International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Mechanical and microstructure characterization of al 2029 by friction stir welding

Ravi Kant[1], Kunal Adhikari[1], Arshad Mehmood[2], Raman Chaudhary[1], Mohd Kashif[1]

[1]*Department of Mechanical Engineering, Meerut Institute of Technology, Meerut, India*
[2]*Department of Mechanical Engineering, University of Burami, Oman*

Abstract

Friction stir welding developed and established by the welding institute (TWI) among the all new welding technologies in 1991, and it is used commonly for welding of high strength aluminium alloy such as Al2029, which are difficult to weld by conventional fusion welding technique. Friction welding (FW) is a collection of a series of Friction- based solid state joining processes which can produce high quality of weld of different component with either similar or dissimilar material and has been attracting increasing attention. This work aim is to weld two plates of Al-2029 and to optimize the different mechanical properties of welded material and base material.

Keywords: Friction stir welding, Aluminum alloy, Mechanical Properties.

1. Introduction

Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. It is primarily used on wrought or extruded aluminium and particularly for structures which need very high weld strength. FSW is also found in modern shipbuilding, trains, and aerospace applications.

Friction stir processing (FSP)/FSW is a method of changing the properties of a metal through intense localized plastic deformation. This deformation is produced by forcibly inserting a non-consumable tool into the workpiece and revolving the tool in a stirring motion as it is pushed laterally through the workpiece. The antecedent of this technique, friction stir welding is used to join multiple piece of metal without creating the heat affected zone typical of fusion welding. Efficient joints in terms of strength of aluminum matrix composite materials cannot be achieved by fusion based welding method due to the reaction between reinforcements and matrices leading to the formation of brittle secondary phase in the weld pool or decomposition of reinforcements on molten metal [1, 2]. As a versatile material, aluminum matrix composites may be selected as an alternative to high strength aluminum alloys in aero engines and aerospace structures like fins, wing and fuselage. In 2001 NASA used composite aluminum AL-Li 2195 rather than aluminum alloy Al2219 for the external fuel tank of space shuttles leading to a reduction of weight by 3400 kg. The saving in weight increases the cargo capacity of space shuttles and enables it to transport more than one components in a single flight to the international space station [3]. Titanium alloy are used extensively in the aerospace industry due to their excellent structure efficiency and good high temperature strength. Welding is an effective way to produce a structure with complex geometry and multiple components. Titanium alloys are readily fusion weld able. However, some problems associates with fusion welding of titanium alloys include porosity, distortion and formation of coarse cast grain structure [4, 5].

A large number of tool deformations occurred during the first 3 inch length welding trial, the tool configuration changed slightly due to reduced stress on the deformed pin part and tool size and weight decreased continuously. The stress induced cracks were responsible for the majority of tool weight loss.

Corresponding author: Kunal Adhikari
Email Address: kunaladhikari27dec@gmail.com

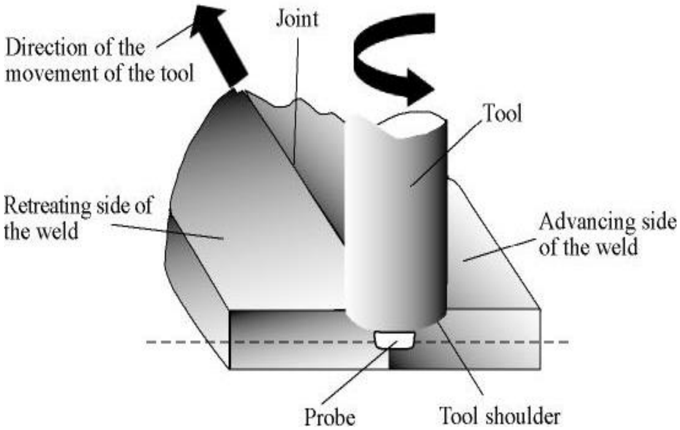


Figure 1: Two discrete metal workpiece butted together, along with the tool (with a probe)

The defect were found in a region with bimodal microstructure of α+ transformed β phase, which indicate local processing temperature below β- transus due to low heat input [6]. The heat affected zones of a friction stir weld of aluminum alloy 7050-T651 were investigated and compare with the unaffected base metal. Composition of 7050-T651 are 5.7-6.7 Zn, 1.9-2.6 Mg, 2.0-2.6 Cu, 0.08-0.115 Zr. The rotation speed of pin was 350 rpm and travel speed was 15mm/min. Compared to parent material microstructure, the strengthening precipitates have coarsened severely and the precipitate free zone along the grain boundaries has increased by factor of five during friction stir welding, The original base metal grains structure is completely eliminated and replaced by a very fine equiaxed grain structure in the dynamic re-crystallized zone (DXZ). The DXZ consisted of re-crystallized, fine equiaxed grains on the order of 1-4 µm in diameter. Most of the DXZ grains contained a high dislocation density with various degree of recovery from grain to grain [7]. Friction stir processing has been successfully used formation of nano grains and increase the mechanical properties i.e. surface hardness, wear resistance, tensile and fatigue strength.

It was observed that when there is increment on travelling speed, hardness value will also be increased. However increased rotation speeds resulted in lower hardness value at the same travelling speed. Processing parameter including tilt angle and target depth are crucial produce sound and depth free processed region. Friction stir processing result insignificant temperature rise with in and around the weld. A temperature rise of 400-500^{0}C has been recorded within the stir zone for aluminum alloy. The temperature rise result in significant micro structural evaluation i.e. fine re-crystallized grains of 0.1-18 mm, texture, precipitate dissolution and coarsened and residual stress with a much lower magnitude [8].

The tensile strength of the joint is lower than that of the parent metal and it is directly proportional to the travel / welding speed. Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints. Microstructure evaluation of FSW joints clearly shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter [9-11].

A mathematical model is developed to quantitatively analyze the material flow and heat transfer during RDR-FSW process. It takes into consideration the heat generated by friction and plastic deformation. The effect of reverse rotating tool pin and assisted shoulder on plastic material flow and heat transfer is numerically simulated. Because the tool pin and the assisted shoulder rotate with opposite direction independently, the material flow mode is more complex than that in conventional FSW, and different material flow patterns appear at different horizontal planes along the plate thickness direction during RDR-FSW. The effects of tool pin and reverse rotating-assisted shoulder on material flow and heat transfer are analyzed [12].

Friction stir welding technology requires a thorough understanding of the process and consequent mechanical properties of the weld in order to be used in the production of component for aerospace application. For this reason, detailed research of friction stir welding is required. Friction stir welding can be used to join a different member of material, the primary research and industrial interest has been join aluminum alloy. Defect free welds with good mechanical properties have been made in a wide variety of aluminum alloys, thickness from 1 mm to more than 35 mm will not be welded by Friction stir welding. In addition, friction stir weld can be accomplished in any position. [13-19]. The ultimate tensile strength and hardness of bimetallic weld joint increases by increasing the pre-stress, and ductility was decreases when thermal loading increases. For preventing brittle failure behavior of carbon steel the value of pre-stress and thermal stress should be low as possible [20-22].

2. Experimental Setup of FSW

The experiments have been carried out on the Friction stir welding machine with necessary equipment details such as tool, process parameter and safety precautions. Process parameter involved here is the tool rotation speed, welding speed, tilt angle and tool geometry. the FSP tool geometry, aluminium alloy 2029 plates, friction stir welding machine, processed zone and various tool manufactured to perform the desired experiments. The process of FSP begins with the tool design and fabrication. The main and the crucial thing of this project were the tool design for friction stir processing process, which would fix in the available Friction stir welding machine shank. Initially FSP tool designed in such a way that the tool geometry was very simple with cylindrical tool, shank dia-25 mm, shoulder dia-20 mm, pin dia-8 mm, pin lenth-4 mm.

The objectives were achieved through a selection of the experimental matrix including all material selection, friction stir processing parameters, conducting a thorough microstructure analysis, and performing representative mechanical tests.

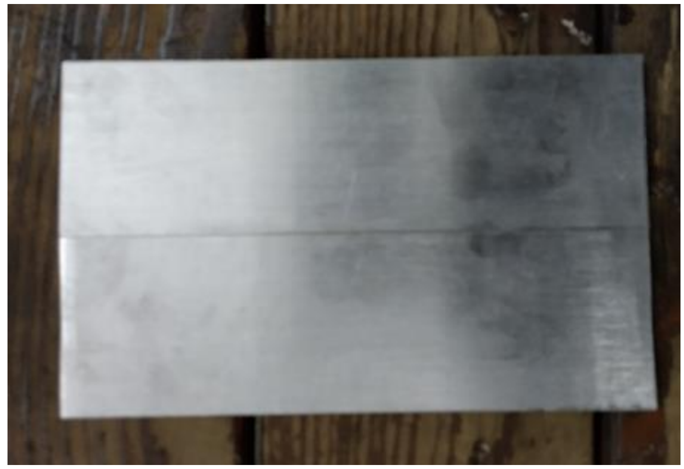
2.1 Tool geometry

By using this tool geometry, generated forces during penetration of tool at a 778 rpm or processing were huge in the magnitude. Then we go for modification in tool geometry to reduce the huge forces at the time of penetration by using threaded pin. This led to the tunnel formation in the processed region in the form of defect and it was the observed that the heat generated was very high and in order to reduce this frictional heat the shoulder diameter was reduced to18mm and pin diameter reduced to 8mm.

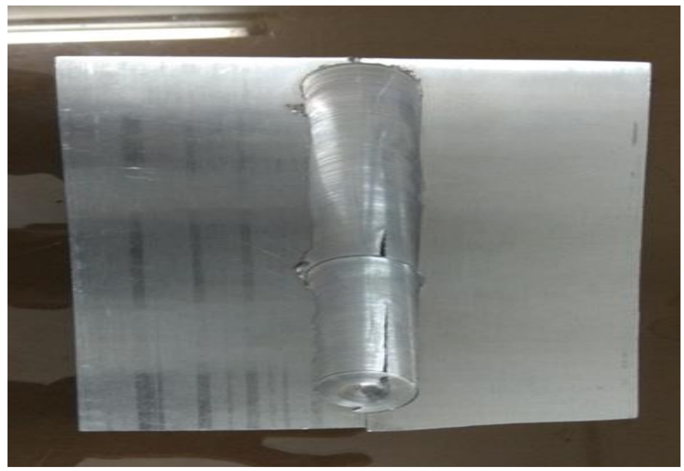
Figure 2: Tool of mild steel for FSW

Hence, we finally came up with a design that resulted in good processed zone at reduced forces. The tool design development discussed above is shown in Designed and Fabricated Tool for Al-2029 alloy had shank diameter-25 mm, shoulder dia-18mm, pin dia-8mm, pin lenth-3.5mm.

Figure 3: Friction Stir Welding set up



(a)



(b)

Figure 4: Al-2029 plates before FSW, (b) Al-2029 plates after welding by FSW process

2.2 Tensile Testing of Base Metal

This test is used to measure the strength of a welded joint. A portion of the welded plate is locate the weld midway between the jaws of the testing machine. The width thickness of the test specimen is measured before testing, and the area in square inches is calculated by multiplying these before testing, and the area in square inches is calculated by multiplying these two figures. The tensile test specimen is then mounted in a machine that will exert enough pull on the piece to break the specimen. The testing machining may be either a stationary or a portable type. A machine of the portable type, operating on the hydraulic principle and capable of pulling as well as bending test specimens. As the specimen is being tested in this machine, the load in pounds is registered on the gauge. In the stationary types, the load applied may be registered on a balancing beam. In either case, the load at the point of breaking is recorded.

2.3 Specimen Design

First the base metal plate of Al alloy 2029 is cut into small plates to make its specimens for tensile testing (according to ASTM E8 standard) which is performed on UTM machine.

Table 1: ASTM E8 standard test specimen dimension

All dimension in mm						
G	A	W	L	R	C	T
25.40	31.75	6.35	101.60	6.35	9.53	6.2

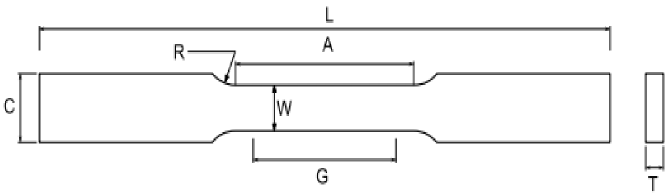


Figure 5: Tensile test specimen

Figure 6: Cutting of base metal plates by power hack saw machine

After cutting the base metal into desired shape the filing and machining process is done and to take the accurate dimension Vernier calliper is used

Figure 7: Dimension inspection by Vernier calliper

Figure 8: Tensile testing of specimen by UTM machine up to fracture point

2.4 Tensile Testing of Welded Material

The welded plates were given to metallurgical laboratory for tensile strength testing purpose.
The following procedure was adopted in ensuring that the data recorded from tensile test specimens was taken in an organized and consistent manner.

- Five specimens were chosen. Care is to be taken to ensure that the specimens did not have any notching or cracks from manufacturing or any surface defects that would adversely affect the tensile tests.
- Before loading the specimens in the UTM machine, the computer system connected to the machine was set up by inputting the necessary information of gauge length and width of the specimen. The computer system was then prepared to record data and output necessary load-deflection graphs.
- The specimens were loaded into the UTM machine, and a tensile test was performed. The data was recorded electronically in text files shown in Appendix B and the load-deflection curve was shown on the computer screen as a visual representation

Figure 9: Setup of tensile testing

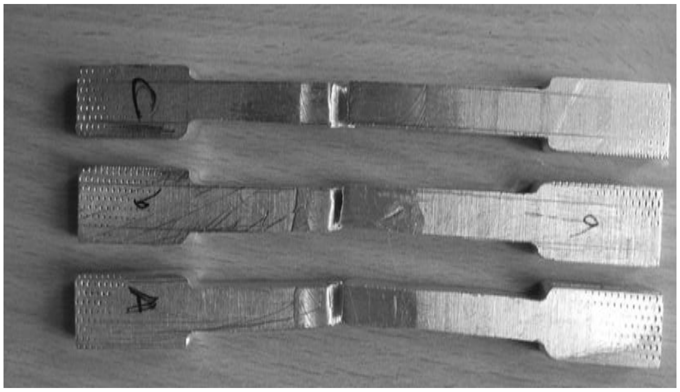


Figure 10: After tensile testing of welded material specimens

All joints were tested up to failure of joints. The force applied to break them and the area of cross section was measured and the final tensile strength was calculated for different joints. The report shown here is of the plate welded by triangular tool profile at speed of 728 rpm.

2.5 Micro Hardness Test

Hardness is defined as the resistance offered by the metal for localized plastic deformation. The Vickers hardness value was obtained by dividing the load by the square mm area of indentation.

$HV = 0.0018544\ L/d^2$

L = Load (in gm's)

d = Mean of d1 and d2 (mm)

HV = Vickers hardness

The micro hardness test of samples was carried on the Vickers hardness tester machine and samples were examined across the cross section of processed zone.

3. Result and Discussion

3.1 Load -Displacement representation of both specimen

In this we have discussed the comparing the maximum load (KN) carrying capacity of welded specimen and the displacement (mm) during tensile testing.

Table 2: Chemical Composition of Al 2029

Al	Cu	Fe	Mg	Mn	Si	Ag	Ti	Zr	Other
93.33-95.42	3.2-4.0	0.15	0.8-1.1	0.2-0.4	0.12	0.3-0.5	0.1	0.8-0.15	0.15

Table 3: Mechanical properties of Al-2029 before and after FSW

Material	Specimen	Max Load (KN)	Mean Max Load (KN)	Displacement (mm)	Mean Displacement (mm)
Al-2029 before FSW	1	4.384	4.290	1.29	1.246
	2	4.259		1.32	
	3	4.227		1.13	
Al-2029 after FSW	1	5.059	4.397	1.04	0.986
	2	4.54		1.39	
	3	3.592		.53	

From the above table, we have observed that, the maximum load (KN) carrying capacity of welded specimen is slightly more than the base metal Al-2029 alloys, with giving less displacement during tensile testing.

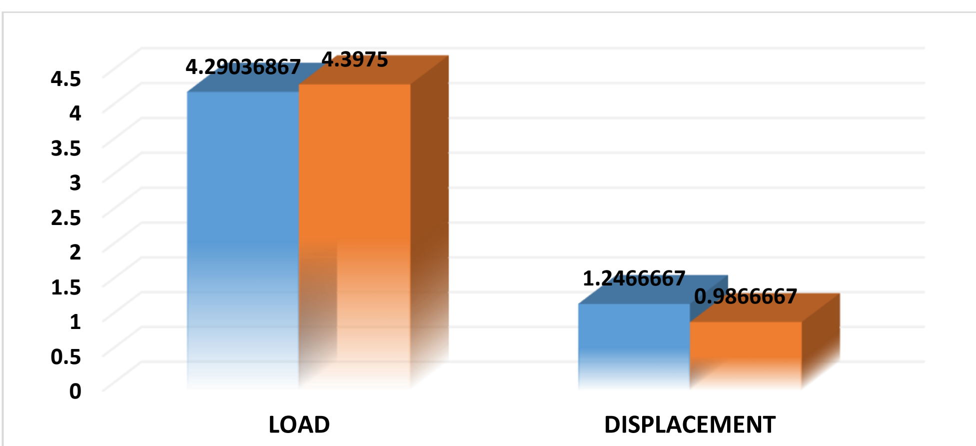


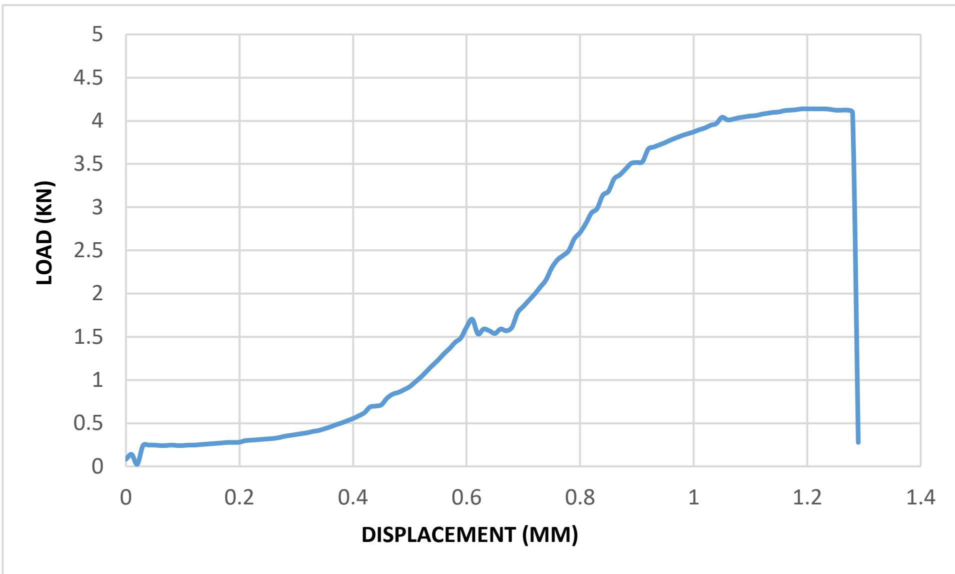
Figure 11: Variation in load and displacement of both before and after welding of FSW on specimen Al-2029

The displacement value of base metal i.e., 1.24mm Al-2029 is, more than the welded material (0.9866). Hence the mean maximum load (KN) increase of welded material is higher than the base metal

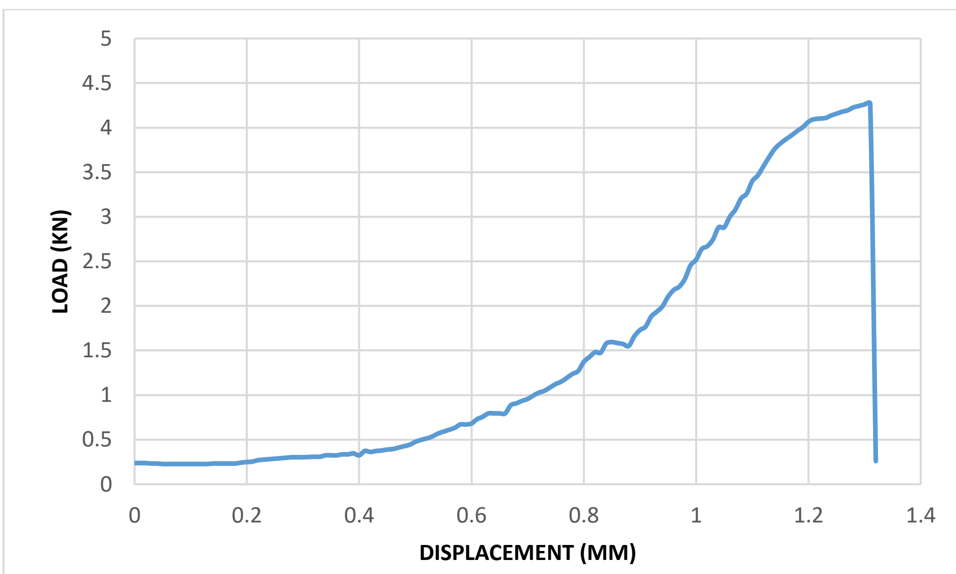
.

Table 4: Mechanical properties of Al2029

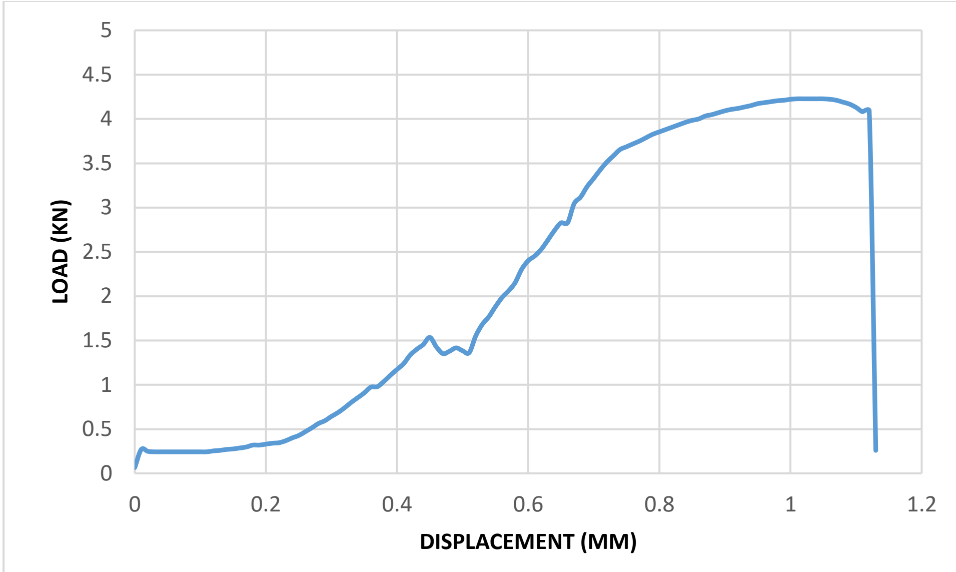
Break (Standard)	Maximum Load	Stress at Maximum Load	Stress at Yield (Offset 0.2%)	Modulus (E)	Reduction of area	Tensile strain %	Thickness	Width	Rate 1
(mm)	(kN)	(MPa)	(MPa)	(MPa)	(%)	(%)	(mm)	(mm)	(mm/min)
1.04	3.619	134.032	129.952	7565.432	3.85	1.85	4.5	6	1



(a)



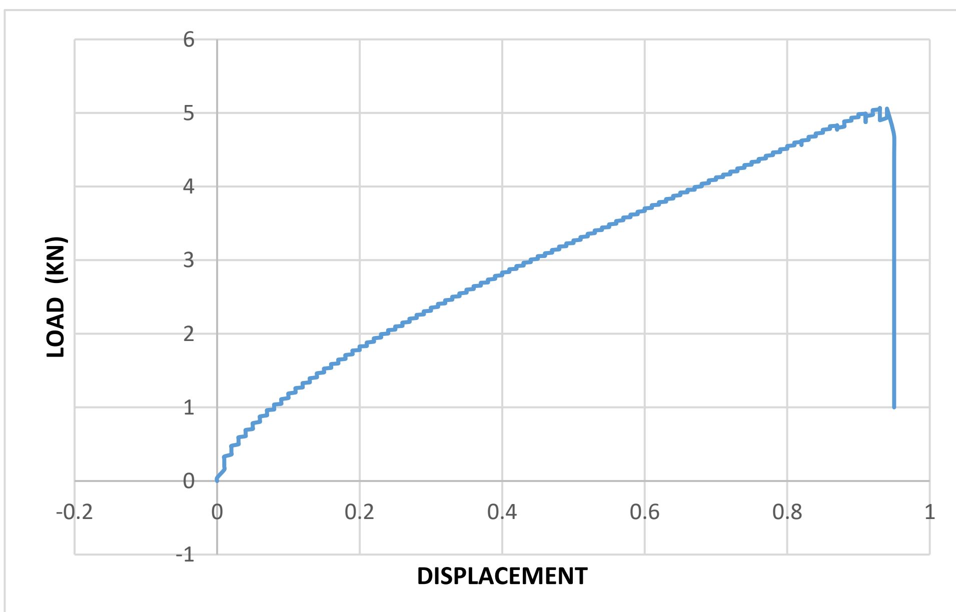
(b)



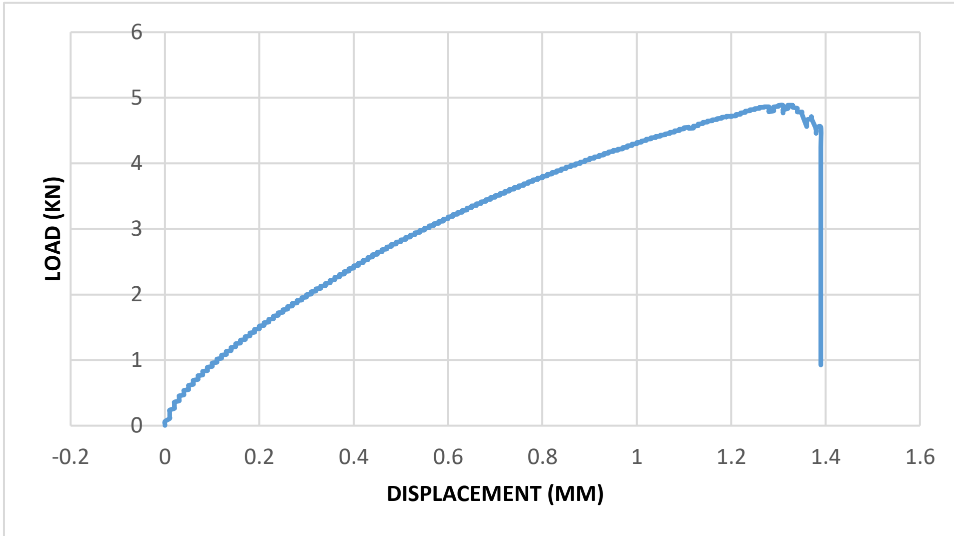
(c)

Figure 12: Variation of load displacement of Al-2029 before friction Stir Welding, (a) Specimen-1, (b) Specimen-2, (c) Specimen-3

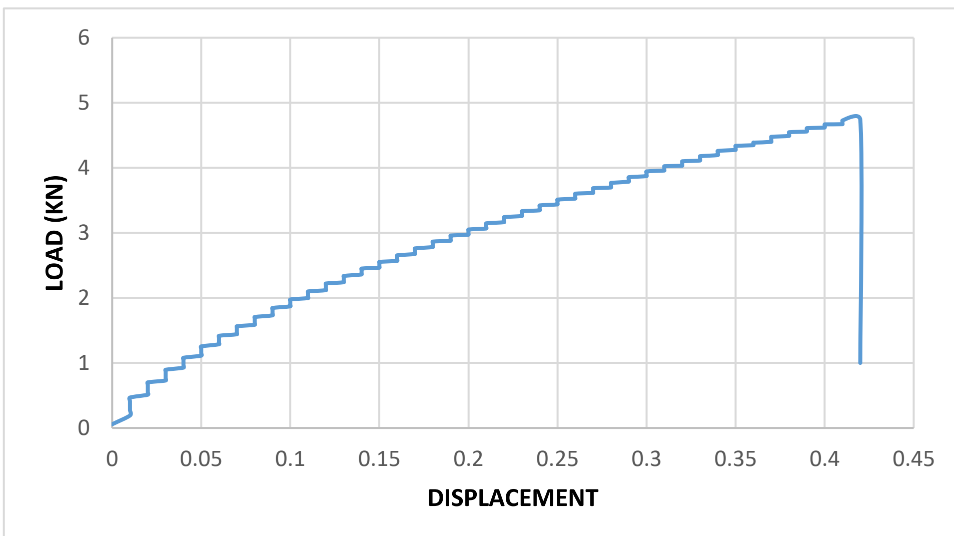
We have observed that from tensile report, the maximum load is varies between the range of 4KN-5.5KN. Therefore, the resulted mean maximum load of tensile test carried out by the 3-specimens are 4.397 and 4.29KN approximately with or without FSW, whereas the resulted mean displacement of tensile test carried out by the 3-specimens are 0.986 mm and 1.246 mm with or without FSW.



(a)



(b)



(c)

Figure 13: Variation of load displacement of Al-2029 after friction Stir Welding, (a) Specimen-1, (b) Specimen-2, (c) Specimen-3

The percentage of tensile strain due to maximum tensile load after testing is absorbed between the value of 35.03% to 43.45%, the value of tensile strain may varies due to small variation in the area of different tensile specimen. For over result, the mean tensile strain percentage calculated is 40% approximately.

Due to variation in the value of percentage strain and cross-sectional area of specimen there is a large variation of percentage reduction range is observed, it is varies from 3.3% to 20.7%. hence for the result point of view, we would be calculated the mean% reduction in area of tested specimen is approximately 13%.

3.2 Micro hardness test report

After tensile test, we have calculated the value of micro-level hardness of welded specimen and absorbed that the value of hardness at advancing side is larger than the retreating side because due to the travel speed of tool during welding. The advancing side is pushed by the tool give the more grain refinement structure or grains than the backward retreating side.

The hardness value is decreasing both side from welding line from 100HV TO 80HV at the distance of 2.5mm towards advancing side and 4mm towards retreating side after that the value of hardness increase up to 140HV. Hence as a result we would absorbed that hardness value of highly polished specimen is approximately 150HV at TMAZ region

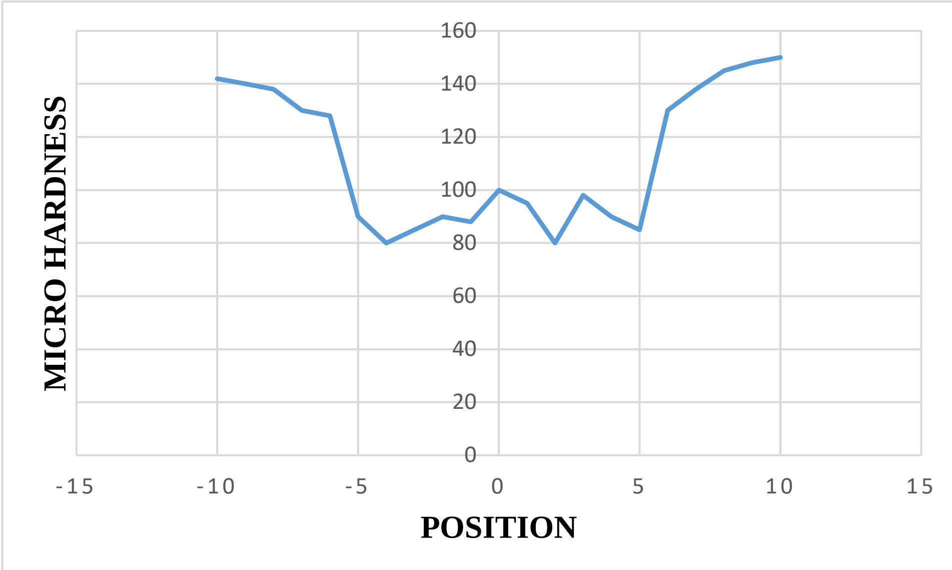


Figure 14: Variation between micro hardness and position

3.3 Microstructure Analysis

This work was based solely on information available from aluminium alloys. However, it has become evident from work on other materials that behaviour of aluminium alloy is not typical of most metallic materials. It is therefore proposed that the following revised scheme is used. This has been developed at TWI, but has been discussed with a number of appropriate people in industry and academia, and also been provisionally accepted by the friction stir welding licensees' association. The system divided the weld zone into distinct region as follows.

3.3.1 Unaffected material or parent material

This is material remote from the weld, which has not been deformed, and which although it may have experienced a thermal cycle from the weld is not affected by the heat in terms of microstructure or mechanical properties.

3.3.2 Heat affected zone (HAZ)

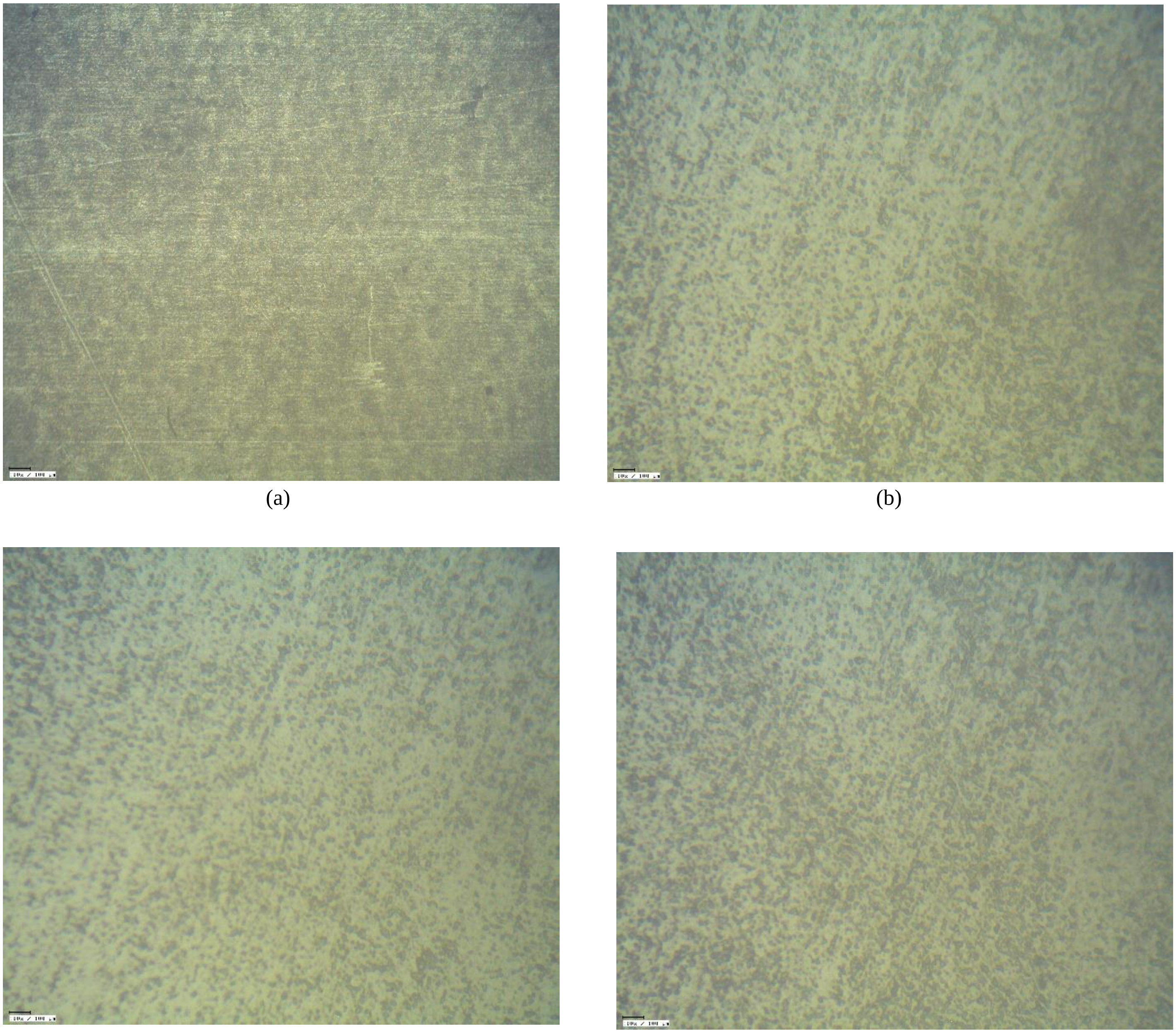
In this region, which clearly will lie closer to the weld center, the material has experienced a thermal cycle, which has modified the microstructure and mechanical properties. However, there is no plastic deformation occurring in this area. In the previous system, this was to as the "thermally affected zone". The term heat affected zone is now preferred, as this is a direct parallel with the heat affected zone in other thermal processes, and there is little justification for a separate name.

3.3.3 Thermo- mechanically affected zone (TMAZ)

In this region, the material has been plastically deformed by the friction stir welding, and the heat from the process will also have exerted some influence on the material. In the case of aluminium, it is possible to get significant plastic strain without recrystallization in this region, and there is generally a distinct boundary between the recrystallized zones and the deformed zones of the TMAZ. In the earlier classification, these two sub-zones were treated as distinct microstructural regions. However, subsequent work on other material has shown that aluminium behaves in different manner to most other materials, in that it can be extensively deformed at high temperature without recrystallization. In other materials, the distinct recrystallized region (the nugget) is absent, and a whole of the TMAZ appears to be recrystallized.

3.3.4 Weld nugget

The recrystallized area in the TMAZ in aluminum alloys has traditionally been called the nugget. A schematic diagram is shown which clearly identifies the various regions. It has-been suggested that the area immediately below the tool shoulder (which is clearly the part of the TMAZ) should be given a separate category, as the grain structure is often different here the microstructure here is determined by rubbing by the real face of the shoulder, and the material may have could below its maximum it is suggested that this area is treated as a separate sub-zone of the TMAZ.



(a) (b) (c) (d)

Figure 15: Optical Microstructure of FSW of Al-2029, (a) Stir zone, (b) HAZ, (c) Base zone (d) Weld nugget

4. Conclusion

- Hardness in advancing side is more than the retreating side in HAZ and TMAZ because the grain refinement is more in advancing side than retreating side.
- The value of hardness in the advancing side at a distance of 10mm is approximately 150 and on the retreating side is 140HV. It would rapidly increase on both the side after a distance of 5mm.
- The temperature of advancing side is more as compared to retreating side.
- Most of the friction welded joints are failed by means of ductile fracture during tensile testing and it is found from the percentage of elongation which varies from 8% to 15%.
- Friction stir welding aluminium alloy Al-2029 joints made with 4mm diameter pinned tool at a rotating speed of 780rpm approximately, feed between 20mm/min to 25mm/min and found to be possessed more than 70% of the base strength.
- As a result of tensile test, it was observed that raptures usually occurred in joint zones and HAZ of aluminium.

References

[1] M.B.D. Ellis, Joining of aluminiumbased metal matrix composites, Int. Mater. Rev. 41(2) (1996) 41–58.

[2] R.Y. Huang, S.C. Chen, J.C. Huang, Electron and laser beamwelding of high strain rate superplastic Al-6061/SiC composites, Metall. Mater. Trans. A Phys. Metall. Mater. Sci. 32 (10) (2001) 2575–2584.

[3] T. Prater, Friction stir welding of metal matrix composites for use in aerospace structures, Acta Astronaut. 93 (2014) 366–373.

[4] G. Lutjering, J.C Williams, Titanium, Springer-Verlag, New York, NY, 2003.

[5] Y.Zhang, Y.S. Sato, H. Kokawa, S.H.C Park, S.Hrano, Stir zone microstructure of commercial purity titanium friction stir welded using pnBN ttol. Material Science and Engineering A, 488 (2008), 25-30

[6] Jiye wang, Jianqing Su, R.S Mishra, Ray Xu, John A. Baumann, "Tool wear mechanism in friction stir welding", wear 321 (2014), 25-32.

[7] J.Q. Su, T.W Nelson, R.S Mishra, M.Mahoney, "Microstructure investigation of friction stir welding 7050-T651 aluminum, acta materialia, 2002.

[8] V.Jeganatham Arumoni, R.S Mishra, "Friction stir processing of Al-alloy for defence application, International journal of advance research and innovation, 2(2), 2014, 337-341.

[9] Husain Mehdi, Mishra R.S (2017b), "Mechanical and microstructure characterization of friction stir welding for dissimilar alloy- A Review." International Journal of Research in Engineering and Innovation, vol-1, issues-5, 57-67.

[10] Husain Mehdi, R. S Mishra, Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy- A Review." Journal of Achievements in Materials and Manufacturing Engineering, 77 (1) pp.31-40, 2016.

[11] Husain Mehdi, R.S Mishra, Influences of Process Parameter and Microstructural Studies in Friction Stir Welding of Different Alloys: A Review, International Journal of Advanced Production and Industrial Engineering, SI-MM 509, pp. 55–62, 2017.

[12] Husain Mehdi, R.S Mishra, Analysis of Material Flow and Heat Transfer in Reverse Dual Rotation Friction Stir Welding: A Review, International Journal of Steel Structures, 2018, https://doi.org/10.1007/s13296-018-0131-x

[13] Kolligan K. Material flow behavior during friction stir welding of aluminum. Weld Res Suppl 1999:229–37.

[14] Kohn, G., Greenberg, Y., Makover, I. and Munitz, A.,LaserAssisted, Friction Stir Welding. Welding Journal, American Welding Society, http://www.aws.org/wj/teb02/Teature2.html.,pp.1-3, February 2002.

[15] Thomas WM, Friction Stir Butt Welding International Patent Application, No. PCT/GB92 Patent Application No. 9125978.8, 1991.

[16] Yutaka SS, Hiroyuki K. Microstructural evolution of 6063, aluminum during friction stir welding. Metall Mater Trans A 1999;30A:2429–37.

[17] Liu G, Murr LE. Microstructural aspects of the friction-stir welding of 6061-T6 aluminum. Scripta Mater 1997;37(3): 355–61.

[18] Yutaka SS et al. Microstructural factors governing hardness in friction-stir welds of solid-solution-hardened Al alloys. MetallMater Trans 2001;32A:3033–41.

[19] Jata KW, Semiatin SL. Continuous dynamic recrystallization during friction stir welding of high strength aluminum alloys.Scripta Mater 2000;43:743–749.

[20] Manoj Saini , Navneet Arora, Chandan Pandey, Husain Mehdi, Preliminary Studies on Thermal Cycling of Reactor Pressure Vessel Steel" International Journal of Mechanical Engineering, vol.4 issue 2, 2014, 51-58.

[21] Manoj Saini , Navneet Arora, Chandan Pandey, Husain Mehdi ,Mechanical Properties of Bimetallic Weld Joint between SA 516 Grade 65 Carbon Steel and SS 304 L for Steam Generator Application, International Journal of Research in Engineering and Technology, vol 3 (7), 2014, 39-42.

[22] Husain Mehdi, Shwetanshu Gaurav, Teetu Kumar, Prasoon Sharna, Mechanical Characterization of SA-508Gr3 and SS-304L Steel Weldments." International Journal of Advanced Production and Industrial Engineering, 2 (1), pp. 41-46 ,2017.