Evaluation of Post-Weld Heat Treatments for Corrosion Protection in 2024 and 7075 Aluminum Alloys

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1. Introduction

Patented in 1991 by The Welding Institute, Ltd., Friction Stir Welding (FSW) is a solid-state joining process capable of joining almost any type of metal, including some previously un-weldable precipitation strengthened 2000 and 7000 series aluminum alloys [1]. FSW can be accurately described as a forging and extrusion, or metalworking, process. In the process, a cylindrical tool, composed of a pin and shoulder, is rotated and slowly plunged into the joint line of the materials to be joined. The pin tool generates heat through friction and plastic strain energy release during mechanical deformation of the workpiece, which softens the material. Then, as the tool traverses the joint line, the material is extruded around the pin and is forged into a consolidated joint by the pressure of the shoulder.

The resulting weld is composed of three primary zones: the heat-affected zone (HAZ), the thermo-mechanically-affected zone (TMAZ), and the weld nugget. Tensile failure most often occurs in the area between the HAZ and the TMAZ, where high temperatures dissolve GP zones and coarsen strengthening precipitates, creating a local strength minima in the region [2,3]. Due to the change in precipitate morphology, this region is also generally susecptible to corrosion [4]. One way to potentially improve the resulting corrosion properties is through post-weld artificial aging (PWAA) treatments. The goal of this research was to identify proper initial temper selection and post weld aging treatments for the enhancement of the corrosion resistance of both 2024 and 7075 alloys, and their dissimilar joints.

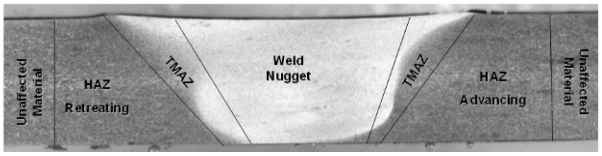

Fig. 1. FSW weld zones.

2. Experiment, Results, Discussion, and Significance

For this PWAA investigation, plates nominally 0.125-inch thick, 6 inch wide, and 25 inch long were friction stir butt welded in 7075 in the T6 and T73 tempers, as well as for 2024 in the T3 and T81 tempers. All of the welds were made at 600 rpm and 8 ipm, under load control, using the fixed pin tool shown in Fig. 2. Samples were machined from steady-state portions of the weld and were evaluated using optical microscopy, microhardness, electrical conductivity, tension, and exfoliation corrosion testing. A large number of heat treatments were investigated. Heat treatments were chosen based on conventional metallurgy, literature review findings [5], and an understanding of precipitation kinetics.

Fig.2. FSW fixed pin tool.

Both T81 and T73 are considered highly-stable overaged tempers, as they have received substantial post-weld artificial aging at temperatures that have allowed the majority of the dissolved solute to precipitate into stable phases. On the other hand, T3 and T6 are stabilized or peak-aged tempers, which have a much higher percentage of dissolved solute and therefore intrinsically possess a greater thermodynamic potential for transformation. Thus greater sensitivity to FSW in observed in 2024-T3 and 7075-T6 than either 2024-T81 or 7075-T73, respectively.

After welding, coupons were prepared for exfoliation testing per ASTM G-34. The heat treatments in Table 1 were applied prior to testing. Samples were exposed for 96 hours. All naturally aged specimens showed obvious signs of severe attack in the weld region, except 2024-T81, which had excellent exfoliation resistance in the as-welded condition. None of the treatments were successful in restoring the exfoliation corrosion resistance to 7075-T6, not even the RRA treatments, which exhibited pitting in the HAZ in all cases. Beneficial treatments were found, however, for both 2024-T3 and 7075-T73. A beneficial treatment was also discovered for a 2024-T81/7075-T73 dissimilar joint, where previous attempts to create a 2024 to

7075 dissimilar joint observed extreme corrosion attack in the weld zone [6]. Micrographs of the exfoliation results are shown in Fig. 3.

Table: 1
Specific heat treatments investigated

2024-T3	2024-T81	7075-T6	7075-T73	2024/7075
Naturally Aged	**Naturally Aged**	**Naturally Aged**	**Naturally Aged**	**Naturally Aged**
24 hrs at 225 °F	**24 hrs at 225 °F**	**24 hrs at 225 °F**	**24 hrs at 225 °F**	**24 hrs at 225 °F**
100 hrs at 225°F	**100 hrs at 225 °F**	**100 hrs at 225 °F**	**48 hrs at 225 °F**	**100 hrs at 225 °F**
9 hrs at 355 °F	**4 hrs at 325 °F**	**9 hrs at 355 °F**	**100hrs - 225°F**	**2 hrs at 325 °F**
1.1 hrs at 365 °F	**1 hrs at 375 °F**	**RRA*: 8 hrs at 320 °F**	**1 hr at 325 °F**	**4 hrs at 325 °F**
2.3 hrs at 365 °F	**2 hrs at 375 °F**	**RRA*: 11 hrs at 320 °F**	**2 hrs at 325 °F**	
4.5 hrs at 365 °F	**4 hrs at 375 °F**	**RRA*: 2 hrs at 355 °F**	**4 hrs at 325 °F**	
9 hrs at 365 °F		**RRA*: 3 hrs at 355 °F**	**8 hrs at 325 °F**	
12 hrs at 375 °F		**9 hrs at 355 °F**	**24 hrs at 325 °F**	
		12 hrs at 375 °F	**3,4,5 hrs at 310,325,340°F**	

* RRA treatments were completed by heating for 24 hours at 250°F.

Both microhardness and electrical conductivity testing were performed to validate and explain the beneficial changes in the corrosion behavior of the various materials. In general, microhardness values decreased with increased aging time at temperatures above approximately 300°F, while electrical conductivity increased. Increases in electrical conductivity are associated with improvements in corrosion properties, especially in 7075 [7].

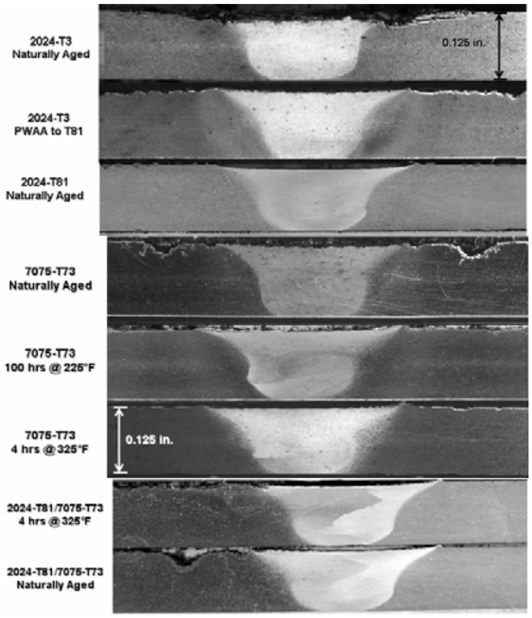

Fig. 3. Micrographs of exfoliation results for select PWAA treatments.

Tensile testing was also conducted to determine the extent to which joint strengths were affected by PWAA. As predicted by the trends in microhardness, a reduction in tensile strength was observed with increased PWAA time when treated above approximately 300°F. This is primarily attributed to a dissolution of the strengthening GP zones, and a coarsening of the fine strengthening precipitates.

3. Conclusions

1) When welding 2024 in the T3 condition, the only treatment found to improve the exfoliation resistance of the weld zone was artificial aging to a full or partial T81 condition.
2) For maximum corrosion resistance, with no PWAA, 2024 material should be welded in the overaged T81 condition.
3) When corrosion is a concern, joining 7075 material originally in the T73 condition followed by PWAA, is preferable to welding in the T6 temper followed by aging to T73. This is primarily because of higher tensile and yield strengths and better exfoliation corrosion resistance.
4) Retrogression and re-aging treatments do not appear to improve joint properties of T6 material due to the severity of the overaging in the HAZ caused by FSW.
5) A PWAA treatment, like 4 hours at 325°F, has the added benefit that while it stabilizes the microstructure and enhances corrosion resistance, with only a slight reduction in tensile strength, it also does not invalidate the bulk material properties of 7075-T73 per AMS 2770 rev G [8].
6) A dissimilar joint with good corrosion resistance is possible between 2024-T81 and 7075-T73 when the 2024-T81 is on the advancing side, followed by PWAA for either 100 hours at 225°F or 2-4 hours at 325°F.

Table: 2
Tensile strength (TS), yield strength (YS), and percent elongation (%EL) for select alloy and PWAA combinations.

Alloy/ Temper	PWAA	TS {ksi}	YS {ksi}	%EL
2024-T3	**Naturally Aged**	**63.5**	**45.8**	**12.2**
2024-T3	**PWAA to T81**	**53.0**	**41.9**	**11.1**
2024-T81	**Naturally Aged**	**59.5**	**44.0**	**11.0**
7075-T73	**Naturally Aged**	**69.2**	**49.2**	**14.0**
7075-T73	**4 hours at 325°F**	**68.7**	**54.9**	**9.5**
7075-T73	**100 hours at 225°F**	**70.1**	**55.6**	**18.4**
7075-T6	**PWAA to T73**	**64.1**	**52.5**	**11.4**
7075-T6	**RRA*: 3 hrs at 355°F**	**62.3**	**49.1**	**7.2**
7075-T6	**Naturally Aged**	**74.9**	**52.8**	**18.3**
2024-T81/ 7075-T73	**4 hours at 325°F**	**61.8**	**46.1**	**9.4**

4. Acknowledgements

The work presented here was conducted with funding from the State of Kansas and the Federal Aviation Administration in partial fulfillment of the requirements for a doctor of philosophy in mechanical engineering at Wichita State University. Special thanks are extended to the author's dissertation committee and to the National Institute for Aviation Research.

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