International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622
International Conference On Emerging Trends in Mechanical and Electrical Engineering
(ICETMEE- 13th-14th March 2014)

RESEARCH ARTICLE OPEN ACCESS

Tensile Behaviour of Friction Stir Welded joints of Aluminium Alloy

Chaitanya Sharma [a] *, S. Sharma [b], V. Upadhyay [c]
[a] Rustamji Institute of Technology, BSF Academy, Tekanpur Gwalior Madhyapradesh 247667, India
[b] IMS Engineering College, Ghaziabad, Uttarpradesh 201003, India
[c] Gautama Buddha University Greater Noida, Uttarpradesh 201308, India
*Corresponding author: e-mail:Chaitanya.sharmaji@gmail.com

ABSTRACT:
Friction Stir Welding is a novel solid state welding process which utilizes frictional heat, plastic deformation and transverse movement for joining difficult to fusion weld aluminium alloys and other materials. In this investigation precipitation hardening aluminium alloy was friction stir welded in order to elucidate the effect of FSW on tensile behavior of the base metal. The weld joints were characterized by tensile and microhardness test and optical and scanning electron microscopy. Tensile properties of the weld joint were found approximately equal to base metal. The joint efficiency of friction stir welded joint was approximately 100%. The weld nugget showed fine dynamically recrystallized grains while HAZ showed coarsened grain structure than the base metal. Fracture of weld joint occurred from base metal on retreating side and fracture morphology was ductile.
Keywords: Aluminum alloys, friction stir welding, tensile properties, and fracture.

I. Introduction

Aluminium and its alloys are very attractive engineering material because of low cost, low density, superior cryogenic properties, ease of manufacturing and fairly high strength. 7XXX series alloys are used in aerospace and other engineering applications due to their high strength and fracture toughness, excellent resistance to stress corrosion cracking together with ability to strengthen by natural aging [1]. The high strength aluminum alloys such as AA7050 and AA7075 are generally considered unweldable using fusion welding processes suh as TIG, MIG etc. Fusion welding results in loss of strength and ductility in heat affected zone , hot cracking, porosity and lack of fusion defects [2]. AA7039 is a medium strength alloy based on Al-Zn-Mg system of 7XXX series alloys which gains strength from $MgZn_2$ precipitates and can be fusion welded with few difficulties arising from the melting and solidification. Further, this alloys has good resistance to hot tearing, low quench sensitivity, better mechanical properties and is used for military (transportable bridges, armor plates, military vehicles) and other structural (railway transport systems and cryogenic pressure vessels) applications [3].

The application of friction stir welding (FSW) for joining difficult to fusion weld precipitation hardening aluminum alloys has gained wide spread acceptance for transportation, rail, marine and aerospace applications[4]. FSW is a solid state process in which joining of the material is due to plastic deformation, extrusion and forging at temperatures below melting point. FSW avoids the melting and formation of weld pool therefore, prevents the formation cast dendritic weld structure responsible for poor tensile properties along with absence of shielding gases, filler material, arc and fumes. FSW results in reduced residual stresses and distortion due to lower thermal flux [5, 6].

Large number of research papers are available in the literature on various aspects of friction stir welded aluminum alloys such as material flow, microstructure and mechanical properties, effect of process parameters, fatigue and corrosion behavior [7-13]. Literature review reveals that not much information is available in open literature on the tensile behavior of AA7039 alloy in annealed condition [14-17] therefore; in this present study an attempt has made to friction stir weld this alloy, in order to experimentally examine the effect of FSW on tensile behavior of the developed joints.

II. Experimental details

Five mm thick plates of alloy 7039 in annealed condition were used as the base metal in this investigation. The nominal composition of alloy was: 4.69% Zn, 2.37% Mg 0.68% Mn, 0.69% Fe, 0.31% Si and 0.05 % Cu, with the remainder Aluminum. Ultimate tensile strength, yield strength, elongation and microhardness of as received base metal were 212.7 MPa, 105.6 MPa, 38.4% and 65 Hv respectively. FSW was performed parallel to plate extrusion direction on modified vertical milling machine. A flat shoulder die steel tool with truncated conical pin was used for FSW. The welding and tool geometry parameters used for the production of weld joints are enlisted in Table 1.

Table 1: Tool dimension and welding parameters used for friction stir welding

Tool dimensions				Welding parameters		
Shoulder diameter (mm)	Pin diameter (mm) Top	Pin diameter (mm) Bottom	Pin length (mm)	Welding speed (mm/min)	Rotary speed (rpm)	Tool tilt (degrees)
16	6	4	4.7	75	635	2.5

Prior to mechanical and microstructural characterization FSW joints were visually inspected for defects. Electro-mechanically controlled UTM (H25K-S, Hounsfield) was used for conducting tensile tests in triplicate using specimens prepared according to ASTM E8M guidelines [18]. A Vickers microhardness tester (VHM-002V Walter UHL, Germany) was used for measuring the variation of hardness across the joint with a load of 1 N and 30 s dwell time. Microstructure of FSW joints etched in Keller's reagent was observed using a light optical microscope (Leica, Germany). Average grain sizes of α Al present in base metal and different zones of FSW joints were determined using Image J, image analyzing software. The fracture surfaces of the tensile tested specimens were investigated by a FE-SEM (FEI-Quanta 200®).

III. Microstructure

Macrostructure perpendicular to welding direction of weld joints is shown in Fig.1. FSW joints exhibited weld nugget zone (WNZ), thermo mechanically affected zone (TMAZ) and heat affected zone (HAZ) which are characteristic to FSW process [16]. The weld joint showed a weld nugget of trapezoidal shape. The dimensions of weld nugget are slightly larger than tool shoulder and pin diameter. The dimensions of WNZ at top and bottom are 17.35 mm and 4.12 mm. Little amount of flash was also observed on the top surface of the weld joint.

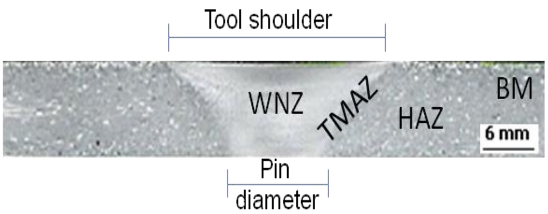

Fig.1: Macrostructure of friction stir welded joint

Fig. 2 shows the high magnification optical micrographs of base metal, WNZ, TMAZ and HAZ.

Base metal had equiaxed grain structure of average size of 27.6 µm with uniformly distributed strengthening precipitates (Fig. 2 a). Friction stir welding radically changed the starting microstructure of the base metal.

The weld nuggets invariably showed fine recrystallized equiaxed grains because of dynamic recrystallization.

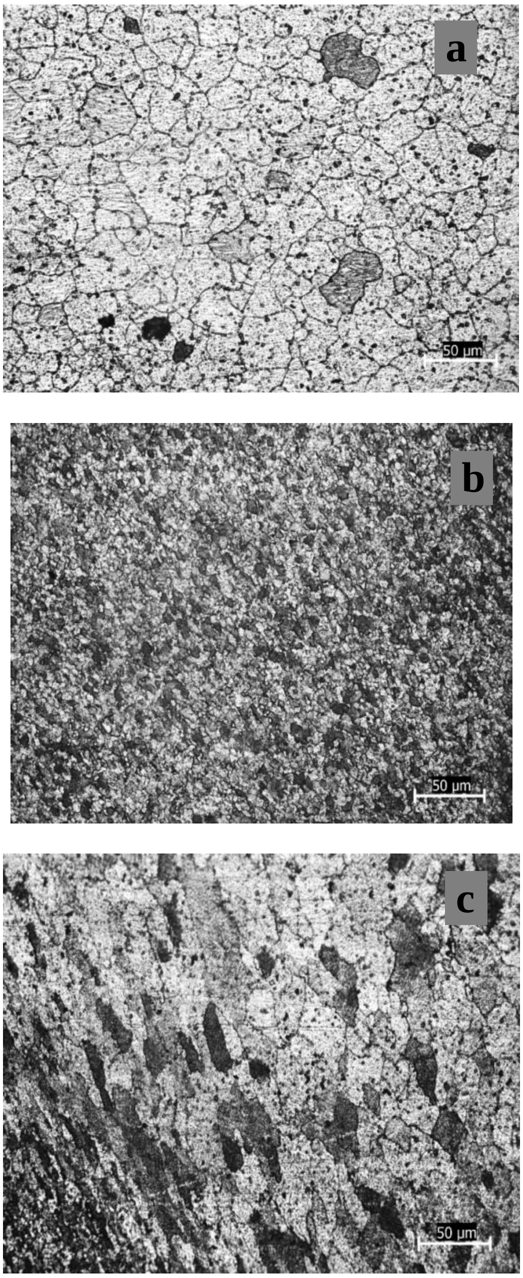

Fig. 2 Microstructure of (a) base metal (b) WNZ and (c) HAZ of FSW joint

WNZ showed dynamically recrystallized equiaxed grains of average size of 6.4 µm (Fig. 2 b). Rotating and traversing tool severely deforms base material, generates temperatures ~ 480 ^{0}C, high enough to cause dynamic recrystallization, transforming coarser grain structure of base metal into fine and equiaxed grain structure in WNZ[6,8]. Further, reduced extent of post weld grain growth owing to shorter weld thermal cycle and lower peak temperatures is also responsible for fine grain size than base metal [17].

Next to WNZ is the TMAZ where grains were deformed bent and elongated in upward flow pattern (Fig. 2 c). The average size of deformed grains in TMAZ was 15.3 µm. HAZ exhibited microstructure similar to the base metal but grains were significantly coarser than the base metal. The average size of coarse grains was 38.3 µm. The HAZ is the outermost region influenced by thermal transient only. The temperatures (250-350 ^{0}C) attained in HAZ are sufficient to cause static grain growth which in turn coarsens grains in HAZ [8]. The extent of grain refinement is found to decrease from the central WNZ to outer most HAZ. Grains in WNZ and TMAZ were approximately 4.3 and 1.8 times finer than the base metal (27.6 µm). While grains in HAZ were 1.4 times coarser than the base metal. Moreover, TMAZ and HAZ showed strengthening precipitates while same were not observed in the WNZ (Fig. 2 b and c), which are either broken down and uniformly distributed by stirring tool or dissolved into α aluminum matrix.

IV. Microhardness

Microhardness measurements provide an easiest way to study the heterogeneous distribution of tensile properties of FSW joints along the weld cross-section. The recorded microhardness profiles for base metal as well as for FSW weld were shown in Fig.3. Friction stir welding of aluminum alloys in annealed O temper condition caused significant strengthening of the WNZ as evident from figure 3.

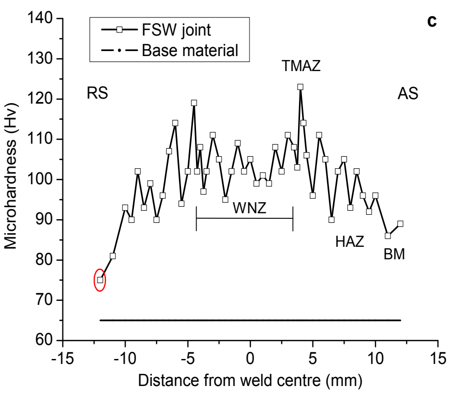

Fig. 3: Microhardness profile of FSW joints

The average microhardness of WNZ and HAZ was higher (104 Hv) than the base metal (65 Hv). The values of hardness minima was 75 Hv, located in the base metal. Microhardness results are in agreement with grain size and satisfy Hall-Patch equation. According to Hall-Patch equation finer is the grain size higher is the strength of the material. Moreover, solution strengthening and strain hardening also contribute in enhancing the microhardness of FSW joints than the base metal. Post weld artificial aging of previously solutionized base metal resulted in higher microhardness of HAZ than base metal. Further, results of microhardness are in good agreement to the microstructure of HAZ.

V. Tensile Properties

Engineering stress and strain diagrams for base metal and friction stir weld joints are summarized in table 2. The mechanical properties of FSW joints are comparable to the base metal. The ultimate tensile strength, yields strength and % elongation of FSW joints, were 208.9 MPa, 88.9 MPa and 23.6% respectively. The extent of loss was found higher for yield strength than ultimate tensile strength. Further, yield strength of FSW joints was significantly lower (about 16.2 %) than the base metal.

terial Condition	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Tensile strength Efficiency (%)	Yield strength Efficiency (%)
Base	212.7	105.	38.	-	-
FSW	208.9	88.9	23.	98.	83.8

Ratio of ultimate tensile strength, and yield strength of FSW joint to that of unwelded base metal is defined as joint strength efficiency, and yield strength efficiency respectively. Ultimate tensile and yield strength efficiency of FSW joints were 98.2% and 83.8 % respectively. High strength efficiency of FSW joint can be attributed to strain hardening effect due to sever plastic deformation of softened base metal and limited possibility of thermal transformation owing to weld thermal cycle experienced by the weld and HAZ during FSW. The results are in accordance to lower % elongation of FSW joints. Chen et al. [13] performed FSW of AA2219-O and reported 100% tensile strength efficiency for FSW joints of AA2219-O.

FSW joints fractured from minimum hardness region of base metal on retreating side during transverse tensile testing. Threadgil et al. [4] aluminum alloys welded in annealed condition failure of cross weld joint during tensile test can occur anywhere on the specimen but it usually occur in base metal away from the weld. Fracture morphology was ductile as evident from the presence of innumerable dimples as shown in fig.4.

The breakage of secondary precipitates rich in Mg and Zn trigger the formation of micro voids at grain boundary particles whose coalescence resulted in fracture of FSW joints.

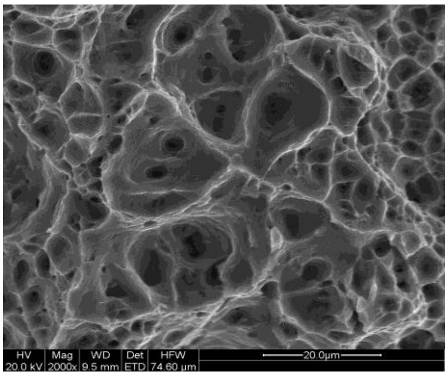

Fig. 4: Fracture morphology of FSW joints

VI. Conclusion

Friction stir welding of aluminum alloy is beneficial owing to better tensile properties of FSW joints and equiaxed fine grain microstructure. FSW joint has mechanical properties approximately equal to base metal. The limited possibility of microstructural transformation due to weld thermal cycle and absence of defects is responsible for enhanced joints tensile properties.

References

[1] Cam G., Kocak M. 2007. Microstructural and mechanical characterization of electron beam welded Al-alloy 7020, Journal of Material Science 42:7154–7161.
[2] Kessler O., Bargen V. R., Hoffmann F., Zoch H.W. 2006. Continuous Cooling Transformation (CCT) Diagram of Aluminium Alloy Al-4.5Zn-1Mg, Material science forum 519-521: 1467-1472.
[3] ASM Handbook Volume 2. 1992. Properties and Selection: Nonferrous Alloys and Special-Purpose materials, ASM international material park,: 434.
[4] Threadgill et al. 2009. FSW of aluminium alloys, International Materials Reviews, 54 (2): 49-93.
[5] Rhodes CG, Mahoney MW, Bingel WH. 1997. Effects of FSW on microstructure of 7075 aluminium, Scripta Materilia, 36:69–75.
[6] Mishra RS, Ma ZY. 2005. Friction stir welding and processing, Mater sci Eng R; 50:1–78.
[7] Colligan K. 1999. Material flow behaviour during friction welding of aluminum, Welding Journal, 229s-237s.
[8] Zhang Z.,Liu Y.L., Chen J.T. 2009. Effect of shoulder size on the temperature rise and deformation in FSW, International journal of advance manufacturing technology, 45:889-895.
[9] Liu H.J., Fujii H., Maedaa M., Nogi K. 2003. Tensile properties & fracture locations of FSWed joints of 2017-T351 Al alloy, Journal of Materials Processing Technology, 142: 692–696.
[10] Jata K.V., Sankaran K.K., Ruschau J. 2000. FSW effects on microstructure and fatigue of Al alloy 7050-T7451. Metallurgical & Materials Transaction, 31A: 2181–92.
[11] Kumar K., Satish V. Kailash. 2008. “On the role of axial load and effect of interface position on the tensile strength of a FSwed Al alloy”, Materials and Design, 29: 791-797.
[12] M. Jariyaboon, A. J. Davenport, R. Ambat, B. J. Connolly, S. W. Williams and D. A. Price. 2009. “The effect of cryogenic CO_2 cooling on corrosion behaviour of FSwed AA2024-T351”. Corrosion Engg. Science & Techno, 44 (6), 425-32.
[13] Chen Y, Liu H, and Feng J (2006) Friction stir welding characteristics of different heat treated state 2219 aluminum alloy plates. Mater Sci Eng A 420:21-25
[14] Chaitanya Sharma, Dheerendra Kumar Dwivedi, Pradeep Kumar. Heterogeneity of microstructure and mechanical properties of friction stir welded joints of Al-Zn-Mg alloy AA7039. Procedia Engineering 2013, Vol. 64, pp. 1384-1394.
[15] Chaitanya Sharma, Dheerendra Kumar Dwivedi, Pradeep Kumar. Effect of post weld heat treatments on microstructure and tensile properties of friction stir welded joints of Al-Zn-
[16] Mg alloy AA7039. Materials and Design, 2013, Vol. 43, Issue 1, pp.134-143.
[17] Chaitanya Sharma, Dheerendra Kumar Dwivedi, Pradeep Kumar. Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of AA7039 aluminium alloy. Materials and Design, 2012, Vol. 36, Issue 4, pp. 379-390.
[18] Chaitanya Sharma, Dheerendra Kumar Dwivedi, Pradeep Kumar. Influence of in-process cooling on tensile behaviour of friction stir welded joints of AA7039. Journal of Material Science and Engineering A, 2012, Vol. 556, Issue 10, pp. 479–487.
[19] ASTM E8/E8M-09. 2009. “Standard test methods for tension testing of metallic materials. Pennsylvania (USA): ASTM International; December.