

Effect of Process Parameters on Mechanical Properties of Friction Stir Welding – A Review

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ABSTRACT: Friction stir welding is the solid state joining technique developed at The Welding Institute (TWI) in 1991. The process was first used at NASA to weld the lightweight external tank for space applications. The current focus of Friction stir welding process is to extend to the new materials which are difficult to weld using conventional fusion welding techniques. The main focus of Friction stir process was on aluminium based alloys and composites. Many researchers have investigated this technology for other alloys and materials such as stainless steels, magnesium, titanium and copper. Compared with other processes, friction stir processing has the advantage of reducing distortion and defects in materials. In this review the process parameters, geometry of tool, microstructure evolution and mechanical properties of aluminium alloys and Al based metal matrix composites have been discussed. The focus of this paper is the comprehensive review of work the researchers has been done.

KEYWORDS: Frictions stir welding, Process parameters, tool geometry, mechanical properties.

I. INTRODUCTION

Friction stir welding has been widely used in welding heat treatable aluminium alloys and it is a new technology in the high performance aerospace automotive industries and marine applications. The process is used for the joining of two dissimilar metal pieces at molecular level without melting [1]. The friction stir welding is a solid state joining technique patented by the welding institute (TWI) in 1991. The process is suitable for joining of dissimilar metals compared to conventional fusion welding process. The advantages of this process are high quality and flexibility. It could join the materials together without melting which reduces many defects existed in fusion welding process. The process parameters such as rotational speed, welding speed, tool geometry have influence on the material flow [2]. The microstructure and mechanical properties of Friction stir welded joints mainly depends on process parameters. Dissimilar material combination products have been becoming increasingly significant in industrial applications due to their technical and economical benefits.

In aerospace, transportation industries, the most common engineering materials used are Al & Copper. In electrical applications Al/Cu bimetallic joints is commonly used due to less material cost and prolonged service life [4]. Joining of these materials, the conventional fusion welding process is not suitable due to their physical and chemical properties [7]. Formation of cracking is expected in fusion welded joint due to high affinity between Al & Cu which affects the mechanical properties. Now a day the process has been used to light weight materials such as joining Aluminium alloys to other materials.

The butt joints of dissimilar Al alloy to advanced high strength steel are produced using FSW technique. The maximum tensile strength was reached 85% of base aluminium alloy. The welding speed had an insignificant effect on mechanical welding force, temperature distribution, material strain rate and IMC layer composition. The effects of material position, welding speed on the material flow, microstructure, microhardness distribution and tensile properties

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of joints of AA6061 and AA7075 are investigated. The tensile strength of the dissimilar joints increases with decreasing heat input. When welding was conducted at highest welding speed and AA6061 Al plates were fixed on advancing side, the high strength of the joint was observed. The joints were failed at positions in HAZ on AA6061 side where the minimum hardness is located and observed that very good tensile strength and ductility. The tool process parameter plays a significant effect on the micro structural evolution [10]. The tools used for FSW of aluminium alloys are straight, cylindrical, taper, triangular made of HSS [4]. The process parameters can influence the friction stir welding joint quality such as welding speed, rotational speed, tilt angle, vertical downward force applied between the tool shoulder and the surface of the work piece [6]. The CNC operated Milling machine suited for friction stir welding process at low cost for joining heat treatable aluminium alloys for aerospace and automobile industries. A detailed review is given on how to convert a conventional milling machine into a CNC milling machine to perform the Friction stir welding. To join a couple of 3-mm thick AA2219 and designed suitable tool and analysed the performance of welded joint. They concluded that the tool profile plays an important role of friction stir welding. The load bearing capacity of tool pin of L80 steel and AA7075 alloy and used a three dimensional heat transfer and visco-plastic model to observe the influence of pin length and diameter on traverse force during FSW. With increase in pin length the total traverse force increases significantly [5].

The tool shoulder diameter of AA6061 aluminium alloys to determine the optimum tool geometry, the torque components used for various shoulder diameters. They observed that due to an increase in the shoulder diameter the strength of the material is decreases and with increase of shoulder diameter the area over which the torque is applied increases [6]. For AZ31B-H24 magnesium alloy, with increasing the tool rotational speed the tensile load initially increases but with further increase of tool rotational speed the tensile shear load decreases and with increasing probe length, penetration depth in to the bottom sheet the shear strength increases [7]. Among the papers related to Frictional Stir Welding process that has been investigated on joining of aluminium alloys as well as dissimilar materials such as Al-Cu[3], Aluminium to steel. The microstructure, fatigue properties, hardness, tensile properties has been investigated [11].

Friction stir welding (FSW) is a widely used solid state joining process for soft materials such as aluminium alloys because it avoids many of the common problems of fusion welding. The friction stir welding process is applied to many materials including aluminium, copper and steels. [D.Trimble, et.al] were experimentally proven at the welding institute (TWI) in 1991 and has become a relevant technology aimed at joining materials that are so called difficult to weld and even unweldable. The FSW process involves the joining of two metal pieces at the molecular level without melting. The tool traverses along the joint causing sufficient frictional heat to soften the material and rotation of the tool then stirs the molecules together leaving behind a fully consolidated joint. The advantage of this process is ability to weld all series of Al alloys. For high melting materials such as steels and titanium, they considered many variables which one of them is the speed of FSW. In this study they observed that the process is time consuming, needs many welders, electrodes and too high energy. According to previous studies, increase in welding speed will reduce the recrystallized grain size. In the friction stir welding process, different welding variables like tool rotation, transverse speed, tilt angle, plunge depth for welding of aluminium alloys or dissimilar alloys. High strength aluminium alloys are difficult to join by using conventional fusion welding techniques. The main characteristic is to join material without reaching the fusion temperature. The limitations of FSW are the welding speeds are somewhat slower than those fusion welding processes and there is a keyhole at the end of each weld seam [10]. The forming of FSW is still challenging because of limit formability.

The tool parameters such as tool pin profile and welding speed. They observed that the Square pin profile tool gives defect free FSP region, irrespective of welding speeds. The joints welded at a welding speed of 0.76mm/s using square pin profiled tool exhibits max tensile strength, higher hardness and fine grain structure [11]. The effect of various process parameters, such as tool rotational speed, traverse speed, axial force and tool geometry on the quality of the welded joint are reviewed [12]. Yield strength, ultimate strength, elongation, toughness, microstructure of the joint are evaluated and correlated with received base material. To compare and validate experimental results, FEA model is the best way to study the quality of welded joint [13].

II. FRICTION STIR WELDING PROCESS

In Friction stir welding process a cylindrical tool with a shoulder, and a profiled pin, is slowly plunged into the abutting edges of the rigidly clamped work pieces and then translated along the length of the abutting edges. The tool serves three primary functions, that is, heating of the work piece, movement of material to produce the joint, and containment the hot metal beneath the tool shoulder. The rotating and traversing tool develops frictional heat that softens the surrounding work piece material and allows the tool to move along the joint line. The axial load and the traversing motion of the tool cause the plasticized material to flow from the front to the back of the tool. When the tool moves forward, the transported material cools down and consolidates to form a joint in solid-state at temperature below the melting point of base metals.

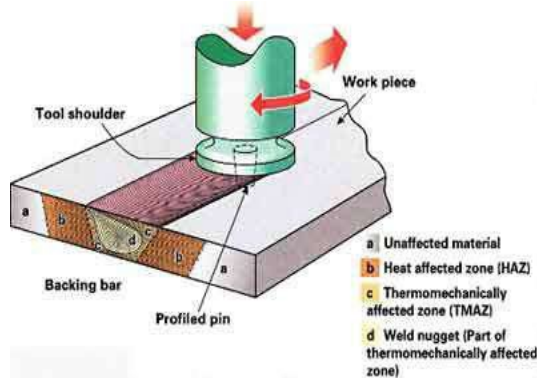


Figure 1: FSW Machining Operation

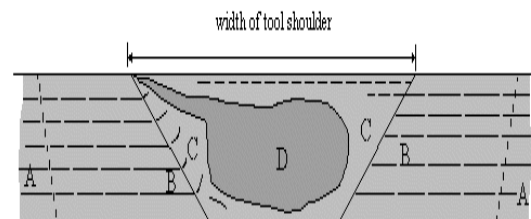


Figure 2: Micro structural zones in FSW

The FSW process includes three phenomena: heating, plastic deformation, and forging. A non-consumable rotating tool, consisting of a probe and shoulder, is plunged into the materials to be joined and then traverses the joint line. Heat is generated through both friction and plastic deformation of the welded material. At elevated temperatures, the material plasticizes and is sheared at the front of the probe and it is rotated to the rear of the probe where it is forged together under significant shoulder pressure. The FSW process is illustrated in Fig:1. The advancing side is the region in which the traverse velocity and the tangential velocity of the rotating tool are in the same direction. The retreating side is the region in which the traverse velocity and the tangential velocity of the rotating tool are in opposite directions. This advancing or retreating phenomenon leads to different mixing characteristics within the weld seam, depending on location. These characteristics will be discussed further in the material flow section of the introduction. FSW can be performed on a variety of joint configurations, including butt joints, lap joints, and T-joints.

The four visually distinct micro structural zones shown in Fig:2 in which welds in aluminium are typically divided into: (A) unaffected parent material, (B) heat affected zone, (C) thermo-mechanically affected zone, and (D) weld nugget. In the heat affected zone, properties and microstructure are affected by the heat from the weld, although there is no mechanical deformation. This zone retains the same grain structure as the parent materials. The thermo-mechanically affected zone shows characteristics that suggest that it underwent plastic deformation but recrystallization did not occur in this zone due to insufficient deformation strain. In weld nugget zone, intense plastic deformation and frictional heating during FSW result in recrystallized fine-grained microstructure. However, its use has become widespread, and as there is no word, which is equally simple with greater scientific merit, this term has been adopted. It has been suggested that the area immediately below the tool shoulder (which is clearly 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 rear face of the shoulder, and the material may have cooled below its maximum. It is suggested that this area is treated as a separate sub-zone of the TMAZ.

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III. TOOL GEOMETRY

The geometry of tool plays an important role in material flow of the joint. The welding tool has two functions such as localized heating and material flow. The functions should be performed by the tool are enable flow of plasticized material, reduce the welding force, facilitates the effect of downward force [12]. Several review papers indicate that the tools widely used in Friction Stir welding are a cylindrical threaded pin, concave shoulder and truncated cone.

IV. WELDING PARAMETERS

The Welding parameters, Tool geometry and joint design exert significant effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material [14]. Therefore, the variables that are used to control the FSW process are the welding speed, the tool rotational speed, the tilt angle of the tool, tool material and the tool design. For Friction Stir Welding process, the two important parameters are tool rotation rate (v , rpm) in clockwise or counter clockwise direction. The motion of the tool generates frictional heat within the work pieces, extruding the softened plasticized material around it and forging the same in place so as to form a solid-state joint. The speed of the welding depends on various factors, such as rotational speed, penetration depth, type of material and type of joint. High temperature developed at high rotation rate results intense stirring and mixing of material [15]. The another important process parameter is the tool tilt angle with respect to the work piece surface. Generally, the tool is characterized by small tilt angle.

PARAMETRIC STUDY OF FSW: Many investigators have performed friction stir welding to study the effect of various parameters on quality of friction stir welded joint.

V. CONCLUSION

From the above review, it is observed that,

- The tool parameters such as the tool rotation speed, traverse speed, axial force and tool design plays a significant role in friction stir welding.
- The tool can be used for modelling of friction stir welded joint are FEA such as WELDSOFT, DEFORM-3D, ABACUS etc.
- The properties of the Tool material such as strength, fracture toughness, hardness, thermal conductivity and thermal expansion coefficient affect the weld quality, tool wear and performance.
- The tool material is also important consideration for good strength of the joint. The cost effective and long life tools are available for alloys of aluminium and other soft alloys. Further developments in FSW tool materials are required for harder alloys to address the problem of high tool cost with low tool life during welding.

REFERENCES

- [1]. Xun Liu, Shuhuai Lan, Jun Ni * "Analysis of process parameters effects on friction stir welding of dissimilar aluminum alloy to advanced high strength steel", *Materials and Design* 59 (2014) 50–62.
- [2]. J.F.Guo, H.C.Chen, C.N.Sun, G.Bi, Z.Sun, J.Wei "Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters" *Materials and design* 56(2014) 185-192.
- [3]. Yongxian Huang, C.L.Liu, Li Zhou, Z.L.Chang, " Effects of Workpiece mating variations on 2219 Al Alloy friction stir welding process", *Journal of Aeronautical Materials* 35(2015) 34-42.
- [4]. Lingaraju Dumpala, D. Lokanadham., " LowCost Friction Stir Welding of Aluminium Nano Composite – A Review" *ELSEVIER Publications* 2211-8128 (2014).
- [5]. Yu E Ma, Z.C.Xia, R.R.Jiang, WenYa Li, "Effect of welding parameters on mechanical and fatigue properties of friction stir welded 2198 T8 aluminium-Lithium alloy joints", *Engineering Fracture Mechanics* 114(2013) 1-11.
- [6]. H.Bisadi, A. Tavakoli, M.Tour Sangsaraki, K.Tour Sangsaraki., "The influences of rotational and welding speeds on microstructures and mechanical properties of friction stir welded Al5083 and commercially pure copper sheets lap joints", *materials and design* 43(2013)80-88.
- [7]. A. Arora , M. Mehta, A. De, T. DebRoy, "Load bearing capacity of tool pin during friction stir welding", *Int J Adv Manuf Technol*, Vol.61, 2012, 911–920.
- [8]. TraciePrater "Friction Stir welding of Metal Matrix composites for use in aerospace structures" *ActaAstronautica*93(2014)366-373.
- [9]. Uyyuru R.K. and Kailas Satish V., *Numerical Analysis of Friction Stir Welding Process*, ASM International, (2006) 15:505-518.
- [10]. Elangovan K., Balasubramanian V., 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* 2 0 0 (2 0 0 8) 163–175.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

- [11]. Cao X., Jahazi M., Effect of tool rotational speed and probe length on lap joint quality of a friction stir welded magnesium alloy, *Materials and Design* 32 (2011) 1–11.
- [12]. Shrikant G.Dalu, M. T. Shete, "Effect of various process parameters on friction stir welding", *International Journal of Research in Engineering and Technology*, 2319-1163, 2321-7308.
- [13]. B.T. Gibson*, D.H. Lammlein, T.J. Prater, W.R. Longhurst, C.D. Cox, M.C. Ballun, K.J. Dharmaraj, G.E. Cook, A.M. Strauss "Friction stir welding: Process, automation, and control" *Journal of Manufacturing Processes* 16 (2014) 56–73.
- [14]. M.Vamsi Krishna, Anthony.M.Xaviour., "An investigation on the Mechanical Properties of Hybrid Metal Matrix Composites" Elsevier 1877-7058(2014).
- [15]. B.T. Gibson*, D.H. Lammlein, T.J. Prater, W.R. Longhurst, C.D. Cox, M.C. Ballun, K.J. Dharmaraj, G.E. Cook, A.M. Strauss "Friction stir welding: Process, automation, and control" *Journal of Manufacturing Processes* 16 (2014) 56–73.
- [16]. RajKumar.V*, VenkateshKannan.M, Sadeesh.P, Arivazhagan.N, Devendranath, Ramkumar.K "Studies on effect of tool design and welding parameters on the friction stir welding of dissimilar aluminium alloys AA 5052 – AA 6061" *Science Direct Procedia Engineering* 75 (2014) 93 – 97.
- [17]. Y.Tao, Z.Zhang, D.R.Ni, D.Wang, B.L.Xiao, Z.Y.Man* "Influence of welding parameter on mechanical properties and fracture behaviour of friction stir welded Al–Mg–Sc joints" *Materials Science & Engineering A* 612 (2014) 236–245
- [18]. D.Trimble, J.Monaghan, G.E.O'Donnell., Force generation during friction stir welding of AA2024-T3, *Manufacturing Technology* 61(2012)9-12
- [19]. Radoslaw Winiaczek*, Mieczyslaw Kaczorowski "Friction welding of ductile iron with stainless steel" *Journal of Materials Processing Technology* 213 (2013) 453– 462.
- [20]. Vivekanandan. P1., Arunachalam. V. P, Prakash. T, Savadamuthu. L, "The experimental analysis of friction stir welding on aluminium composites", *International Journal of Metallurgical Engineering*, Vol.1(4), 2012, pp. 60-65.
- [21]. Mustafa Kemal Bilici, Ahmet Irfan Yüklér, "Influence of tool geometry and process parameters on macrostructure and static strength in friction stir spot welded polyethylene sheets", *Materials and Design*, Vol.33, 2012, pp.145–152
- [22]. M. K. Bilici, Ahmet Irfan Yüklér, "Influence of tool geometry and process parameters on macrostructure and static strength in friction stir spot welded polyethylene sheets", *Materials and Design*, Vol.33, 2012, pp.145–152.
- [23]. M. MEHTA, A. ARORA, A. DE, T. DEBROY, "Tool Geometry for Friction Stir Welding—Optimum Shoulder Diameter", *The Minerals, Metals & Materials Society and ASM International*, Vol. 42A, 2011, pp.2716-2722. Uzun et al.,
- [24]. Elangovan K. & Balasubramanian V. & Valliappan M., Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy, *Int J Adv Manuf Technol* (2008) 38:285–295.
- [25]. R.S. Mishra, Z.Y. Ma, "Friction stir welding and processing", *Materials Science and Engineering*, Vol.50, 2005, pp. 1–78.
- [26]. Mustafa Kemal Bilici, Ahmet Irfan Yüklér, "Influence of tool geometry and process parameters on macrostructure and static strength in friction stir spot welded polyethylene sheets", *Materials and Design*, Vol.33, 2012, pp.145–152.
- [27]. Radoslaw Winiaczek*, Mieczyslaw Kaczorowski "Friction welding of ductile iron with stainless steel", *Journal of Materials Processing Technology* 213 (2013) 453– 462
- [28]. Patil H.S, S.N.Soman, "Experimental study on the effect of welding speed and tool pin profiles on AA6082-O aluminium friction stir welded butt joints", *International Journal of Engineering, Science and Technology*, Vol.2.No.1.5, 2010, pp.268-275.
- [29]. Abdul Arif, Abhishek, K.N.Pandey, "Thermomechanical Modelling for Residual stresses of Friction Stir welding of Dissimilar Alloys", *International Journal of Engineering, Science and Technology*, Vol.5., 2013, pp.1195-1204.
- [30]. N.Rajamanickam, V.Baluswamy, P.R.Thyala, G.Hari Vignesh, "numerical simulation of thermal history and residual stresses in friction stir welding of Al2014-T6", *Journal of scientific & industrial research*, Vol.68, 2009, pp 192-198.
- [31]. C.M. Chen, R. Kovacevic * "Finite element modeling of friction stir welding—thermal and thermo mechanical analysis" *International Journal of Machine Tools & Manufacture* 43 (2003) 1319–1326.
- [32]. Jata KV, Sankaran KK, Ruschau J. —Friction-stir welding effects on microstructure and fatigue of aluminum alloy 7050–T7451" *Metall Mater Trans* 2000;31A:2181–92.
- [33]. S. Rajakumar*, C. Muralidharan, V. Balasubramanian "Influence of friction stir welding process and tool parameters on strength properties of AA7075-T6 aluminium alloy joints" *Materials and Design* (2010) Article history, Accepted 16 August 2010.
- [34]. M. K. Bilici, Ahmet Irfan Yüklér, "Influence of tool geometry and process parameters on macrostructure and static strength in friction stir spot welded polyethylene sheets", *Materials and Design*, Vol.33, 2012, pp.145–152. [18].
- [35]. Muhsin J. J., Moneer H. Tolephih, Muhammed A. M., "effect of friction stir welding parameters (rotation and transverse) speed on the transient temperature distribution in friction stir welding of AA 7020-T53", *ARP Journal of Engineering and Applied Sciences*, Vol. 7, NO. 4, 2012, pp.436-446.
- [36]. Dr.Ayad M. Takhakh, Asmaa M. Abdullah, "The Optimization Conditions of Friction Stir Welding (FSW) for Different Rotational and Weld speeds", *Nahrain University, College of Engineering Journal (NUCEJ)*, Vol.15 No.2, 2012, pp.187 – 196.
- [37]. B. London, M. Mahoney, B. Bingel, M. Calabrese, D. Waldron, "Proceedings of the Third International Symposium on Friction Stir Welding, Kobe, Japan, 27–28 September (2001)
- [38]. C.M. Chen, R. Kovacevic * "Finite element modeling of friction stir welding—thermal and thermo mechanical analysis" *International Journal of Machine Tools & Manufacture* 43 (2003) 1319–1326).