A brief review on Friction Stir Welding of Aluminium Alloys

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Abstract:

Friction stir welding is a solid state welding technique specifically for Aluminum and its alloys. But with the passage of time, the research in the field of FSW extended to a variety of metals including magnesium. In friction stir welding, the weld is made within the workpieces by a solid non-consumable rotating and traversing uniquely fabricated tool having a shoulder & pin which causes necessary heating for the joint. The tool used in FSW is the most important part as, initially the pin contact with specimens creates frictional heating and deformation thus softening the metal and then contact of shoulder further increases the heating and there is an expansion in the zone of softened material.

Keywords: Aluminum alloys, FSW, magnesium alloys, FSW tool

1. INTRODUCTION:

Friction stir welding abbreviated as FSW was invented specifically for Aluminum and its alloys [1-3]. FSW; an extension of Friction Welding (FRW) has a lot of advantages associated with it [4]. The basic principle of operation of FSW process is that the plasticized material formed in the abutting surface, due to localized heating, is rotated with the pin from front to back, thereby filling the created hole and forming a strong metallurgical bond. The joint fabricated by FSW is acted upon by high temperature gradients and high strain rates. Due to variations in the temperatures and strain rates at various locations in the friction stir welded specimens, there are distinct zones created, which are the weld nugget, thermo-mechanically affected zone, heat affected zone and unaffected base metal. These zones are distinguishable based upon the microstructures and mechanical properties.

The tool in FSW process serves very important functions of creating heat in the workpiece, softened material movement from front to back of the pin to create the joint, and restricting the hot material under shoulder surface such that it does not flow outside the joint forming the flash [5, 6]. The pin length of the tool is kept slightly shorter than the workpiece thickness so as to avoid contact with the backing plate and shoulder diameter is generally kept 2-4 times of the pin diameter. The space left out in-between the end of the tool pin and end surface of specimens is known as penetration ligament [7].

Since its initiation, FSW is being focused upon by many researchers across the globe. In the beginning, only soft aluminium alloys were being focused for welding through FSW. But gradually, various other materials like high strength aluminium alloys, magnesium alloys, copper alloys, dissimilar metals and even steel are being considered for joining through FSW. During friction stir welding the important points to be considered are the process variables i.e. tool rotational speed, tool travel speed, plunge depth, axial force and tool parameters i.e. tool dimensions, tool pin profile and tool material.

2. BRIEF REVIEW OF FSW ON ALUMINIUM ALLOYS:

Since the initiation of FSW, various researchers have focused on optimizing process parameters for obtaining high strength aluminium alloy welds. Adamowski et al. [8] analyzed the effects of varying rpm and travel speed on mechanical and microstructural changes in FSW of AW6082-T6 aluminium alloy. FSW welds were fabricated at 7 different rotational speeds and 5 different travel speeds. Temperature measurements during FSW showed that temperature at advancing side is higher as compared to retreating side. At constant rotational speed, with the increase in welding speed, the amount of heat input decreases. Visual inspection of the welds revealed the occurrence of excessive flash and surface-open tunnel, as shown in Figure 1A and 1B respectively, which is attributed to insufficient downward pressure. Microstructural examinations of welded samples revealed grain refinement after FSW which was attributed to dynamic recrystallization resulting due to elevated temperatures and high strain rates.

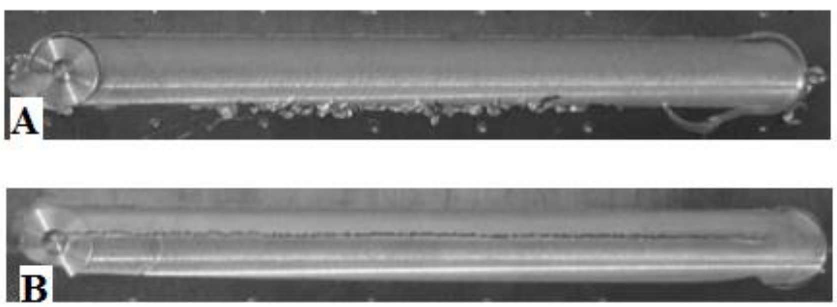

Figure 1: FSW joint representing, A) Lateral flash, B) Surface open tunnel [8]

Tensile strength was observed to be directly proportional to the travel speed. Hardness in the weld nugget and heat affected zone were observed to be lower than the base metal. Arora et al. [9] evaluated the development of microstructure in different zones of friction stir welded AA2219 aluminium alloy. It was found that weld nugget contains very fine grains which are of almost equal size. This was attributed to continuous dynamic recrystallization as observed from grain boundary misorientation. Astarita et al. [10] measured the forces acting in the tool during friction stir welding of AA2024-T3 aluminium sheets. The forces were measured parallel (X-axis) and perpendicular (Z-axis) to the tool movement using a dynamic dynamometer.

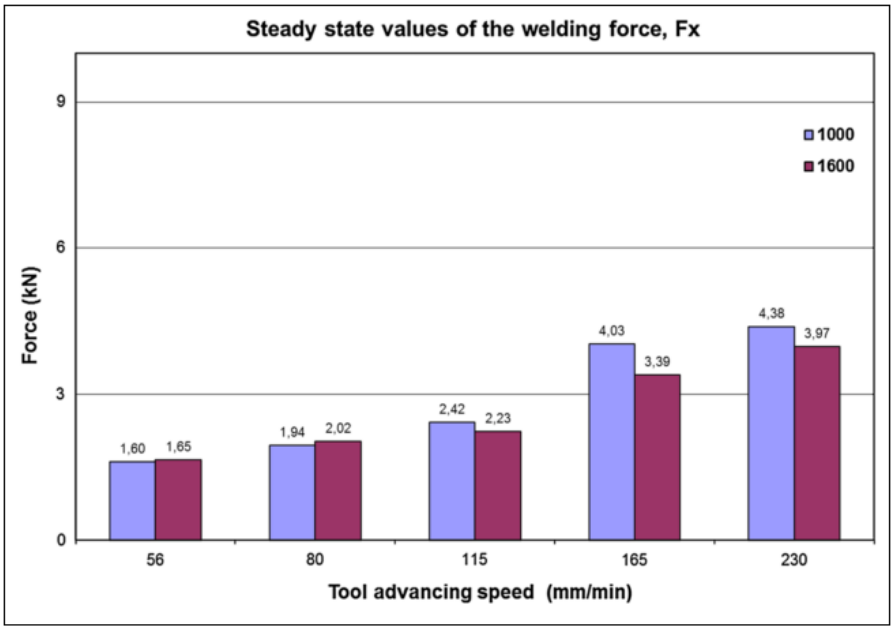

Figure 2: Variation of force in x direction with increasing tool travel speed [10]

The experiments were carried out at two rpms (1000 and 1600) and varying travel speeds from 56mm/min to 230mm/min. At constant rpm, with increasing travel speed, the forces measured in X and Z directions were found to increase as shown in Figure 2. Cavaliere et al. [11] analyzed mechanical and metallurgical properties of friction stir welded 6056 aluminium alloy at varying rpm (500, 800 &1000) and varying welding speeds (40, 56 and 80mm/min). Forces measured in X and Z directions were found to increase with increasing welding speed. Higher values of tensile strength were achieved at higher rotational as well as traverse speed (1000rpm and 80mm/min). Similar pattern was observed in the microhardness values measured in transverse distance from weld centre. Microstructural investigation revealed fine and equiaxed grains after FSW. They also fabricated joints of aluminium alloy AA6082 using friction stir welding at fixed rotational speed (1600rpm) & varying traverse speed (40-460mm/min) [12].

Similarly, Gaafer et al. (2010) studied the variation of input process variables: tool rotational speed and travel speed on the microstructural and mechanical characteristics during friction stir welding of aluminium AA7020-O alloy. Three rotational speeds (1120, 1400 & 1800rpm) and three welding speeds (20, 40 & 80mm/min) were used for fabricating the joints.

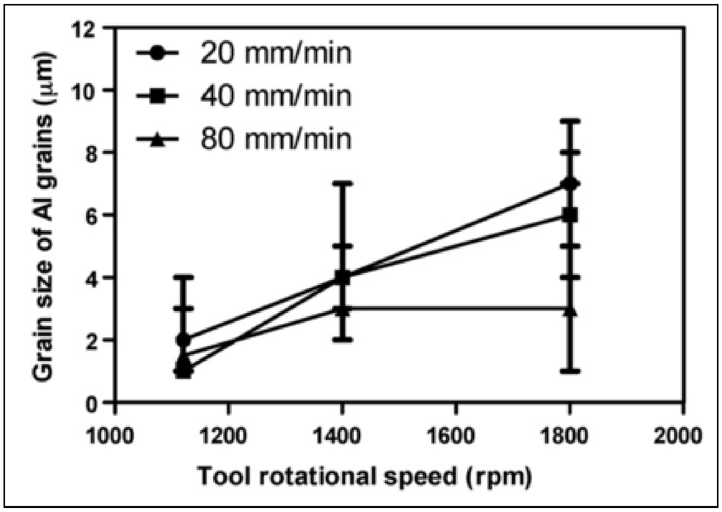

Figure 3: Variation in grain size with varying rotational and travel speed [13]

During microstructural analysis for identifying the defects, cavity free joints were observed only at 1400rpm and 20 & 40mm/min. Higher rotational speed and lower travel speed yielded comparatively larger grains due to higher heat input and slower cooling rates as shown in Figure 3. Boz et al. [14] studied the effect of stirrer (pin) geometry on the bonding and mechanical properties of 5mm thick friction stir welded Al 1080 alloy. They used two different stirrer geometries: square and threaded cylindrical with varying pitch (0.85, 1.1, 1.4 and 2.1mm) as shown in Figure 4. They observed that welds fabricated using higher pitch (1.4 and 2.1mm) were not proper and instead of acting as a stirrer, the tool acted as a drill.

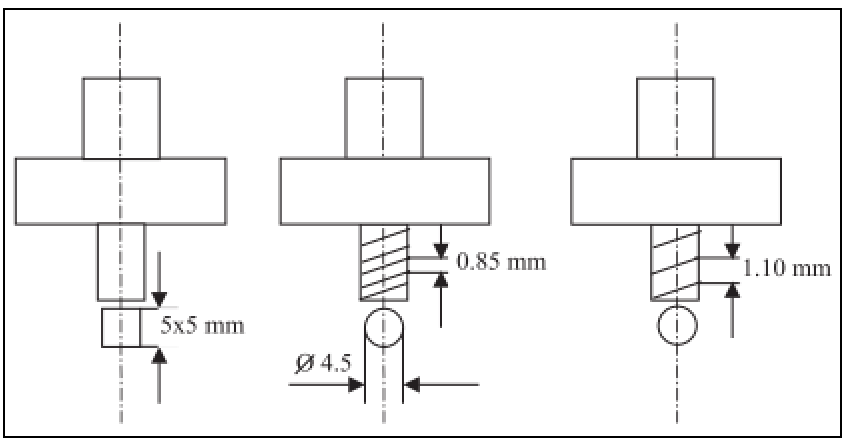

Figure 4: Various stirrers used for fabricating FSW joints [14]

It was suggested that pin plunge depth as well as pin profile need to be chosen carefully to avoid the formation of defects. At lower tilt angle i.e. 1˚, there appeared an open groove type defect. On increasing the tilt angle to 1.5˚, the groove disappeared but voids were observed in the root of advancing side. Five different tool pin profiles: straight cylindrical, taper cylindrical, threaded cylindrical, square and triangular for fabricating FSP joints of aluminium AA2219 alloy were used by Elangovan and Balasubramanian [15]. Rotational speed was kept constant at 1600rpm and welding speeds were varied as 0.37, 0.76 and 1.25mm/s.

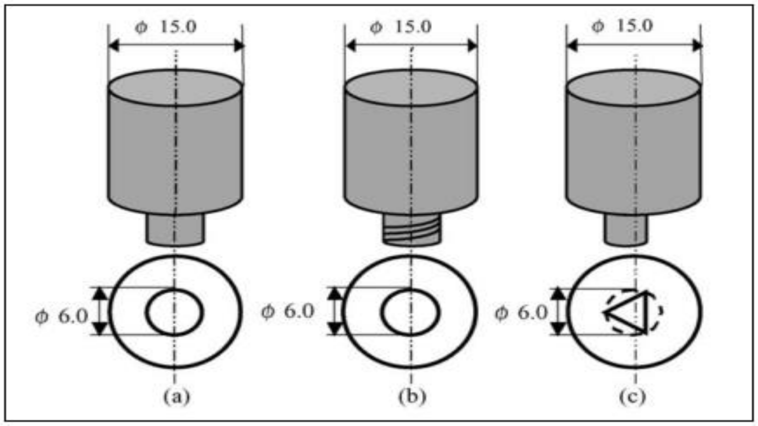

Figure 5: Various tool pin profiles used for experimentation [16].

Similarly Fujii et al. [16] used three different tool pin profiles (column with and without threads, triangular prism), as shown in Figure 5, for welding three different grades of aluminium alloys (1050-H24, 6061-T6, 5083-O). The rotational speed and travel speed used were different for different alloys. They used a parameter called revolutionary pitch {mm/r (distance/revolution)} for comparing the microstructure and properties of the welded specimens. Aval et al. [17] investigated the thermo-mechanical behavior and microstructural evolution of FSW of similar and dissimilar metal of AA5086 and AA6061 using 3D finite element software and compared with the experimental result at different process parameter. It was found that by using different strengthening mechanism in AA5056 and AA6061, hardness variation was observed at welded section and the fine grain size distribution was there in AA6061 side.

Improvement in mechanical properties of natural ageing of AA6061 after weld for similar weld joint was more as well as peak temperature and cooling rate for similar weld of AA6061 was large as compared to dissimilar weld. Elangovan et al. [18] performed friction stir welding experiments on 6061 aluminium alloy 6mm thick plates to optimize the process parameters for maximizing tensile strength. They used 4 factor 5 level central composite design and performed 31 experiments as per the experimental design matrix. For high strength AA2024-T351 aluminium alloy, corrosion behaviour of friction stir welded joints was discussed by Jariyaboon [19]. Joints were fabricated at three different rotational speeds (215, 350 & 468rpm) and three different travel speeds (75, 95 and 154mm/min). Maximum temperature observed during the welding process was 481˚C and it was observed that peak temperatures were higher at lower rotational speeds as the material was exposed to higher temperatures for longer time.

Hwang et al. [20] studied the temperature variations and thermal histories during friction stir welding of 6061 aluminium alloys. There were three different layouts used for mounting thermocouples in the specimens to be welded. These layouts were: a) 'same side equal distance' in which the temperatures were recorded in four thermocouples placed equidistant on advancing side at a distance of 6mm from the weld centre line, b) 'opposite side equal distance' in which two thermocouples each were mounted on advancing as well as retreating side,

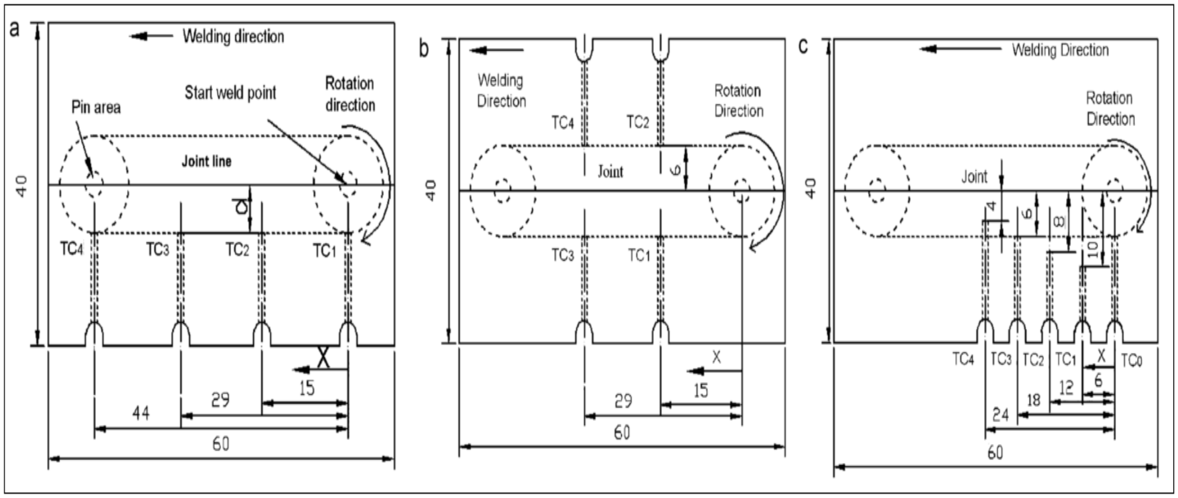

Figure 5: Thermocouple layouts used for measuring temperature distribution a) same side and equal distance, b) opposite side and equal distance, c) same side and unequal distance [20]

c) same side and unequal distance, in which the temperatures were recorded at varying depths, corresponding to different zones of friction stir welding. The different layouts used are represented in Figure 6. The peak temperatures measured in different conditions were discussed.

3. Conclusions:

The major conclusions derived from brief literature review on Friction stir welding of aluminium alloys yields that researchers have focused upon parametric study of various grades of aluminium alloys for automobile and aerospace applications. Temperature plays a crucial role during joining of alloys through FSW. Various researchers have also focused on temperature and force measurements during FSW of aluminum alloys.

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