Mechanical Properties of the Aircraft Materials during Friction Stir Welding

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Abstract - Friction Stir Welding (FSW) is an emerging solid state welding process used to join dissimilar or similar metals based on the requirements. It was first developed in the Welding Institute (UK) as a solution for welding of high strength aluminium alloys with difficulty in joining under conventional joining process and widely used in the aircraft and aerospace industries. Hence, FSW was suggested to be used as a suitable procedure to provide for the bonding of the required metals. Aluminium is a widely used material in many engineering applications ranging from packaging material (cans, foils) to automotive (vehicles, aircrafts, trucks). In this work, dissimilar aluminium alloy plates of AA7075-T651 andAA6061 with 6mm thickness are friction stir butt welded by varying the tool parameters such as tool tilt angle, tool offset and pin diameter by using Central Composite Design (CCD) of Response Surface Methodology.

Key word: Friction Stir Welding, Aluminium alloy

1. INTRODUCTION

Aluminium may be a soft, durable, light weight, non-magnetic, non-sparking, malleable metal with an appearance starting from silvery to dull gray, betting on the surface roughness. It is conjointly insoluble in alcohol, though it is often soluble in water in specific forms. The metallic element has about common fraction of the density and stiffness of steel. GMAW is employed to weld materials with thicker sections an GTAW for thin sheets. The high conduction, high reactivity and high constant enlargement create difficulty in welding of Aluminium alloys. The high heat input related to high thermal conductivity and a high coefficient of expansion (approximately twice as that of steel) may lead to severe distortion of elements throughout welding. The FSW process is free from the dangerous fumes and it avoids the formation of solidification porosity and cracking as reported by Li *et al.* (2019). Moreover, it significantly improves the weld properties and has been widely used in aluminium alloy welding. Since the time of its invention, this method has been frequently improved and its scope of application has been expanded. In recent years, weight factor plays an important role in the manufacturing of aircraft, automobile and aerospace engineering in order to provide low fuel consumption and safety to the passengers. Engineers are working on the structural design of vehicles from small size fasteners to large size components in order to reduce the weight of existing designs. The first choice of the designer is aluminium material, which governs the lightweight production and reduces weight up to 50%. Aluminium alloys AA7075-T651 and AA6061 fascinate the manufacturers to facilitate lightweight, high strength and comfortable usage conditions. These alloys were used in the fabrication of aircraft parts like wings, fuselage and Main Gear Landing (MLG) links. There are plenty of welding processes available in the industries for fabrication work. Nevertheless, importance was given to the strength of the weld joint. Fusion welding causes the essential elements present in the aluminium alloy to evaporate due to the heat involved in the process. It causes high residual stress and hot cracking, which makes the weld joint to lose its strength. FSW is a developing environment-friendly welding technology in which the parent material was subjected to plastic deformation without melting. The quality of FSW joint depends upon the process parameters like tool rotational speed, tool hardness, tool shoulder diameter, tool pin diameter, tool tilt angle, welding speed and tool offset. Therefore, significant research work is essential to optimize the FSW parameters and evaluate the mechanical properties and microstructural behaviour of dissimilar alloy AA7075-T651 and AA6061 joint.

II. LITERATURE REVIEW

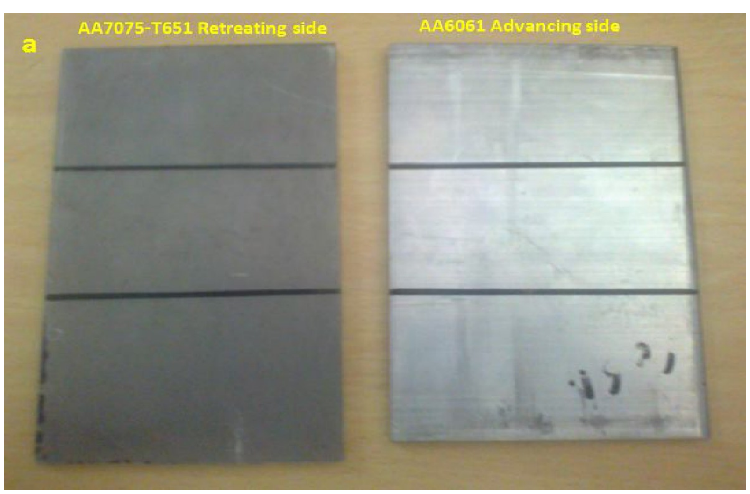
Safeen *et al.* (2016) made an attempt to frame a mathematical model for predicting the hardness, tensile strength and impact toughness. Experiments are designed for four factors and five levels with 95% confidence level by using Response Surface Methodology (RSM). FSW parameters such as tool tilt angle, tool pin profile, rotational speed and welding speed has been used to fabricate AA6061-T6 joints. Optimum level of FSW parameters attained 92% of tensile strength, 87% of impact toughness and 95% of hardness when compared to base metal. Rajendran *et al.*

(2017) made an attempt to optimize the FSW parameters such as tool shoulder diameter, tool tilt angle, welding speed and tool rotational speed to improve the tensile strength of AA2024-T6 joint by using Response Surface Methodology (RSM) at 95% confidence level. Joint fabricated with the tool speed of 1500rpm, tool shoulder diameter of 6mm, welding speed of 40mm/min and tool tilt angle of 1.50 exhibiting the maximum tensile strength of 380MPa.

Asadi *et al.* (2015) made an attempt to optimize the FSW parameters such as rotational speed, traverse speed, shoulder diameter pin shape, pin diameter, tool tilt angle, shoulder concave angle and penetration depth by using Taguchi L27 orthogonal array. The process parameters were optimized to determine the ultimate tensile strength, yield strength, hardness and grain size. Through the confirmation test, the predicted optimized value were confirmed. ANOVA analysis exhibits that tool traverse speed is the most influencing factor on the responses. Jayaraman *et al.* (2009) studied the experiments with three different FSW parameters like axial force, welding speed and tool rotational speed to evaluate the optimum process parameters for maximizing the strength of the weld joint. Taguchi experimental design technique and ANOVA analysis were used to investigate the effect of FSW parameters on attaining the maximum tensile strength. Axial force of 4kN, tool rotational speed of 1200rpm and welding speed of 40mm/min exhibited the maximum joint strength of 147MPa.

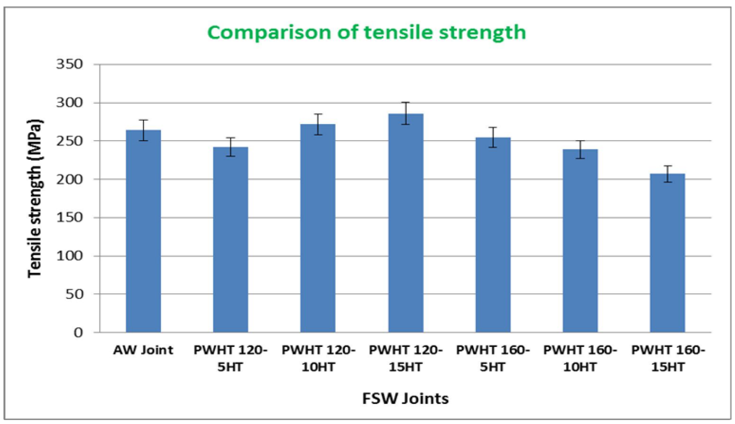
III. EXPERIMENTAL DETAILS

Experimental work was conducted on dissimilar aluminium alloy plates of 6mm thickness. The dissimilar aluminium AA7075- T651 and AA6061 alloys are friction stir welded to fabricate the joint. The experimental setup consists of a Friction Stir Welding
machine, which is manufactured by R.V Machine tools, Coimbatore, India. The FSW machine has a rigid base, tool head, table, rotating spindle, horizontal and automated process control which favours the FSW process as shown in Figure 3.1. The spindle speed can be varied from 100rpm to 3000rpm and it is displayed in the digital indicator. The axial downward force, which ranges from 2.5kN to 50kN, favours the plunging action of the FSW tool and generates frictional heat between rotating tool and work piece.
The work table with (700 x 350mm) dimension consists of two axis movements. The first movement is along the table length (X-axis), which is controlled by hydraulic control unit. The second movement is crosswise (Y-axis), which is controlled manually. Specially designed fixtures are employed to hold the work piece rigidly. The work table consists of
maximum stroke length 600mm. Single pass butt welding procedure was used to fabricate the dissimilar AA7075-T651 and AA6061 FSW joints in the plates size of 150x150x6mm Friction stir welding process parameters, namely tool rotational speed, tool traverse speed and axial force are kept as constant for fabricating the dissimilar alloy joint. Tool speed is set as 2000rpm, traverse speed is fixed as 60mm/min and the axial force is set as 2kN. Tool tilt angle, tool offset and tool pin diameter are varied according to the feasible range observed from trial experimental runs. These FSW parameters are optimized to attain the maximum tensile strength and hardness of the weld joint.



IV. RESULT AND DISCUSSION

The plates of dissimilar aluminium alloys AA7075-T651 and AA6061 of size are cut into 300mm (length) x 150mm (wide). A specially designed fixture arrangement is employed to firmly hold the square butt joint against the tool axial force. The FSW joints are fabricated by single pass welding procedure normal to the direction of rolling as shown in the Figure 4.1 a and b. In this work, FSW is done by using the optimum parameters from the previous chapter viz., 6mm tool pin diameter, 3^0 tool tilt and 0.9mm tool offset. Moreover, the FSW parameters like 2000rpm tool rotational speed, 60mm/min traverse speed and 2kN axial force are kept constant. PWHT is a process of reheating the welded specimen to a temperature less than its lower critical transformation temperature and retaining it in that temperature for a specific amount of time (holding time). The PWHT analysis enhances the mechanical properties and microstructural behaviour of the welded joint by eliminating the residual stress. The FSW joints are classified into two different categories, such as a) As Welded joints. (AW) and b) Post weld heat treated samples. PWHT of samples are done in two different aging temperatures and three different holding time. The tensile strength, hardness and bending strength of the joints are evaluated before and after PWHT analysis. PWHT by artificial aging method is done at two different temperatures of 120°C and 160°C with three different holding time of 5, 10 and 15 hours. The tensile properties of the friction stir welded dissimilar alloy AA7075-T651 and AA6061 joint undergone PWHT analysis were investigated in detail. The mean average value obtained after three tests per condition are documented. The measured values of tensile strength and % of joint efficiency are shown in Figure 4.8 and 4.9. The FSW as welded (AW) joints exhibits the yield and tensile strength of 231MPa and 264MPa respectively. Furthermore, there is a reduction of 10 to 30% joint strength when compared to the base material.



V. CONCLUSION

In the FSW process, tool geometry plays a vital role in heat generation and material mixing. The concave profile tool shoulder with three different angles of 1.5, 3 and 4.5 degrees was employed. Besides, three different pin profiles like straight cylindrical, square and triangular have been used to fabricate the FSW joints. Concave shoulder profile acts as a reservoir for collecting material during the stirring action of the pin. The concave shoulder angle regulates the frictional heat, and the tool pin profile enhances the material flow to improve the mechanical properties of the joint. From this work, it was found that 3-degree concave shoulder profile with square pin exhibited the maximum tensile strength, hardness and bending angle of 298N/mm2, 143Hv and 490 respectively. The pulsating stirring action of the square tool pin exhibited ductile fracture which was evident from the presence of very fine dimples in the fractured surface.

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