious part of the final FSW technique and there is a clear need for a DOE to characterize the optimum relief that should be used.

Acknowledgment

The accomplishments of this summer would not have been possible without the technical input and direction from my NASA colleague, Jeff Ding of the Metals Processes Branch (EH23). I would also like to thank and commend all of the SFFP administrators and staff for a professionally and smoothly operated program.