

Experimental Thermo-mechanics of Friction Stir Welding

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Introduction

Friction stir welding has seen increasing use in industry during the past few years. While the welding process has been optimized to perform welds in a variety of alloys, weld geometries, and material thickness, there is still substantial disagreement about the best way to model the process. One reason that this process is so difficult to model is that little data exists for modeling the stress characteristics of metals under the unique combination of temperature, strain, and strain rate present in a friction stir weld.

In the current work, friction stir welding was performed with a combination of spindle speeds and feed rates. The forces and peak temperatures were measured for each of these combinations to experimentally measure the effects of the input parameters on the forces and consequently the stresses.

Experimental Procedure

A smooth nib tool was used to do bead on plate welds in ¼" thick Aluminum 6061-T6 plate. Eight combinations of speed and feed rate were used, and are given in Table 1.

Table 1. Welding Parameters

	3 in/min	5.125 in/min	7.250 in/min
220 rpm	Data Taken		
400 rpm	Data Taken	Data Taken	Data Taken
593 rpm	Data Taken	Data Taken	Data Taken

The combinations of 5.125 in/min and 220 rpm and 7.25 in/min and 220 RPM were not tested because it was thought that the forces produced from such a cold weld would break the tool. The tool was mounted in a Kistler model 9124B rotating cutting force dynamometer and was used to measure the translational force (force opposite the direction of travel), the transverse force (force perpendicular to the direction of travel), the axial force (force directed along the tool axis), and the torque imparted to the tool. Thermocouples were imbedded along the centerline of the weld and were welded through to measure the peak welding temperature.

Results and Discussion

The most interesting discovery was that in almost all of the welding combinations used, the transverse force was greater than the translational force. The ratio of transverse to translational forces is given in Table 2.

Table 2. Transverse/Translational Force

	3 in/min	5.125 in/min	7.25 in/min
220 rpm	0.45		
400 rpm	2.47	2.08	0.54
593 rpm	5.70	3.92	2.60

As seen in the Table 2, only the combinations of 3 in/min and 220 rpm and 7.25 in/min and 400 rpm produced translational forces higher than the transverse forces. The ratio in Table 2 is related to another interesting ratio, that is the ratio of the surface velocity due to rotation to the translational velocity. This ratio can be seen in Table 3.

Table 3. Radial Surface Velocity/Translational Velocity

	3 in/min	5.125 in/min	7.25 in/min
220 rpm	58		
400 rpm	105	61	43
593 rpm	155	91	64

As seen from the two tables above, the first ratio is proportional to the second. As radial surface velocity increases relative to the translational velocity, the transverse force increases relative to the translational force. If we assume that the transverse force is due mainly to the shearing action of the tool against the metal, and that the translational force is due mainly to the normal force on the front of the tool, the results would indicate that in most cases, shear is the dominant mechanism. This would make sense since the radial surface movement would cause shear and as it increases, so does the transverse force. The two cases above in which the translational force was higher than the transverse force also had the lowest ratio of radial surface velocity to translational velocity. This would seem to indicate that at some critical point when the radial surface velocity is too low to move the metal out of the way fast enough, the metal piles up in front of the tool, and the net result would be a higher normal force.

Conclusions

This work showed that there is a unique combination of shear and normal forces at work in producing a friction stir weld. An understanding of the contribution of the two forces and their relationship to each other is important in modeling the friction stir welding process.