Research Article

S. Dharani Kumar* and S. Sendhil Kumar

Investigation of mechanical behavior of friction stir welded joints of AA6063 with AA5083 aluminum alloys

https://doi.org/10.2478/mme-2019-0008
Received Apr 3, 2018; revised Jun 5, 2018; accepted Nov 20, 2018

Abstract: Aluminum alloy finds its applications in various sectors of engineering. This paper discusses the investigation of mechanical characteristics of butt weld joints of aluminum alloy AA6063 along with AA5083. An experiment was conducted for different tool rotational speeds of 600 rpm, 800 rpm and 1000 rpm. Specifications of friction stir welding machine were 4 kN axial load and welding speed of 40 mm/min. Friction stir welded (FSW) joints of higher tensile strength, lower flexural strength and lower impact strength with maximum hardness, for the work piece fabricated at 1000 rpm using a high speed steel tool with a cylindrical profile was observed. Better understanding of the effect of tool rotational speed and mechanical properties was illustrated through the experimental result.

Keywords: Aluminum alloy, tensile strength, impact strength, cylindrical pin profile

1 Introduction

Aluminum alloy finds its application in aeronautical, automobile and marine industries with different configurations. Welding of dissimilar aluminum alloy with thickness more than 3 mm is quite difficult in the fusion welding processes. The major defect noted in dissimilar fusion welding is of solidification cracks in the heat affected zone. Welding porosity occurs during fusion as a result of varying degree and speed of the welding processes. Joining of dissimilar aluminum alloy materials with different properties using conventional fusion welding process can be dealt with, but the efficiency of the joint is unsatisfactory. A suitable filler material is a crucial problem in fusion welding process. Friction stir welding (FSW), developed by the Welding Institute (TWI) in 1991 [1], is the available option to overcome the above mentioned problems. It is a solid state welding process, which has many advantages such as joining of dissimilar aluminum alloys, possessing excellent mechanical properties when compared to TIG and MIG welding [2], grain refinement with fine distribution of precipitates (which is an evidence of better strength) and ductility [3]. The results indicate that 79% joint efficiency is achieved with tensile strength of 289 MPa for FSW joints, whereas the best tensile strength of 210 MPa with 57 % joint efficiency is achieved using TIG welding [4]. A dissimilar FSW process was carried out by placing the high strength aluminum alloy AA204-T6 on the retreating side and alloy AA5083-H321 on the advancing side [5]. In AA7075-AA2024 dissimilar welds, the tensile properties in the longitudinal direction of the stirred zone were found to be better when the AA7075 alloy is placed on the advancing side [6]. The welds that are fabricated using straight tool profiles have no defects, while the tapered tool profiles cause tunnel at the bottom of joints [7]. Structurally, transformation occurs in dissimilar friction stir weld of AA5083-O and AA6082-T6 aluminum alloys when the weld is anodized in H_2SO_4 solution [8]. Effects of the sleeve plunging speed on the microstructure and lap shear failure load of the dissimilar 6063/5083 joints were discussed [9]. In the FSW process, two different grade aluminum alloys can be used with AA6063 as the heat treatable alloy and AA5083 as the non-heat treatable alloy. Hence, the combinations of these alloys are used in ship hulls and automobile inner panels. Hence, preliminary investigation was carried out in this area of research to understand the mechanical properties like tensile, bending, impact, toughness and hardness of dissimilar FSW joints over tool rotational speeds. This paper discusses the relation between the mechanical properties and tool rotational speed of friction stir welded AA5083 with AA6063 aluminum alloy joints. The following sections discuss the experimental work, results and

***Corresponding Author: S. Dharani Kumar:** Department of Mechanical Engineering, Sri Eshwar College of Engineering, Coimbatore - 641202, India; Email: sdharanikumarmech@gmail.com
S. Sendhil Kumar: Department of Mechanical Engineering, Info Institute of Engineering, Coimbatore - 641107, India; Email: ssk333c@yahoo.co.in

discussions of the FSW carried out using two different aluminum alloys, namely AA 6063 and AA5083.

2 Experimental work

Chemical composition and mechanical properties for aluminum alloy are tabulated in Table 1 and Table 2 respectively. The rolled plates with 6 mm thickness of AA6063 aluminum alloy and AA5083 aluminum alloy have been slashed into the required size of 100 mm × 50 mm × 6 mm and grinded to achieve a superior surface finish. The square butt joint configuration is selected for FSW welding. There are two inverting positions in FSW welding for the base metal AA6063 placed in retreating side (RS), while AA5083 is placed in the advanced side (AS). The aluminum alloy of AA6063 is placed in the retreating side due to its lower tensile strength. A non-consumable rotating tool made of high speed steel (HSS) is shown in Figure 1(a). The tool pin is a straight cylindrical profile with shoulder diameter of 20 mm, 5 mm pin diameter, 5 mm pin tip length and D/d ratio of 4. The friction stir welds using AA5083 and AA6063 aluminum alloys were fabricated using a FSW machine with the motor specifications of 2.2 kW/440V and a maximum tool rotational speed of 3000 rpm. The welds were made along the longitudinal direction of the plate with the tool rotational speeds of 600, 800 and 1000 rpm, keeping the constant welding speed of 40 mm/min and axial load of 4 KN.

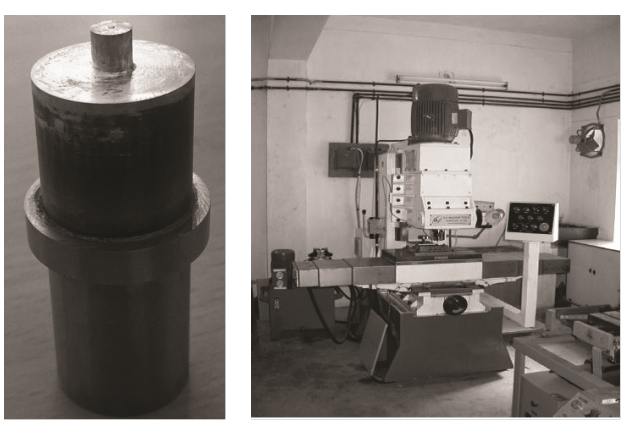

Figure 1: (a) Cylindrical tool, (b) Friction Stir welding machine

Quality welds can be produced with tool rotation speeds ranging from 600 to 1200 rpm. The single pass welding procedure was adopted for fabrication of dissimilar joints, which is shown in the Figure 2.

Table 1: Chemical composition of the material AA6063 and AA5083

Alloying Elements	6063	5083
Al	Bal	Bal
Si	0.20–0.60	0.7–1.3
Fe	0.0–0.35	0.50 max
Cu	0.0–0.10	0.10 max
Mn	0.0–0.10	0.40–1.00
Cr	0.0–0.10	0.25 max
Mg	0.45-0.49	0.06–1.20
Zn	0.0–0.10	0.20 max
Ti	0.0–0.10	0.10 max
Other Each	0–0.05	0.05 max
Others Total	0–0.15	0.15 max

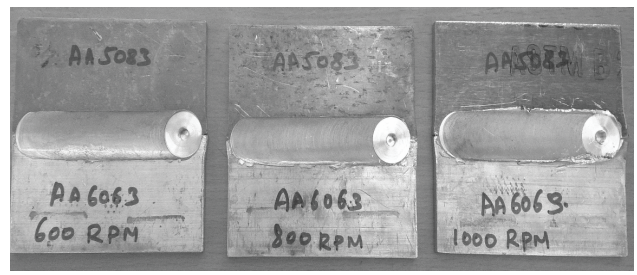

Figure 2: Friction stir Welded specimens of different tool rotational speeds

Table 2: Mechanical properties of base materials

Base metal	Ultimate tensile strength [MPa]	Hardness Brinell [HB]	Tensile elongation [%]
AA6063	130	25	18
AA5083	345	75	12

2.1 Mechanical properties

The mechanical properties of joints like tensile, bending, impact and hardness are determined. To determine the mechanical properties of dissimilar FSW welded joints, tests were performed as per the American Society for Testing of Materials standards (ASTM). Tensile and bending test were conducted at room temperature using an electromechanical controlled universal testing machine with an ultimate load of 100 KN. Tensile specimens were prepared as per the ASTM E8 M04 standard for evaluating the yield strength, ultimate strength and the percentage of elongation of the weld joints. The samples were machined along the transverse welding direction. The specimen were prepared for three point bending test as per the ASTM E22-04 standard

for evaluating the ductility of the weld metal, HAZ, test of defects particularly lack of side wall fusion (side bead), root fusion penetration of welded joints. Hardness test was carried out according to the ASTM E10 standards using a Brinell hardness testing machine with a 10 mm ball indenter and a 500 kg load. Impact testing was conducted at room temperature using a pendulum type impact testing machine with a maximum capacity of 300 J. Charpy impact specimens were prepared as per the ASTM E23-04 standards. The Charpy test was carried out with an impact testing machine for determining the amount of energy absorbed in fracture, which was recorded. The absorbed energy is defined as the impact toughness of the material.

3 Results and Discussion

3.1 Tensile test

Yield strength, tensile strength, percentage of elongation of the dissimilar FSW joints have been evaluated for three different tool rotational speeds. Three specimens are tested for each rotation speed and the average of the results is presented in Figure 3. All the joints have lower yield strength, tensile strength and percentage of elongation compared to the base material of both aluminum alloys. All the joints are fractured along the retreating side, which is shown in Figure 4. This happened due to the smaller yield strength and minimum hardness value of the base material AA6063 compared to the advancing side base material AA5083.

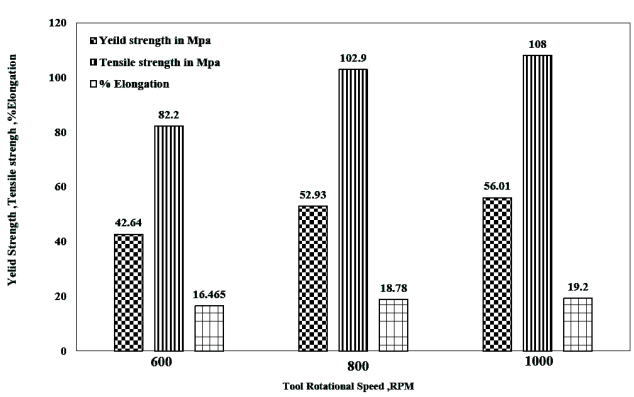

Figure 3: Effect of tool rotational speed on transverse tensile properties

The influence of the welding speed on the tensile properties of FSW joints is inferred through Figure 4. Among the three tool rotational speeds, 1000 rpm exhibits superior tensile properties. This is the result of the effect of higher heat input during welding as it results in good ductility. This shows that an increase in tool rotational speed increases the tensile properties of a joint. The overall observation was that the essential nature of use of higher rotational speed for providing good heat input, welds thus obtained displayed good tensile strength. These reveal that the ductility of stir zone is lower than base materials.

Figure 4: Transverse tensile specimen

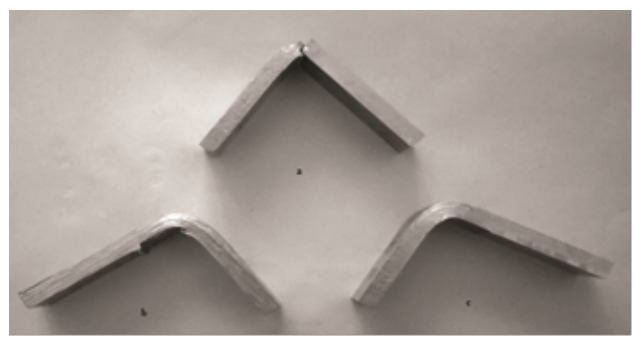

Figure 5: Bending test specimen

3.2 Bending test

Three point bending tests were carried out for dissimilar FSW joints .The transverse face and root bending test were meant for the evaluation of ductility of the FSW joints for different tool rotational speed. Table 3 illustrates the reduction in flexible strength, as the tool rotational speed increases.

The FSW joint becomes brittle and embrittled. Brittleness arises due to the decrease in FSW joint ductility, which is due to embrittlement. After performing the bending test, visible cracks are identified across the cross sec-

Table 3: Impact and Bending Strength results

Tool rotational speed [Rpm]	Impact Strength [J/mm^2]	Flexural Strength [MPa]
600	0.46	267.628
800	0.45	267.527
1000	0.43	227.403

tion of the joint for tool rotational speed of 1000 rpm, as shown in Figure 5.

3.3 Impact test

The Charpy impact strength of dissimilar FSW weld joint was evaluated and presented for three different tool rotational speeds. Impact strength of FSW joint with the notch was placed at the weld center line. Table 3 illustrates that an increase in the tool rotational speed causes reduction in the impact strength of weld joint due to the evolution of high heat, resulting in coarse grain structure. The impact strength for the tool rotational speed of 600 rpm is 0.46 J/mm^2, which is 6.5% higher than the 1000 rpm welded specimen. All the impact tested specimen do not break into two pieces, as shown in the Figure 6, reveals that the FSW joint does not lose its ductility.

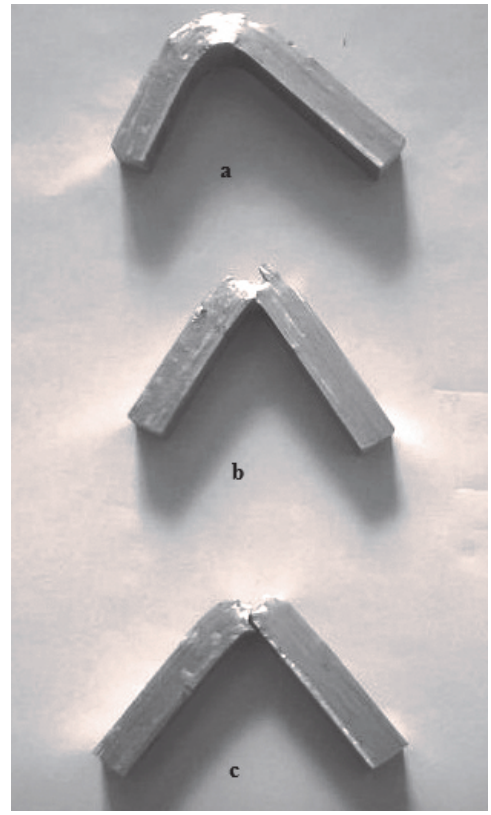

Figure 6: Impact test specimen

3.4 Hardness test

AA5083-AA6063 for three different tool rotational speeds is illustrated in Figure 7. The fusion zone has a lower hardness compared to the base material AA5083 and 68% higher than the base material value of AA6063. Retreating side was identified with hardness value of 35 HB and advancing side hardness value of 75 HB due to the base material in the retreating side. The hardness value of the stir zone increases as the tool rotational speed increases. This was due to the HAZ region by retreating side, that is, 34.07 HB, which is 36% higher in the base material of AA6063 revealing the effect of the tool rotational speed on the hardness of the FSW dissimilar joint. As the rotational speed amplifies, the rate of heat input increases, resulting in fine microstructure, in turn increasing the hardness.

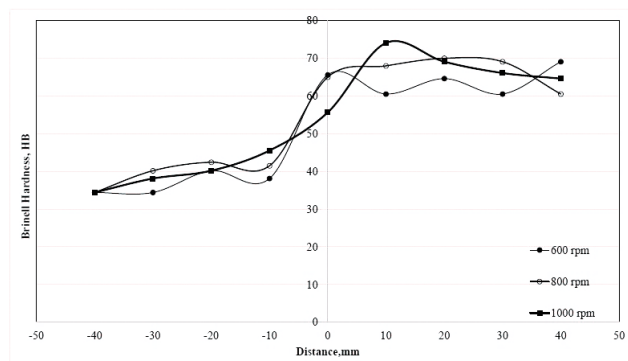

Figure 7: Hardness variation from stir zone

4 Conclusion

Aluminum alloy AA5083 along with AA6062 can be successfully used for friction stir weld for tool rotational speeds ranging from 500 rpm to 1200 rpm; with step variation of 200 rpm the axial load and welding speed is maintained constant. Investigation of the mechanical properties of fabricated joint and its effects are discussed in this paper. The following conclusions can be drawn based on the experiments carried out:

1. The joint fabricated using FSW process parameters 1000 rpm (tool rotational speed), 40 mm/min (welding speed), 4 kN (axial load) with the cylindrical tool profile has the highest yield strength and ultimate tensile strength properties compared to the other

tool rotational speeds. All the specimens during tensile test failed on the retreating side only.

2. The flexural strength 227.403 MPa of the weld specimen is lower than the other specimens. Minimum impact strength occurs for the tool rotational speed of 1000 rpm. The brittle fracture is observed on the FSW weld joint. Maximum hardness is achieved for the rotational speed of 1000 rpm.
3. Impact strength of FSW weld joints has been evaluated for different tool rotational speeds. These are 0.46, 0.45 and 0.42 J/mm^2 for 600, 800 and 1000 rpm, respectively.
4. The hardness of stir zone is variable for different tool rotational speed 74.2 HB for 1000 rpm and 800 rpm. The minimum hardness value (64.61 HB) of stir zone is observed on the 600 rpm tool rotational speed.
5. The flexural strength and impact strength decreases when the tool rotational speed rises, whereas the tensile strength and hardness increases.

References

[1] Jannet, S., Mathews, P. K., Raja, R.: "Comparative investigation of friction stir welding and fusion welding of 6061-T6 and 5083-O aluminum alloy based on mechanical properties and microstructure", Journal of Achievements in Materials and Manufacturing Engineering, 61, 181–186, 2013.

[2] Kulekci, M. K., Erdinç Kaluç, A. S., Ozden, B.: "Experimental Comparison of MIG And Friction Stir Welding Processes For En Aw-6061-T6 (Al Mg Si Cu) Aluminum Alloy", The Arabian Journal for Science and Engineering, 35, 321–330, 2009.

[3] Masayuki, A. and Kazuhiro, N.: Dissimilar Metal Joining of 2024 and 7075
Aluminum Alloys to Titanium Alloys by Friction Stir Welding", Materials Transactions, 52, 948–952, 2011.

[4] Da Silva, A. A. M., Arruti, E., Janeiro, G., Aldanondo, E., Alvarez, P. and Echeverria, A.: "Material flow and mechanical behaviour of dissimilar AA2024-T3 and AA7075-T6 aluminium alloys friction stir welds", Materials & Design, 32, 2021–2027, 2011.

[5] Jonckheere, C., de Meester, B., Denquin, A. and Simar, A.: "Torque, temperature and hardening precipitation evolution in dissimilar friction stir welds between 6061-T6 and 2014-T6 aluminum alloys", Journal of Materials Processing Technology, 213, 826–837, 2013.

[6] Gibson, B. T., Lammlein, D. H., Prater, T. J., Longhurst, W. R., Cox, D. C., Ballun, M. C., Dharmaraj, K. J., Cook, G. E. and Strauss, A. M.: "Friction stir welding: Process, automation, and control", Journal of Manufacturing Processes, 16, 56–73, 2014.

[7] Mubiyai, M. P. and Akinlabi, E. T.: Friction Stir Welding of Dissimilar Materials: An Overview, World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronics and Manufacturing Engineering, 7, 635–640, 2013.

[8] Donatuset, U. al., "Areas of concern in an anodized dissimilar friction stir weld of AA5083 and AA6082 aluminium alloys," The International Journal of Surface Engineering and Coatings, 2967, 2016.

[9] Li, Z., Xu, Z., Zhang, L. and Yan, Z.: "Friction spot welding of dissimilar 6063/5083 aluminium alloys," Mater. Sci. Technol., 1–9, 2017.

[10] Palanivel, R., Koshy Mathews, P. and Murugan, N.: "Influences of Tool Pin Profile on the Mechanical and Metallurgical Properties of Friction Stir Welding of Dissimilar Aluminum Alloy", International Journal of Engineering Science and Technology, 2, 2109-2115, 2010.

[11] Shanmuga Sundaram, N. and Murugan, N.: "Tensile behavior of dissimilar friction stir welded joints of aluminium alloys", Materials & Design, 31, 4184–4193, 2010.