Effect of Welding Processes on Tensile Behavior of Aluminum Alloy Joints

Chaitanya Sharma, Vikas Upadhyay, A. Tripathi

Abstract**—**Friction stir welding and tungsten inert gas welding techniques were employed to weld armor grade aluminum alloy to investigate the effect of welding processes on tensile behavior of weld joints. Tensile tests, Vicker microhardness tests and optical microscopy were performed on developed weld joints and base metal. Welding process influenced tensile behavior and microstructure of weld joints. Friction stir welded joints showed tensile behavior better than tungsten inert gas weld joints.

Keywords**—**Friction stir welding, microstructure, tensile properties and fracture locations.

I. Introduction

ALUMINUM alloys of 7xxx series are mainly used for aerospace, automotive and rail and defence applications [1], [2]. The weldable aluminum alloys of this series like AA7005 and AA7039 has Cu content less than 0.1% to improve resistance to stress corrosion cracking and hot tearing. Addition of Zn along with Mg in smaller amount to aluminum results in heat-treatable alloys of moderate to very high strength which gains their strength from the precipitation of $MgZn_2$ precipitates [3].

Al-Zn-Mg alloy AA7039 is a medium strength armor grade alloy used in military, railway and automobile industries for innumerous application like transportable bridges, girders, armor plates and vehicle for military and railway transport systems, and storage tank [4], [5]. As of now, this alloys is welded by fusion welding techniques like Tungsten Inert Gas (TIG) welding, Metal Inert Gas (MIG) welding and friction stir welding [6]-[8]. Fusion welding promotes coarser dendritic structure and porosity in fusion zone (FZ) and grain growth in heat affected zone (HAZ) adjacent to fusion line because of prevailing thermal conditions during weld metal solidification. All these factors are responsible for deteriorating tensile properties (i.e. low ductility and strength) which in turn adversely affect stress corrosion cracking and fatigue failure. Further, oxidation of magnesium present in filler metal and loss of zinc may affect chemical composition of the metal being deposited [7], [8].

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Solid state friction stir welding process (FSW) avoids almost all the problems of fusion welding due to the absence of melting and solidification. FSW is a green, low heat input process. Pollution and distortion is zero, and does not require shielding gases, filler material, edge preparation and removal of oxide layer. Therefore, it is now widely used for welding various ferrous and nonferrous alloys like aluminum, magnesium, copper, zinc, lead, low-carbon steel and aluminum matrix composites [1], [9].

Some work on various aspects of friction stir welding is already reported in the literature, the results indicates that AA 7039 alloy is readily weldable by friction stir welding with excellent mechanical and fatigue behavior [10]-[13].

Literature review revealed the scarcity of research papers on the effect of welding processes on the mechanical behavior of weld joints of alloy AA7039. Therefore, in this research an attempt has been made to weld the chosen alloy using friction stir welding and metal inert gas welding process to investigate their effect on the mechanical properties of welded joints.

II. Experimental Procedure

In this research work, 5 mm thick extruded plates of Al-Zn-Mg 7039 alloy was welded in T6 temper, using friction stir welding and tungsten inert gas (TIG) welding techniques. The composition of base metal alloy was: 4.69% Zn, 2.37% Mg, 0.68% Mn, 0.69% Fe, 0.31% Si, 0.05 % Cu, and remaining aluminum. Base metal plates of size 300 mm x 50 mm were machined on shaper to have V groove on faying edges for TIG welding. TIG welding was performed by depositing metal into V groove from top in single pass. A sealing run was also laid on TIG weld joints, to achieve complete joint penetration. Prior to welding, plates were thoroughly cleaned with acetone to remove dirt, grease, oil or other adhering foreign material. The extensive trials were done to choose TIG welding parameters. So, based on extensive trial runs following parameters were chosen for TIG welding: voltage 12V, welding non pulsed current 140–150A, argon as shield gas (flow rate 18 l/min, pressure 170 KPa), and 2.8 mm diameter wire as filler material. The welding speed was 12 mm/s. Vertical milling machine (HMT India, 5 KW and 635 rpm) was modified to perform single pas friction stir welding, using previously optimized process parameters. Experimental details such as welding and tool geometry parameters, tensile testing, scanning electron microscopy, determination of α aluminum grains size are described elsewhere [10].

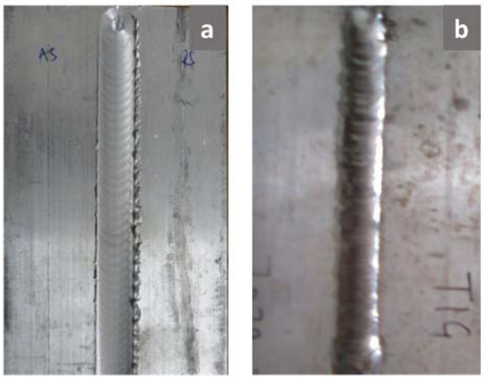

Fig. 1 TIG and FSW welded joints

III. Microstructure

Photographs of developed TIG joints and FSW joints are shown in Fig. 1. The appearance of top surface of FSW joints was smooth and uniform than TIG joints. FSW joints showed semicircular arcs on the top surface while TIG joints showed rippled weld bead. The area of weld zone was significantly higher for TIG joint than FSW joints due to reinforcement. The developed joints were free from visible surface defects.

High magnification micrographs of FSW joint are presented in Fig. 2. From the micrographs it is evident that FSW changed starting microstructure of base metal and resulted in the formation of different zones characteristics. FSW joints showed weld nugget zone (WNZ), thermomechanically affected zone (TMAZ) and heat affected zone (HAZ).

The WNZ is the central zone which lies just beneath the tool shoulder and observes highest peak temperatures due to maximum frictional and deformational heating during FSW. This condition favors dynamic recrystallization which transforms coarse grain structure of base metal into recrystallized grain structure in WNZ [10]-[13]. WNZ revealed fine recrystallized grain structure (Fig. 2 (b)), 6-7 times finer than that of base metal. TMAZ is adjacent to WNZ and shows unrecrystallized deformed grains. Contrary to WNZ; HAZ showed grain structure similar to base metal (grain structure) but 2-3 times coarsened. Moreover, strengthening precipitates were also found coarser and in less numbers than base metal. The HAZ is away from the tool so did not subjected to either friction or deformation. However, conduction of generated heat from the weld nugget results in peak temperature to cause static grain growth and coarsening of precipitates.

Fig. 3 shows high magnification micrographs of TIG weld joints TIG welded joints have fusion zone (FZ), partially melted zone (PMZ) and HAZ.

PMZ is a narrow zone which separated FZ and HAZ. In this zone, partially melted grains of the base metal and fusion line are clearly visible (Fig. 3 (a)) as maximum temperature is in between the liquids and the solidus for the base alloy and liquid and solid coexisted. These partially melted grains are the substrate for the solidification of liquid metal in fusion zone. In FZ, base metal has undergone thorough melting during welding due to heating above the liquidus temperature.

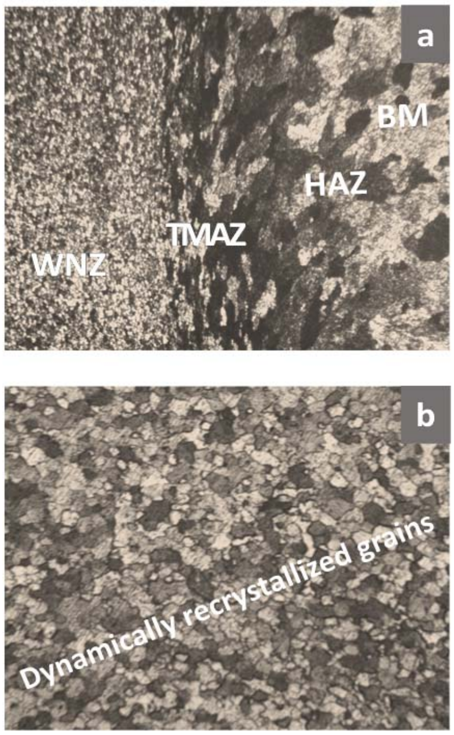

Fig. 2 Evolution of microstructure in FSW (a) Different Zones and (b) WNZ

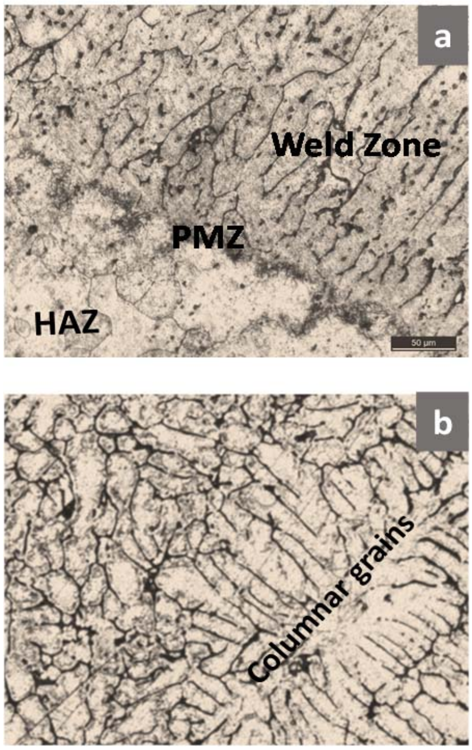

Fig. 3 Evolution of microstructure in TIG Welding (a) Different Zones and (b) FZ

Subsequent cooling from liquidus temperature resulted in cast columnar/dendritic grain structure. The cast grains are found finer than grains in other zones. Solidification of liquid metal starts when liquid metal and substrate i.e. partially melted grains acquire same temperature and liquid surrender their latent heat and join the existing crystal structure of the adjacent base metal. HAZ is adjacent to PMZ and farther away from FZ. In HAZ, peak temperature never reached liquidus or fusion temperature of base metal but was high enough to initiate solid-state transformations which change the grain structure and strengthening precipitates morphology [14]. The base metal grains and strengthening η precipitates are significantly coarsened (Fig. 3 (a)) though initial base metal grain structure is preserved. The dark lines in micrographs 3 shows grain boundary liquation which may be attributed to the fact that alloys melt and solidify over a range of temperatures.

The comparison of microstructure suggests that transformation of grain structure is gradual in case of FSW than TIG welding process. This evolution of microstructure (different zones) in crystalline base metal after welding is because of associated weld thermal cycle. The grain structure was fine and extent of grain coarsening was quite small in case of FSW joint than TIG weld joints. Liquation along grain boundaries is clearly visible in PMZ and FZ of TIG weld joints which is totally absents in FSW. HAZ in FSW joints were found to be narrower and had finer grains than TIG weld joints. The strengthening η precipitates was found severely coarsened in TIG weld joints than FSW joints.

IV. Tensile Behavior

The engineering strain stress curves for welded joints and base metal are presented in Fig. 4.

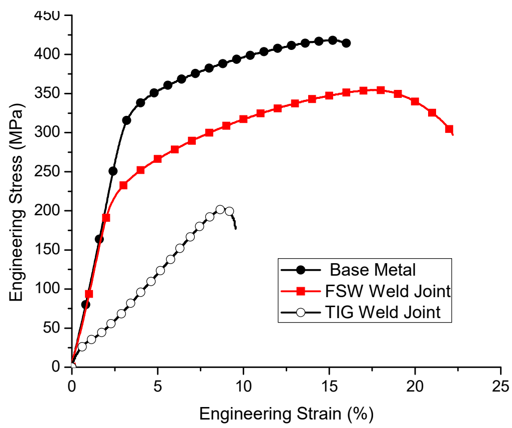

Fig. 4 Engineering strain stress curve

The tensile strength of FSW joints, TIG weld joints and base metal was 354 MPa, 202 MPa, and 414 MPa respectively and ductility was 21%, 9.5, and 15% respectively. The tensile strength of both the weld joints was found to be lower (14.5%, 51.2%) than the base metal. The tensile strength of FSW joint was found higher (75.2%) than that of TIG weld joints. The FSW joints ductility was 40% higher than the base metal while ductility of TIG weld joints was significantly lower (36.7%) than the base metal. Many researcher [8]-[11] attributed better tensile strength and ductility of FSW joints to fine recrystallized grains and smaller extent of dissolution/ coarsening of precipitates. While cast dendritic grain structure and liquation are responsible for poor tensile strength and ductility of TIG weld joints (Fig. 3). During tensile test strain may localize in weakest region reducing the ductility of TIG weld joints drastically.

The tensile behavior of both the weld joints is well supported by microhardness profiles (Fig. 5).

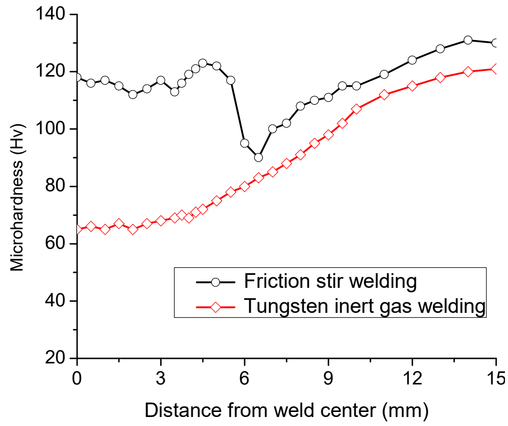

Fig. 5 Microhardness variation of across the friction stir and metal inert gas welded joints

Base metal hardness is 135 Hv while average hardness of WNZ and HAZ of FSW joints was 116 Hv and 108 Hv. The microhardness of both the weld joints were found lower than the base metal. The FSW joints showed higher microhardness than TIG weld joints in all zones. The hardness is found to increase with distance from weld center toward the outer most edges of base metal plates i.e. with decreasing heat input. The TIG weld joints had cast columnar/dendritic grain structure and hardening precipitates were either dissolved in FZ or severely coarsened in HAZ (Fig. 3 (d)). These factors are responsible for lower microhardness of TIG weld joints than others. The low microhardness region was located in HAZ and FZ for FSW and TIG weld joints respectively. The fracture of weld joints during tensile test occurred from low microhardness regions i.e. HAZ and FZ for FSW and TIG weld joints. Necking was observed on fracture end of FSW weld joints while TIG weld joints did not underwent necking. The Mode of fracture was ductile for FSW joints while other showed features of brittle fracture.

V. Conclusion

Selection of welding process is critical for successful welding of precipitation hardening aluminum alloys as it influences the tensile behavior and microstructure of weld joints ominously. Weld thermal cycle associated with welding process affects evolution of microstructure and tensile properties of weld joints. The FSW joints offered superior tensile properties compared to TIG welded joints that may be due to gradual transformation of grain structure. The tensile behavior of weld joints can be improved by selecting welding process carefully i.e. controlling structure-property relationship. The finding suggests that FSW is better technique to weld precipitation hardening alloy AA7039 than TIG welding.

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