The Influence of Tool Geometry on Mechanical Properties of Friction Stir Welded AA-2024 and AA-2198 Joints

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Abstract

The tool geometry in friction stir welding (FSW) is a critical parameter to produce reliable and consistent joints, especially when it comes to joining dissimilar alloys with different mechanical and thermal properties. The aim of the present work is to investigate the effect of FSW tool design on the mechanical characteristic of as-welded AA2198(T3)-AA2024(T3) joints. Three shoulder profiles (flat, spiral, and fan) and five different pin profiles (tapered cylindrical, straight cylindrical, threaded cylindrical, cone and square) were tested. A visual inspection and metallographic characterization were conducted to evaluate the sound state of the joint. Tensile tests and scanning electron microscopy combined with energy-dispersive X-ray spectroscopy were used to assess the mechanical properties of the different joints in regard to fractographic analyses and local chemical composition. Significant flash was produced for flat shoulder configurations. FSW tools with fan or with spiral shoulders prevent the formation of the flash defect. Lack of penetration (LOP) and kissing bond defects were avoided by tapering the tip of the pin with a diameter greater than or equal to the plate thickness. The tapered cylindrical pin with a fan shoulder was the optimal tool design configuration for mechanical properties.

Keywords: FSW tool design; friction stir welding; Al-Li alloys; 3rd generation aluminum alloys; 2024 aluminum alloy.

1. Introduction

Developing advanced alloys with superior mechanical properties and new manufacturing processes is essential for the aerospace industry. Recently developed aluminum alloys, such as the AA-2198 Al-Li alloy, emerged to improve the mechanical properties and lower density of their conventional counterparts, e.g., AA-2024 [1]. However, these benefits come at the expense of higher material cost. Therefore, an economical solution is to use AA-2198 alloys only for critical regions/components, with the remaining structure retaining AA-2024 alloys. A method for to joining these dissimilar materials is therefore needed. Unfortunately, conventional fusion welding methods are not appropriate solutions as they result in welding defects, such as hot cracking [2].

Friction Stir Welding (FSW) is a solid-state welding technique that has evolved as a solution for joining dissimilar materials that are difficult to weld [3]. It is currently used as an alternative to riveting for the assembly of airplane fuselages. FSW uses a rotary pin to locally mix the materials of the two sides of the joint below the melting point temperature. Thus, the formation of welding defects such as hot cracking is prevented.

Selecting appropriate FSW tool and process parameters is essential for creating a reliable joint in aerospace applications, especially for joining dissimilar alloys with different mechanical and thermal properties. Both the shoulder and pin profiles are important for having a defect-free

joint. The optimization of either the shoulder [4 - 6] or the pin design [7 - 11] for FSW tools has been reported in the literature for producing joints with optimum mechanical properties. Trueba Jr. et al. [6] showed that the fan shoulder has a great potential for producing high quality welds, even under non-ideal process conditions. Krasnowski [12] showed that cylindrical pins with and without thread are capable of producing defect-free joints for AA-6082-T6 aluminum alloys. The effect of pin geometry on the mechanical properties of FSWed 2014 aluminum alloy was also reported by Zhao et al. [13]. They found that the optimum weld quality was obtained by using the taper pin with a screw thread.

The last generation of aluminum alloys comprises relatively new materials, and tool design optimization for these materials required particular investigation. Among the few works conducted on the FSW of dissimilar aluminum alloys, Velotti and Astarita reported critical technological challenges facing FSW for lap joints of AA-2198-T351 and AA-7075-T6 alloys [14] and T-shaped joints of AA-2198-T3 and AA-6056-T4 [15]. Dissimilar friction stir welded butt joints made of AA-2024-T3 and AA-2198-T3 have already been investigated in terms of microstructural and specific mechanical characterizations [16, 17]. In this study, the effect of tool shoulder and pin profile on the microstructure and mechanical properties of FSWed AA-2024-T3/AA-2198-T3 joints were documented right after welding, without any natural aging. To that end, three different shoulder and five tool pin profiles were used to fabricate the joints, while the other welding parameters were kept constant.

2. Experimental

2.1. Tool design

The possibilities in tool design are endless, but the combinations of shoulder and pin profiles are crucial for the quality of the finished weld. A comprehensive literature review was carried out in order to determine relevant choices for the tool design. A review of all the selected design parameters is detailed in Table 1 [5, 6, 18 - 22]; based on this review, seven tool configurations denoted from A to G in Figure 1 were designed and manufactured to evaluate the quality of the joint. Because information on the minimal pin diameter in the tapered pins at the welding joint was lacking in the literature, the effect of this parameter is also evaluated in the present study (Table 1).

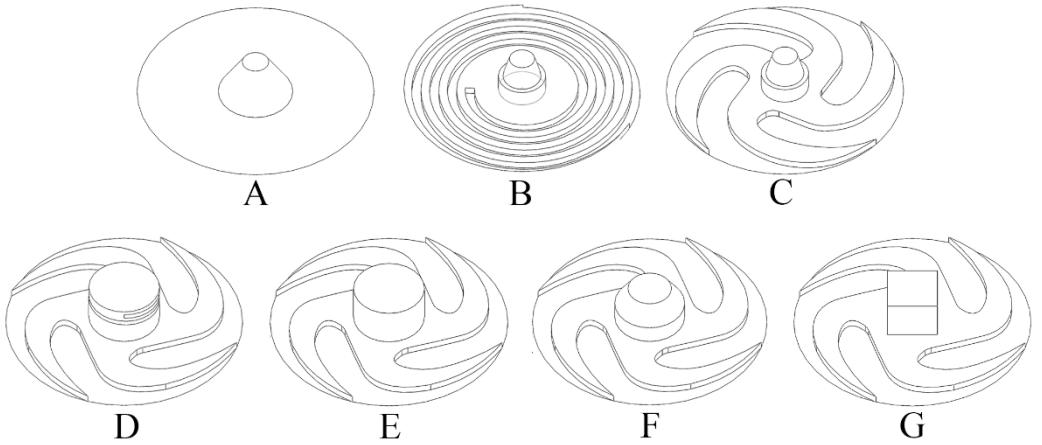

Figure 1. Tool configurations: (A) Flat shoulder with conical pin, (B) Spiral shoulder with stepped conical pin, (C) Fan shoulder with stepped conical pin, (D) Fan shoulder with threaded cylindrical pin, (E) Fan shoulder with cylindrical pin, (F) Fan shoulder with tapered cylindrical pin, (G) Fan shoulder with cubic pin.

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6. References

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