Comparison of Heat Inputs: Friction Stir Welding vs. Arc Welding

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Introduction

Friction Stir Welding (FSW) is a relatively new solid-state joining process developed at TWI in 1991. The process has proven very successful in economically joining Al alloys. Recent advances in tool materials and designs have also permitted FSW of steel and Ti alloys (Refs. 1,2). Mechanical properties of FSWs in Al alloys typically exceed those of arc welds produced on the same alloys. Acceptable mechanical properties have also been achieved in FSWs on steel and Ti alloys (Refs. 1,2).

Among the advantages cited for FSW is a decreased heat input relative to arc welds. Lower heat input in FSW is credited with improved mechanical properties as well as decreased distortion and residual stress. However, no measurements of heat input have been reported to corroborate this claim. The objective of this work was to measure heat inputs for FSWs to allow comparison with heat inputs calculated for GTAW and GMAW of the same materials.

Experimental Procedure

The materials used include plates 7075-T6, 5083-O, 6082-T6, and 6061-T6 Al alloys as well as 1010 steel and Ti-6 Al-4 V. All materials were nominally ¼" in thickness. The welds were made using a tool with a ¾-in. shoulder diameter with previously optimized parameters for each alloy. A set of strain gauges was permanently attached to the tool holder to give both torque readings during welding. The strain gauges were wired to modules in a plastic ring attached to the spindle of the FSW machine. The data from these modules was transmitted, during welding, from the rotating spindle via an antenna system to a data acquisition system and then downloaded to an oscilloscope. The instrumentation was calibrated prior to welding using a torque load cell. Further details of the equipment have been reported previously (Ref. 3)

The power consumed and heat input for FSW were calculated using the following expressions:

$$\text{Power (energy / time)} = [2\bullet \text{(RPM) (Torque)}] / 60$$

and

$$\text{Heat Input (energy / length of weld)} = f_1 \text{ (Power / Travel Rate)}$$

where f_1 is the process efficiency, i.e. the fraction of heat generated that remains in the workpiece. Power and heat input for GTAW and GMAW were calculated using similar expressions:

$$\text{Power (energy / time)} = [V \times I]$$

and

$$\text{Heat Input (energy / length of weld)} = f_1 \text{ (Power / Travel Rate)}$$

where V and I are arc voltage and current, respectively. For arc welding calculations, values for V, I and travel rate were taken from tables of recommended practices (Ref 4). Values for f_1 were estimated from publications by other authors (Ref 4). A value of 0.8 was used for f_1 in calculations for both GTAW and GMAW.

Results and Discussion

Values for heat input for FSW, GTAW and GMAW of all of the materials are given in Table 1. Process efficiencies of 0.9 were assumed for FSW of the Al alloys, while a value of 0.6 was used for the steel and Ti alloys. Approximate travel speeds for FSW are given in parentheses next to each alloy in the first column of the table. While different FSW parameters were used for FSW of the Al alloys, the same parameters were assumed for GTAW of all of the Al alloys. Similar assumptions were made for GMAW of the Al alloys. Power and heat input are not reported for GTAW of the 1010 steel or Ti alloy since this process is rarely used with these alloys.

Inspection of the data reveals that heat inputs for FSW of Al alloys ranges from approximately 6.5 kJ/cm to 14.4 kJ/cm, while typical heat inputs for GTAW and GMAW of the same alloys are both approximately 6 kJ/cm. Note that the uncertainty associated with the process efficiency assumptions for FSW is at least $\pm$ 25%. Nonetheless, it is clear from the data that the heat inputs for FSW are of the same order of magnitude as those for arc welding even if the uncertainties are considered. Faster FSWs can be successfully produced on all of the Al alloys and the heat input lowered somewhat. The data further suggest that heat inputs for FSW of steel are greater that that for arc welding. Finally, heat inputs for arc welding of Ti-6 Al-4 V appear to be close to those for arc welding.

Conclusions

Heat inputs were determined for FSW of several materials to allow comparison with arc welds on the same materials. Heat inputs for FSW appear to be of the same order of magnitude as those for arc welding despite the large uncertainty associated with the process efficiency assumptions for FSW.

References

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4. Welding Handbook, Eighth Edition, 1996, Volumes 3 and 4.

Table 1: Power and Heat Input for FSW and Arc Welding

Alloy	FSW		GTAW		GMAW	
	P (W)	HI(kJ/CM)	P (W)	HI(kJ/CM)	P (W)	HI(kJ/CM)
6061Al (11 ipm)	3265	6.59	3850	6.05	5200	6.10
5083 Al (4.5 ipm)	2030	9.57	3850	6.05	5200	6.10
7075 Al (3.1 ipm)	2105	14.36	3850	6.05	5200	6.10
6082 Al (11 ipm)	3382	6.53	3850	6.05	5200	6.10
1010 steel (3 ipm)	2710	12.80	NA	NA	10120	6.38
Ti-6 Al-4 V (4 ipm)	2200	8.31	NA	NA	9300	9.38