NSEMX_Conf2021_025

The Nigerian Society of Engineers
Minna Branch
1st NSE Minna Branch National Conference 2021

Conference theme
Role of Engineering in
Sustainable Development Goals

Friction Stir Welding of Some Selected High Strength Aluminium Alloys- A Review

B. I . Attah[1], S. A Lawal[1], E.T Akinlabi[2], K. C Bala[1], O. Adedikpe[1] O. M Ikumapayi[3]
1. Mechanical Engineering Department, Federal University of Technology, Minna- Nigeria
2. Directorate, Pan African University for Life and Earth Sciences Institute, Ibadan-Nigeria
3. Department of Mechanical and Mechatronics Engineering, Afe Babalola University Ado-Ekiti
Corresponding author: benilehttah@yahoo.com

ABSTRACT

Friction stir welding is a solid-state joining technique which involves the plastic deformation of materials to create a solid joint. The tool generates the temperature and pressure to create the solid joints. The process can be used for joining both similar and dissimilar materials. This review addressed the friction stir welding of some selected high strength aluminium alloys. These alloys are used for applications where premium is placed on high strength to weight ratio, thus making them suitable for the aerospace industry where weight reduction is of great importance.

KEYWORDS: *Welded joints, Structural, Rotational speed*

1 INTRODUCTION

Friction stir welding was invented in the U.K in December 1991 at the weld institute. It is a technique used for joining materials in their solid state after undergoing plastic deformation to create a solid joint. The automobile and aerospace industries have found this technique very attractive in light weighting as joints are formed without riveting or bolts and nuts and also without filler metals as is the case with fusion (conventional welding technique) in order to improve vehicle and aircraft performance respectively. The high strength aluminium alloys can withstand stress under service condition making them suitable for structural and other applications in the aircraft industry (TWI, 2015).

The technology has been used to produce vehicle bonnets, wheel rims (Smith et al., 2012) and vessels bulkheads and decks (Gesto et al, 2008) and freezing plants (Midling et al. 1999). It has been used in joining metals in both similar and dissimilar manner and also considered as the most significant improvement in the metal joining processes as it is unharful to the environment, efficient in energy utilisation and with wider areas of application (Akinlabi et al. 2012).The benefits of this welding technique is that it does not generate harmful fumes, no cracking after it has solidified, results in less distortions and improvement in weld quality for the proper conditions, adaptable to all positions and is a relatively noiseless process (Hussain, 2010).

The joining of aluminium however can only be successful when the process parameters are properly selected as mechanical properties are used to qualify the soundness of a weldment and also ascertain the integrity of the welded portion (Attah et al., 2021). Figure 1.0 by Attah et al., (2021) is a schematic representation of the friction stir welding process indicating the advancing and retreating sides (AS and Rs) and the dissimilar alloys pairs of AA1200 and AA 7075 been joined in a butt-welding configuration arrangement.

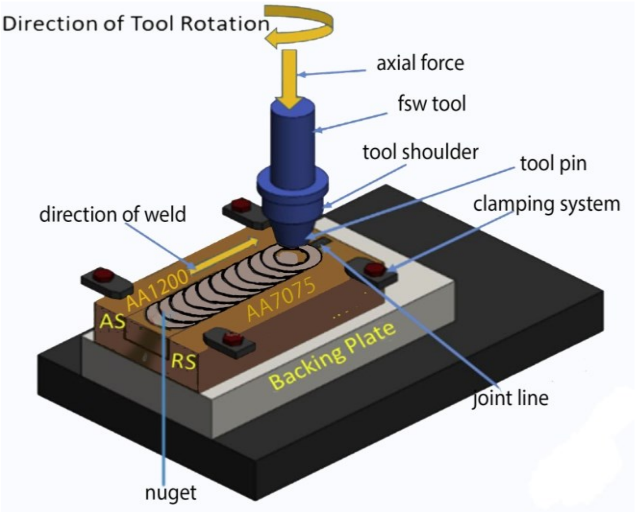

Figure 1.0: Schematic Representation of the friction stir welding Process

2 OPTIMISATION OF OPERATIONAL PARAMETERS IN FRICTION STIR WELDING OF AA7075-T6 ALUMINIUM ALLOYS USING RESPONSE SURFACE METHODOLOGY.

The welding of AA7075 was conducted by applying the response surface methodology approach at five levels of three process variables (Farazadi et al. 2017). The rotational, welding speeds and tool diameter were varied from 350-650 rpm, 35-95 mm/min, 12-18 mm tool diameter respectively and pin length of 4-6 mm and represents the parameters for consideration.

It was observed that the optimal range of the process parameters required to produce the joint with efficiency of 85 % is 380–530 rpm, 90–95 mm/min, 14.2–17.8 and 5–6 mm. It was also observed that the highest value of 458.9 MPa was obtained as the UTS when the spindle speed was varied between 350-500 rpm and at above 500 rpm it begins to decrease. It was also observed that the UTS is mostly affected by both the transverse and rotational speeds as well as pin and shoulder diameters with welding speed been the major factor of influence.

2.1 Microstructural Features of Friction stir Welded dissimilar Aluminium Alloys AA2219-O - AA7475- T761

Dissimilar welding of the alloys both of plate thickness 2.5 mm was performed by Noor et al., (2018) in butt configuration to examine the effect of spindle speed on micro-hardness distribution and microstructure of the dissimilar alloy's joints. The process parameters used are tool rotational speeds of 710, 900 and 1120 rpm. The dimensions of the workpieces are 180 x 50 x 2.5 mm. Micro hardness; microstructural analysis and optical microscopy were done on the materials. The softer material AA 2219-O was positioned on the advancing side while the harder material AA7475 was positioned on the retreating side; high carbon die steel tool was used with pin length of 2.2 mm, pin diameter of 4mm and 10mm shoulder diameter. The results showed the highest value of micro- hardness of 168.8HV at the nugget zone at a spindle speed of 1120 rpm on the retreating side.

The results also revealed that spindle speed significantly affects hardness due to increase in grain size, coarsening and dissolution of strengthening precipitates and re-precipitation. It was observed that as a result of refined grains at the stir zone, there was higher micro-hardness value at the zone. There was proper mixing of the workpieces (along the stir zone) at both advancing and retreating sides for all set of chosen parameters. Microhardness values at the advancing side are reduced by increase in spindle speed due to coarsening of grains. At high rotational speeds at nuggets, precipitates were dissolved and re-precipitation occurred. Hardness value increased with increase in rotational speed on retreating side and decreased on Advancing side.

2.2 Multiscale Electrochemical Study of Welded Al Alloys Joined by Friction Stir Welding

Dissimilar AA7475-T651 and AA 2024-T3 were butt-joined using friction stir welding by Caio-Palumbo et al., (2017) and the properties of the joints were evaluated.

The corrosion behavior of the two alloys was investigated using global and local electrochemical methods and SEM analysis before and after exposure to 0.1 M Na2SO4 + 0.001 M NaCl solution. Corrosion of the system results from the attainment of a galvanic coupling in which the AA7475 acted as anode with regards to the AA2024. The results of the anodic polarisation curves and of the global EIS diagrams displayed much lower corrosion resistance for the FSW affected zones compared to the two aluminum alloys tested seperatey. Local pH measurement allowed demonstration of the location of the enhanced reactivity for the welded system.

2.3 Effect of process parameters on the tensile strength of friction stir welded dissimilar Aluminium Alloy joints

The effects of tool rotational and welding speeds on the tensile strength of dissimilar weldment of AA2024-AA7075 joints were examined by Padmanaban et al. (2017). The two plates each of size 150 mm x 60 mm x 5 mm were used along with cylindrical threaded tool, having a shoulder and pin diameter of 17.5 mm and 5 mm respectively and height 4.65 mm was used with the tool rotational speed varied from 900 to 1200 rpm at10-20 mm/min welding speed, the tensile strength of the weldment is measured.

Mathematical model was developed for tensile strength in terms of tool rotational and welding speed. The results revealed higher tensile strength for the base metals as compared to that of the weldment. Lower tensile strength is recorded at low tool rotational speeds as a result of insufficient heat required for mixing. It was observed that the tensile strength increased when the tool spindle speed increased from 900 rpm to around 1100 rpm. This is because higher rotational speed generates higher amount of heat, better material flow and good mixing. Increasing tool rotational speed above 1100 rpm led to lower tensile strength which may be due to increase in grain size resulting from grain growth at higher peak temperature. However, higher tool spindle speed (beyond 1100 rpm) produces flash and tunnel defects probably due to stirring effect of the pin at high speed. Elangovan and Balasubramanian (2008) obtained a similar result. They reported flash and tunnel defects at tool rotational speeds above 1100 rpm and can be attributed to increased turbulence in the weld zone as reported by Elangovan et al. (2009). It was observed that the change in tensile strength remains constant regardless of weld speed and that the joints made at a tool spindle speed of around 1050 rpm gave the peak tensile strength for a given weld speed.

It was concluded that both the tool spindle and travel speeds affect the tensile strength of the weldment. That tensile strength increases with increase in tool spindle speed up to a value of 1050 rpm but reduces upon further increase. Also, that the tensile strength increases with increase in weld speed up to 15 mm/min and with additional increment decreased. Surface and contour plots revealed that when tool travel and spindle speeds are within 1075 rpm and 1125 rpm, and weld speed are within 13 mm/min to 15 mm/min that the tensile strength would be very near to highest.

2.4 Influences of processing parameters on induced energy, mechanical and corrosion properties of friction stir welded joints of AA 7475 Aluminium Alloys

Butt welding was done by Rajesh et al. (2011) on the alloy plate of 9 mm thickness under the following parameters: travel speed of 50 mm/min, spindle speed was varied between 300-100 rpm, plunge depth of 865 mm, tilt angle of . Tensile, microhardness and corrosion tests were performed

The result revealed that hardness increases from base material to a maximum at the stir zone regardless of the rotational speed due to finer grains. It was observed that a joint efficiency of 89.5 % can be obtained from the welding of the alloy. It was also observed that highest tensile strength of 355 MPa can be attained at a tool spindle speed of 400 rpm, and 50 mm/min travel speed. Also, corrosion resistance from potentiostatic polarisation for both SZ and TMAZ increase with increase in rotational speed from 300-1000 rpm with a maximum corrosion resistance obtained at 1000 rpm and welding speed of 50 mm/min with the stir zone having the highest resistance to corrosion.

3 MULTI-OBJECTIVE OPTIMISATION OF FRICTION STIR WELDING PROCESS PARAMETERS OF AA6061-T6 AND AA7075-T6 USING A BIOGEOGRAPHY BASED OPTIMISATION ALGORITHM

In this study by Mehran et al. (2017), dissimilar welding of the two alloys was conducted on the weldment in butt configuration with dimensions 100 x 50 x 6 mm. The ultimate tensile strength and elongation of AA 6061 and AA7075 are 310 MPa, 524 MPa and 12% and 11% respectively as determined before welding. Experiment was performed on UTS, % elongation and hardness of the weldment, the result was employed in developing a mathematical regression model which was validated.

Analysis of the experimental data by the developed model indicates that it can be employed predicting the stated mechanical properties of the weldment within 9% of their experimental values at a 95% confidence limit. They developed a multi objective optimization algorithm based on two phases: generation of a Pareto set by MOBBO, and the use of two different decision-making methods (Shannon's entropy and TOPSIS) to achieve the best compromise solution from the Pareto set.

The result shows that multi-response algorithm along with mathematical model can be used in friction stir welding to attain maximum mechanical properties. The optimal values for spindle and travel speeds and tilt angle which gave the UTS value of 252.23 MPa, elongation of 8.1% and 72.11 HV were 1002.14 rpm, 149.73 mm/min and 1.92 % respectively at -0.74 mm tool offset. Setting these parameters closely within those of theoretical and milling machine, the experimental values achieved are 253 MPa, 8.2 % and 71.4 HV respectively.

3.1 Characteristics of AA7075-T6 and AA6061-T6 Friction Stir Welded Joints

Dissimilar AA7075-T6 and AA6061-T6 were friction stir welded by Sathish and Vaddi (2015). The metal is in cylindrical form with a cross section of 23 mm diameter and 75 mm length. The process parameter was in three levels and varied from 1000 to 1500rpm at 250rpm interval. Mechanical and metallographic characterizations were performed on the weldments. Taguchi method was used for experimental design.

The result obtained from the experiment gave a range of values for the ultimate tensile strength as 53-203MPa with the highest elongation of the strain rate of 11.56 %. It was noticed that increasing the upset and frictional pressure while decreasing the spindle speed resulted in better tensile strength and ductility.

3.2 Mechanical Strength of Dissimilar AA7075 and AA6061 Aluminium Alloys Using Friction Stir Welding

Sathari et, al (2015) studied the effects of material location and tool spindle speed on the tensile strength of the dissimilar weldment with dimensions 100 x 50 x 2 mm. The tool rotational speeds were varied from 800-1400 rpm while welding speed and tilt angle were kept fixed at 100 mm/min and 3° respectively and by changing the fixed position of the material on the advancing and retreating sides. A total of 10 weldment were made.

From the result, a maximum value 207 MPa was obtained as tensile strength when AA6061 alloys were positioned on the advancing side at a spindle speed of 1000 rpm with good surface features and non-defective internally across the weld area, while the least tensile strength of 160 MPa was attained when AA6061 was located on the retreating side with accute tunnel defects across the weld area leading to crack propagation.

3.3 Experimental Study and Analysis of the Wear Properties of Friction-Stir-Welded AA7075-T6 and A384.0-T6 Dissimilar Aluminium Alloys of Butt Joints

The workpieces with dimensions 100 x 50 x 6.35 mm were joined by Karruppannan et al., (2017). The ultimate tensile strengths of the joints were tested to obtain their highest and a lowest level of these specimens and wear analysis was conducted on them. Their results were compared with the wear resistance of the parent metals. Before obtaining the results, the tool rotational speed, time and weld speed were held constant at 500 rpm, 300s and 3.141m/s respectively while the applied load was varied as 20, 40 and 60 N.

Wear analysis was conducted and 92 and 35.8 HRB were respectively obtained as hardness for AA7075 and A384.0 while for wear rate, A384.0 was higher and those for the weldment were within the wear rate values of the base metals. The hardness of the weldment was between 35.8 and 92 HRB. They concluded that the hardness of materials and the level of wear are inter-related parameters.

3.4 Optimization of the friction-stir-welding process and tool parameters to attain a maximum tensile strength of AA7075–T6 aluminium alloy

Welding was done in a butt joint arrangement using 300 mm x 150 mm x 5 mm thick plate to derive a relationship empirically between the friction stir welding process and tool variables (spindle and travel speeds, axial load, shoulder and pin diameters, and hardness of the tool) and the joints tensile strength. Empirical relationship was developed using experimental design, ANOVA, and regression analysis. The developed model was applied in predicting the tensile strength of the weldment confidently at 95% limit, employing friction stir welding process and tool variables.

Highest tensile strength of 375 MPa was recorded by the weldment produced with the optimised conditions of 1438 rpm, 67.64mm/min, 8.29 kN axial load, shoulder and pin diameters of 15.54 and 5.13 mm, and tool material hardness of 600 HV. It was concluded that higher sensitivity was displayed by rotational speed compared to other variables followed by travel speed then others. Rajkumar *et al.* (2010).

3.5 Study on mechanical, macro and microstructural characteristics of friction stir welding of AA7075-T6 to AA6061-T6 aluminium alloys

Dissimilar joining of the alloys both of 5mm thick plates was done in a butt arrangement by Pouya et al. (2010). Welding was done at travel speeds of 80,100, 120 and 60 mm/min. The rotational speed and tilt angle were fixed at 900 rpm. Temperature readings were taken at 5mm apart and range of 10-

30mm from the 7075 side. Harness and tensile strength of the weldment were investigated.

The result revealed a steady increase in tensile strength while increasing the travel speed to a level and then starts declining. 255 MPa was obtained for UTS at peak value at travel speed of 120 mm/min and thereafter begins to decrease while the hardness increased with increase in travel speed and the highest value obtained at around 127 HV at 160 mm/min travel speed.

Conclusion

In conclusion, a review of friction stir welding of some selected high strength aluminium alloys has been undertaken. This review has shown that significant progress has been made in both similar and dissimilar welding using friction stir welding process. Most of the cited literature were directed at understanding the appropriate process parameters, Mechanical and microstructural properties as well as microstructure and corrosion characteristics of the weldment. The knowledge of friction stir welding technology can be utilised in fabricating joints of both similar and dissimilar materials in order to maximize their benefits and minimize their drawbacks. The technology is suitable for aerospace, railway and electrical industries amongst others.

ACKNOWLEDGEMENTS

The authors' wishes to acknowledge the assistance given by Prof. E.T Akinlabi, Director Pan African University for Life and Earth Sciences Institute (PAULESI) Ibadan Nigeria and Engr. Dr. Joshua Attah of National Universities commission Abuja, Nigeria to embark on a research visit to the Indian Institute of Technology, Kharagpur India to conduct experiments on dissimilar friction stir welding. The support received from Prof. S.K Pal, Chairman and Professor in charge of friction stir welding research laboratory of the Indian Institute of Technology Kharagpur is also acknowledged.

REFERENCES

Akinlabi, E.T., Annelize, E & Patrick, J. M (2012). Effect of Travel speed on Joint Properties of Dissimilar Metal Friction Stir Welds. *Second International Conference on Advances in Engineering and Technology*

Attah, B.I., Lawal, S.A., E.T Akinlabi & K. C Bala (2021) Evaluation of mechanical properties of dissimilar aluminium alloys during friction stir welding using tapered tool. Volume 8 issue 1:1909520. https://doi.org/10.108023311916.2021.1909520

Caio Palumbo D. A., Isolda Costa., Hercilio Gomes D. M, Nadine, P., Bernard T. and Vincent, V. (2017). Multiscale Electrochemical Study of Welded Aluminium Alloys Joined by Friction Stir Welding. *HAL Achievers- ouvertes HAL Id: hal 01611642* https://hal.sorbonneuniversite.fr/hal-01611642.

Divya, D. D., Anuj. S, & Charit, V. (2014): Optimisation of Friction Stir Welding Parameters for AA 6061 and AA 703 Aluminium Alloys by Response Surface Methodology (RSM). *International Journal of Advanced Mechanical Engineering. ISSN 2250-3234 Volume 4, Number5 (2014), pp. 565-571 © Research India Publications* http://www.ripublication.com

Elangovan, K.; & Balasubramanian, V. (2008). Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy. *Journal of Materials Processing Technology*, 200(1-3), 163175.

Elangovan, K.; Balasubramanian, V.; & Babu, S. (2009). Predicting tensile strength of friction stir welded AA6061 aluminium alloy joints by a mathematical model. *Materials & Design*, 30(1), 188-193.

Farzadi1, A., Bahmani, M. & Haghshenas, D.F (2017). Optimisation of Operational Parameters in Friction Stir Welding of AA7075-T6 Aluminium Alloys Using Response Surface Methodology. *Arab Journal of Science and Engineering 42:4905 4916 DOI 10.1007/s13369-0172741-6.*

Gesto, D., Pintos, .V., Vazquez, .J. Rasilla J., & Barreras, S. (2008). Application of Friction stir welding in ship building. Proceedings of TWI,s 7th Int. Sympsium on Friction stir welding', May 4th-7th 2008, Awaji Island, Japan.

Hussain, A.K. (2000). Evaluation of parameters of friction stir welding for aluminium AA6351Alloy, *International journal of engineering science and technology*, 2(10),59775984.

Mehran, T., Hang, B. T., Baharudin, T., Shahla, P., Khamirul, A. M.,Shamsuddin, S & Firouz, F.(2017). Multi-Objective Optimisation of Friction Stir Welding Process Parameters of AA6061-T6 & AA7075-T6 Using a

Biogeography Based Optimisation Algorithm

Midling, O. T., Kvåle, J. S. & Dahl, O. (1999). Industrialisation of the Friction Stir Welding Technology in Panels Production for the Maritime Sector. Proceedings of TWI 1st International Symposium on 'Friction stir welding', June 2nd- 5th 1999, Thousand Oaks, CA, USA.

Noor, Z. K., Mohammed, U., Arshad, N. S., Zahid, A. K.., Abdulrahman, A. A, Xizhang, C & Mustufa, H. A . (2018) :Microstructural Features Of Friction Stir Welded Dissimilar Aluminium Alloys Aa2219 AA7475. *Journal of material research express* Vol (5) https://doi.org/10.1088/2053-1591/aac4e1.

Pouya, B., Mohammad, H., Mohammad, K. B. G & Sahand, A. (2010). Study on mechanical, macro and microstructural characteristics of friction stir welding of AA7075-T6 to AA6061-T6 aluminium alloys . *Proceedings of the Institution of Mechanical Engineers part B journal of Engineering Manufacture* 1:1-12. DOI: 10.1243/09544054JEM1959

Rajkumar, S., Muralidharan, C & Balasubramanian, V. (2010). Optimisation of the friction-stir Welding process and tool parameters to attain a maximum tensile strength of AA707-T6 aluminium alloy. *Proceedings of the Institution of Mechanical Engineers part B journal of Engineering Manufacture* 1:1-12. DOI: 10.1243/09544054JEM1959

Rajesh, K .G., Hrishikesh D., & Tapan K. P. (2012) Influence of Processing Parameters on Induced Energy, Mechanical and Corrosion Properties of FSW Butt Joint of 7475 AA. *Journal of Materials Engineering Performance* 21:1645–1654 _ASM International. DOI: 10.1007/s11665-011-0074-21

Karruppanan, A., Subramaniam, P & Mayakrishnan, M (2017) Experimental Study and Analysis of the Wear Properties of Friction-Stir-Welded AA7075-T6 and A384.0-T6 Dissimilar Aluminium Alloys of Butt Joints. UDK 620.1:620.178.16:669.715

Sathish R & Vaddi S. R. (2014). Characteristics Of AA7075-T6 and AA6061-T6 Friction Welded Joints. *Transactions of the Canadian Society for Mechanical Engineering*, Vol. 39, No. 4, 2015

Smith, C. B,, Hinrichs, J. F., & Ruehl, P. C. (2012). Friction Stir and Friction Stir Spot Welding – Lean, Mean and Green. Retrieved on October 20 2017 from: www.frictionstirlink/Pub14AwssmcLeanMeanGeen-UnitedStates

TWI, (2015). What is welding? Definition, processes and types of welds. Retrieved on 25th March, 2021 from www.twi-global.com.

Padmanaban, R.V., Balusamy, V. & Nouranga, K.. N.(2015): Effect of Process Parameters on the tensile strength of friction stir welded dissimilar aluminum joints. *Journal of Engineering Science and Technology Vol. 10, No. 6. 790 – 801 © School of Engineering, Taylor's University*