REST Journal on Emerging trends in Modelling and Manufacturing
Vol: 6(1), 2020
REST Publisher
ISSN: 2455-4537

Website: www.restpublisher.com/journals/jemm

Study of Joining Dissimilar Aluminium Matrix Composites Using Friction Stir Welding - A Review

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Abstract

In the broader engineering world, nowadays metal matrix composites are having increased applications in almost all domains ranging from industrial requirements, structural components, research materials, improving aesthetic values and more recently domestic appliances. They are preferred over metal alloys, which happened to be the primary choice of consumers, some years ago. Their properties like low cost, high power to weight ratio, improved tensile strength, high hardness and rigidity, good resistance to corrosion and wear make them attractive and most sought after in the fields, they are being used. Particularly, Aluminium matrix composites (AMCs) are having the capability to replace traditionally used metals and their alloys like iron, brass, bronze, copper and steel due to its reduced weight and improved properties. In modern days, welding two alloys or composites (same or different) together has gathered momentum, due to its adaptability and flexibility to be used in any adverse environmental conditions. Joining two dissimilar grades of aluminium matrix composites with different reinforcements is considered to be a challenging one because of the varying physical and chemical properties of the matrix material. Friction stir welding is considered to be most suitable method to join two aluminium alloys or their composites. This review paper deals with an objective to provide deeper insight about the analysis of various process parameters involved in joining two dissimilar grades of aluminium matrix composites with different reinforcements using friction stir welding process.

Keywords: aluminium matrix composites; metal alloys; tensile strength; flexibility; reinforcements; matrix; friction stir welding

I. Introduction

Composite is a combination of materials, in which either two or more metals or a metal and a non metal are joined together in required proportions. The main purpose of fabricating composites is to obtain superior mechanical and technological properties, otherwise cannot be obtained in individual material. The advantageous attributes of the individual materials are combined together, when they are joined to form composite. Literally, joining of two materials together by melting, as the composite is traditionally processed, alters the mechanical properties (i.e)The mechanical properties or macro properties of the composite is far more superior when compared to individual materials. But, there will be no comprehensive variation in the physical and chemical properties, as the materials in the composite exhibit the same micro properties that of individual materials, even when they are joined together(distinctive phases exist). This particular attribute make the composites differ from alloys, in which the physical and chemical properties of the resultant alloy material changes compared to individual metals, when two or more metals are mixed together at specific proportion to form alloys(single phase emerges when mixing). Aluminium Matrix Composites are one of the most promising materials, having profound applications in almost all fields, due to their formability, weldability and machinability. Welding is the predominantly used metal joining process, due to its low cost, strength and versatility and certainly has the upper hand when compared to its peers like fastening, brazing and soldering. It forms a strong bond, as a result of the tailoring action in which, when two metals are placed by touching each other and heated, the interface region called the Heat Affected Zone (HAZ) melts and stick together, initiating the release of atoms and ion particles from both the metals and ensuring the smooth transfer of those particles from one metal to adjoining metal alternatively. Friction Stir Welding is one of the most popular and widely used welding process, which join metals by applying frictional heat and static pressure. It does not melt metal using plasma heat from electrode like other welding processes, but uses a rotating pin tool, which produces frictional heat and welding action, when it comes in contact with the stationery metals, that are clamped together touching each other. This method has been used to weld aluminium workpieces previously, but now it is used to weld aluminium composites, dissimilar metals, soft metals, etc. Many researchers have carried out Friction Stir Welding process with different combinations of metal alloys and metal matrix composites. Their research findings have been discussed below.

2. Literature review

P.Hema et al. investigated the effect of process parameters on the friction stir welded joints of AA2014 and AA6061[1]. Their mechanical properties have been evaluated. Process parameters have been constantly fixed with Tool Rotational speed of 2000rpm, Welding Speed of 37mm/min and Axial Force of 37 Kn to obtain a tensile strength of 132.91MPa, which is fairly good. Hasan Jafari et al. Studied about the residual stress distribution in joining dissimilar Al-7075-T6 and Al6061-T6 strengthened with SiO2 nanoparticles as reinforcements by friction stir welding process[2]. With the addition of SiO2 nanoparticles in both the metal matrices, the ultimate tensile strength (UTS) increased but the yield strength and the residual stress decreased. Marie Noelli et al.reviewed the Friction Stir Welding of Metal Matrix Composites. It is found that heat emited is lesser than any other mode of welding[3]. The oxidation rate is found to reduce compared to other welding processes. S. Shashi Kumar et al. developed optimal FSW process parameters for maximizing the Tensile Strength of Friction Stir Welded AISI SS 316L Butt Joints[4]. The optimized tool spindle speed is fixed as 597 rev/min, tool traverse speed is 74 mm/min, downward force was 13 kN and tool tilt angle is adjusted to 1.5o. Majid eliyasi et al investigated the rotating and travelling speed of the friction stir welding (FSW) tool on the dissimilar lap-joint of AA5058 aluminum alloy and polycarbonate[5]. The hardness of the Poly carbonate after FSW decreased by the molecular weight reduction and AA5058 micro-hardness increased because of the fine grinding after sustaining thermo-mechanical cycle. C.Devanathan et al. created the Friction Stir Welding of Metal Matrix Composite using Coated tool[6]. Aluminum particles are deposited over the tool pin and no physical wear observed after welding. The optimal FSW process parameter combinations are spindle speed of 1200 rpm, traverse feed at 40 mm/ min and an axial load at 8 KN. The percentage of contribution of FSW process parameters are found that the axial force had the maximum contribution of 35% followed by traverse speed and spindle speed with 25% and 12% respectively. Amlan kar et al. examined the effect of niobium interlayer in dissimilar friction stir welding of aluminum to titanium alloys[7]. The presence of Nb in the weld nugget influences the microstructural evolution and tensile properties of the weld by reducing the formation of intermetallics. Luca Boccarusso et al. analyzed the dissimilar friction stir lap welding of AA6082-MgAZ31 by conducting Force analysis and microstructure evaluation[8]. The hardness in the aluminium sheet close to the tag was lower than the one of the base material due to the heat input experienced during the welding that leads to the dissolution of the strengthening particles. Seung-Joon Lee et al. studied the Friction stir welding of multi-walled carbon nano tubes reinforced Al matrix composites[9]. The friction-stir welded composite obtained by adding 3vol% MWCNT and a plunging load of 600kg possessed two-times better balance between strength and ductility than the base metal, due to the presence of both MWCNTs and the partially decomposed Al4C3 in the composite. Madhavarao et al. investigated the Friction Stir Welding of Metal Matrix Composite using Coated tool[10]. Tensile test results show that at 1200 rpm & 20mm/min, tensile strength is 52.14 MPa. At 1600 rpm & 20 mm/min, tensile strength is increased to 97.97 MPa. This shows that for a constant feed, tensile strength increased, when speed increases. Tanmoy Medhi et al. explained the thermal modelling and effect of process parameters in friction stir welding[11]. The coefficient of friction and temperature do have a synergic influence on each other. The coefficient of friction in the FSW condition is found to be as high as 1.2 at 300-3500C. M.V.R.Durga Prasad and Kiran kumar Namala optimised the Process Parameters in Friction Stir Welding using ANOVA[12]. Welding speed is the major factor, contributing for the effect of % elongation with 54.88% while tool rotation speed has the least effect of 5.39%. The optimum condition to get good percentage of elongation is found to be tool rotation speed of 800rpm, feed of 20mm/min and tool tilt angle of 1 degree. Welding speed is the major influencing factor again to the hardness at weld zone with 67.52% while tool rotation speed has the least effect with 4.39%. Tracie Prater studied the applications of Friction Stir Welding in Metal Matrix Composite for aerospace structures[13]. The good hardness at weld zone is obtained at a tool rotation speed of 800rpm, welding speed of 20mm/min and vertical tool position without any tilt. Saurabh Singh Rajpurohit et al. studied the mechanical strength, maximum temperature between the edge of the stir zone and the top surface, and effect of force against the tools on the FSW of Aluminium Based Composite Material[14]. It is found that the temperature is maximum at the region very nearest to the tool. J. Zhou et.al. described in detail, the experimental and numerical investigation of high velocity soft impact loading on aircraft materials[15]. The response of friction stir welded aluminium and laminated glass targets under soft impact loading was investigated using both rubber and gelatine projectiles. It enables the optimisation of real, large scale aircraft structures and components. Min Ao et al. examined the effect of La2O3 addition in intermetallic-free aluminium matrix composites reinforced with TiC and Al2O3 ceramic particles[16]. They prepared aluminium matrix composites with reinforcements having greatly refined average grain size of 20.6 micrometres. The composites showed up to two times higher Brinell hardness value than the individual 6063 aluminium alloy. M. Balakrishnan et.al. examined the effect of friction stir processing on microstructure and tensile behavior of AA6061/ Al3Fe cast aluminum matrix composites[17]. The sharp edges of Al3Fe particles are removed and rounded into near spherical shape and the grain size is also reduced remarkably due to severe plastic deformation and the pinning effect of reinforced particles. The microstructural changes showed an improvement of tensile strength and ductility. Isaac Dinaharan et al. demonstrated FSP done on Fly ash reinforced MMCs based on aluminium alloy AA6061, magnesium alloy AZ31 and copper[18]. The morphology and microstructure is examined using optical microscopy, scanning electron microscopy (SEM) and electron back scattered diffraction (EBSD). A homogenous distribution of FA particles is observed in all the composites. R. Guan et al. fabricated the aluminium matrix composites reinforced with Ni-coated graphene nano sheets[19]. Ni-coated-GNS-reinforced aluminium (Al) MMCs are fabricated by graphene synthesis and powder metallurgy. It is revealed that Ni-coated GNSs exhibit high strength with the enhanced Vickers hardness and Young's modulus .Sahayam Joyson Abraham et al. characterised the microstructure of vanadium particles reinforced AA6063 aluminum matrix composites via friction stir processing with improved tensile strength and appreciable ductility[20]. Change in the shape of vanadium particles is observed due to higher strain rate of the process. The reinforcement of vanadium particles proved to be beneficial in improving the tensile strength up to 25% without losing appreciable ductility.

III. Selection of Materials and Methodology

F. Erdemir et al. characterised the microstructure and mechanical properties of functionally graded Al2024/SiC composites prepared by powder metallurgy technique and friction stir welded with another similar composite specimens[21]. Jaswinder Singh et al. examined the fabrication, characterisation and evaluation of tensile strength of novel Al2024/SiC/red mud composites processed via stir casting route[22]. Ali Hosseinzadeh et al. analysed the high temperature characteristics of Al2024/SiC Metal Matrix Composite fabricated by Friction Stir Processing[23]. At ambient temperature notable improvement of the yield strength is observed reaching about 240% of the as-received samples while the ductility was reduced near to 4%. Wenya Li et al. examined the microstructural, mechanical and tribological behaviours of AA2024/Al2O3MMCs modified by FSP with different rotation speeds[24]. By X-ray analysis it is found out that the AA2024/Al2O3 MMCs shows a higher wear resistance in comparison with the individual alloys. D. Ghanbari et al.investigated the influence of Heat Treatment on Mechanical Properties and Microstructure of the Al2024/SiC Composite Produced by Multi–Pass Friction Stir Processing. Nano particles of SiC were uniformly distributed within the structure during the FSP method[25]. M. Movahedi et al. studied the effects of the zinc, copper and brass interlayers on the microstructure evolution and mechanical properties of the wrought aluminum friction stir welds[26]. Omar S.Salih et al. investigated the effect of process parameters on the microstructure and mechanical properties of friction stir welded AA6092/SiC metal matrix composite[27]. The process parameters are rotational speed and transverse speed. The Scanning Electron Microscope (SEM) is used for study the microstructure. Rotational speed was 1500rpm and transverse speed was 100mm/min. The results show that the maximum joint efficiency obtained was 75% at 1500rpm rotational speed and 25 & 50mm/min transverse speed. From the results it was clear that the rotational speed has the high influence on heat generated. Halil Ibrahim Kurt et al. applied FSW technique to silicon reinforced AA 2124 and studied the effect of process parameters on temperature distribution, micro hardness and tensile strength of joints[28]. Temperature measurements taken from 4 points. Tool used was HSS. Process parameters studied were tool transverse speed(40, 50, 80 and 100 mm/min), tilting angle(2°), tool rotational speed(365 and 1400 rpm) and direction of rotation of tool(clock wise). Daniel Solomon et al. applied friction stir processing to reinforced composite material[29]. The main objective was to study the micro structure of welded joint. The micro structure at HAZ, TMAZ and weld nugget were studied. B.Vijaya ramnath et al. reviewed the friction stir welding of Aluminium metal matrix composite. The Mechanical property Ultimate Tensile Strength(UTS) was investigated[30]. Taguchi method and Grey relational analysis were used for study. The process parameters transverse speed, rotational speed, axial force and reinforcement % are varied and studied. The predicted and experimental value of the UTS and hardness are reviewed. .X.Zhang et al. investigated the effects of welding speed on the multiscale residual stresses in friction stir welded Al 2009/T4[31].The samples are tested via Neutron Diffraction(ND) and Decoupled hierarchical multimodal analysis which includes a constant coefficient of friction based thermal model.

IV. **Process Parameters**

N.Moham kumar et al. investigated the effect of process variables in FSW of Aluminium alloy A356[32]. The Tool used was High Carbon Steel and the process parameters involved were transverse speed, rotational speed and axial load of 50KN was applied. Sonal khurana et al. used ANOVA for the optimization of the process parameters. The Graphite powder of 400 mesh size was used as reinforcement in Aluminium matrix[33]. The process parameters involved were Rotational speed(800 to 1400rpm), transverse speed(0.6 to 1.2m/min) and tool diameter(5 and 5.5mm). Samah Mohammed et al. used Taguchi method for the optimization of FSP of AA 2024/ Alumina[34]. The process parameters taken for study were rotational speed(900-1400 rpm) and transverse speed(10-20mm/min). Santha rao dakarpu et al. attempted to optimize the process parameters for producing Al6061/TiB2 composite by FSW[35]. Taguchi analysis was adopted. The process parameters taken in consideration are rotational speed(800-1700rpm), transverse speed(20-80mm/min), axial load(4-7N), and reinforcement %(0-12%). G.Raja kumar et al. fabricated Al7075/WC metal matrix composite by FSW[36]. This paper extensively focussed on the preparation procedure of Al-wc metal matrix composite and fabricate by using FSW. R.Arokiadass et al. attempted to predict and optimize the FSW parameters for Al6061/Tic metal matrix composite[37]. This paper focuses the feature of development of mathematical model for correlating the interactive and higher order influence of process parameters on sliding wear behaviour of FSW. The process parameters were rotational speed, axial force(4 to 8KN) and reinforcement %(0 to 20%). Five types of pin were used(square head, hexagonal head, pentagonal head, triangular head and tapered head). V.Seshagir Rao et al. attempted to optimize the process parameter of FSW using RSM based Grey-Fuzzy approach[38]. The process parameters were rotational speed(1500, 1700 and 1900rpm), weld speed, axial load(3, 6, 9KN) and pin shape (Tapered, Square and Cylindrical). B.Ram gopal reddy et al. fabricated Al/SiC metal matrix composite by FSW. This paper exclusively focussed on the preparation procedure of Al/SiC composite and testing[39]. AMC was produced by stir casting method. 10% and 15%(SiC) reinforcement composition plates were produced. Results are Impact test: 10%-20J, 15%-16.35J, V.J.Badheka et al. fabricated Al7073/B4C surface composite by novel friction stir process and investigated the wear properties[40]. The samples are fabricated by FSW and micro hardness was recorded for all samples using Vickers hardness test at 300gm load and 10S of dwell time using ESEWAY Vicker's Hardness Tester.

V. **Working Principle and Experimental Procedure**

G.Rambabu et al. attempted to optimize the FSW process parameters for improved corrosion resistance of AA2219 alloy joint[41]. The main objective was to develop a mathematical model to predict the corrosion resistance. Corrosion resistance is measured by Dynamic Polarization Testing Further RSM was used to develop the model. Shanmuga Sundaram et al. attempted in parameter designing and analysis of continuous drive friction welding of Al6061/SiC Composites[42]. The urge for parameter design had prompted the disclosure of a new integrated methodology based on technique for order of preference by similarity to ideal solution(TOPSIS) and grey relational analysis(GRA).The effectiveness of the proposed approach was validated by conducting a confirmation test and the field emission scanning electron microscope(FESEM) images of the fractured surface were also examined. M.Ilangovan et al. investigated the effect of tool pin on microstructure and tensile properties of friction stir welded dissimilar AA6061-AA5086 aluminium alloy joints[43]. Scanning Electron Microscope and Optical microscope were used to study the microstructure. Tools of Cylindrical, Threaded Cylindrical and Tapered Cylindrical are used. N.Murugan et al. attempted to synthesis and characterise TiC particulate reinforced AA6082 Al-alloy composite via FSW[44]. Only we were varying the Volume % of reinforcement. Optical and Electron Microscope were used for study. I.Dinaharan et al. investigated the influence of transverse speed on the microstructure and mechanical properties of AA6082-TiC surface composite fabricated by FSW[45]. Transverse speed was varied from 40mm/min to 80mm/min in steps of 20mm/min. D.R.Ni et al. studied the tensile properties and strain hardening behaviour of friction stir welded AA2009/SiC composite joints[46]. Tensile properties and work hardening behaviour of FSW joints were studied at strain rates from 1/100 to 1/100000 (per second). Fracture occurs at HAZ which exhibited low hardness and maximum joint efficiency of 77%. A.Thangarasu et al. fabricated AA6082-TiC surface composites by FSW and analysed the wear characteristics[47]. TiC particles influenced the wear mode as well as the morphology of the wear debris. TiC particles altered the wear mode from adhesion to abrasive. M.Jayaraman et al. attempted to optimize the process parameters for FSW of cast Al alloy by Taguchi method[48]. This paper discuss the use of Taguchi design technique for maximum tensile strength of friction stir welded cast Al319 alloy using ANOVA signal to noise ratio of robust design. The process parameters were rotation speed, welding speed, axial force. Visible defects were tunnel defects, pinhole, cracks etc. S.Chainarong et al. fabricated SSM356 Al alloy by FSW. The main aim of this experiment was to improve the mechanical properties of SSM Al alloy by FSW[49]. B.Ashok kumar et al. attempted to optimize the process parameters in friction stir welding to maximize the tensile strength of stir cast AA6061-T6/AlNp composite[50]. Regression model were developed to predict UTS and elongation of the FS welded joint. V.Jeganathan et al. processed aluminium alloy by FSW for defence applications[51].
Prashant Prakash et al. studied the process parameters of FSW on AA6061. This joining technique was energy efficient, environment friendly and versatile[52]. K.Kalaiselvan et al. characterize the friction stir welded Boron Carbide particulate reinforced AA6061 aluminium alloy stir cast composite[53]. Applications of this material are Aircraft, Marine, Automotives etc.., Optical Photo Microscopy and Scanning Electron Microscope(SEM) were used for study. Mohsen Bahrami et al. investigated the effects of SiC reinforcement incorporation on mechanical properties of friction stir welded Al7075 alloy[54]. Scanning Electron Microscope (SEM) and Atomic Force Microscopy(AFM) is used for study.

VI. **Results and Discussion**

N.Murugan et al. studied the welding parameters to join AMC AA6061/ZrB2 for the automation of the process. UTM is used for tensile testing. The model was developed by Statistical Software SYSTAT 12 to predict by ANOVA technique[55]. The optimized parameters were Tool rotational speed 1132rpm, ZrB2-10%, UTS-226MPa, Axial force-5.8KN and welding speed-5mm/min. The joint shows high tensile strength, ductility and wear resistance. M.Puviyarasan et al. attempted to optimize FSW process parameters for AA6061/SiC composite. Taguchi Method is used for study, design mathematical model and optimize parameters. The optimized process parameters are Tool rotational speed 1200rpm, weld speed 40mm/min and axial force 4KN[56]. Adel Mohammed Hassan et al. statically analysed some of the mechanical properties of friction stir welded AMC. Aim is to Statistically analyze the factors affecting hardness and tensile strength[57]. The tool profile was mainly focussed and it was found that Square pin exhibits the good mechanical properties. M.Koilraj et al. studied the friction stir welding of dissimilar aluminium alloys AA2219 to Al5083 by Taguchi technique[58]. The cylindrical threaded pin tool profile was found to be the best among other profiles. The joint efficiency was around 90% and D/d ratio contribute to 60% of overall contribution. Adel Mohammed Hassan et al. investigated the process parameters in FSW of AMC which influence the wear behaviour[59]. The experimental results indicates that the wear resistance of joint increase at high welding speeds (>45mm/min). N.Murugan et al. fabricated AA6061 matrix titanium particulate reinforced composite by enhanced stir casting method and investigated on the wear characteristics[60]. The results shows that the wear rate decreases with increase in TiC %, the wear rate increase with increase in the travel speed and wear rate increases with the increase in normal load. N.Murugan et al. investigated the effect of FSW on microstructure and wear properties of AA6061/ZrB2 in stir cast composites[61]. ZrB2 Weight % varies from 0 to 10% in steps of 5%. Macrostructure and Microstructure of welded joints revealed dendritic structure. Micro hardness high at the weld nugget. Grain size did not show appreciable difference compared to parent composite, Weld zone was Homogeneous and UTS of joint was comparable to the parent metal. Abbass et al. optimized process parameters in friction stir welding of AA 6061 alloy by Taguchi method[62]. The main objective was to make a weld so that beyond HAZ no change in properties of material and to show that Taguchi method can be controlled in way both HAZ to weld line and maximum temperature in weld were minimized simultaneously. Also studied yield stress of the material at different welding temperature. The results shows that the variation of rotational speed of tool results in 51% contribution of HAZ distribution in weld line and recommends a minimum process temperature of 458°C shows a reduction of 91°C from nominal temperature of 550°C. Gopala Krishnan et al. attempted to predict the tensile strength of FSW Al6061/TiC composite. Axial force played a vital role and it influenced UTS and reduced the thermal stress[63]. At Higher welding speeds, there IS no metallurgical deformation and also low heat input so AMC did not flow easily, Axial force increase UTS decrease steadily and for tapered square pin @ 0.5mm/s UTS was max, max UTS for tapered hexagonal pin profile @ 2.25mm/min and joint efficiency is more than 90%. S.J.Vijay et al. investigated the influence of tool pin profile on the metallurgical and mechanical properties of friction stir welded Al-10wt%TiB2 metal matrix composite[64]. This paper mainly aims at understanding the effect of tool pin profiles on properties of material. Results show that the maximum joint efficiency and tensile strength obtained was 99% and 281Mpa for Square profile pin. Huseyin Uzun et al. fabricated the AA2124/SiC by FSW. In this paper feasibility of FSW, analysis of micro and macrostructure, micro hardness, EDS(Electron Dispersive Spectroscopy) analysis and electrical conductivity were tested[65]. The results show the reduction in hardness, high electrical conductivity at weld nugget and EDX and SEM confirmed the presence of fine and coarse SiC particles. bWatanabe et al. applied FSW which was developed by TWI to weld aluminium magnesium alloy to steel. The maximum tensile strength of a joint was obtained at the pin offset of 0.2mm toward steel in this study[66]. At a larger offset, steel pieces were scattered in aluminum alloy matrix. J.F. Dos Santos et al. established a friction stir welding (FSW) process parameters envelope for an AA 6061 alloy reinforced with 20% of Al2O3 particles, and determine properties of the obtained joints[67]. The parameter envelope determined in the present study resulted in defect free, high strength welds. G.J.Fernandez et al. attempted to optimize the FSW parameters for cast Al359/SiC metal matrix composite[68]. Lesser tool wear occured when using threaded tool. Transmission Electron Microscopy shows little difference in the dislocation, density from the base material to weld zone.

VII. **Research Gap**

Based on the Literature survey, the following research gap is identified: There is no pertinent information about any research carried out in joining dissimilar metals with different reinforcements using friction stir welding.

VIII. **Problem Identified**

Tool rotational speed, traverse feed or weld speed, tool inclination angle and axial force are the input process parameters which should be high for joining dissimilar materials. Strength of the composites which are obtained by the joining two or more materials is less compared to the alloys.

IX. **Conclusion**

In this paper a study of friction stir welding process is carried out. Based on the review, following conclusions are drawn
It is revealed that FSW depends upon various parameters such as welding speed, traverse speed, axial force etc.
These parameters influence the heat input and properties of the weld.
Dimensions of the tool influence the welding capabilities.
Mechanical properties of the composite material depend upon process parameters of FSW.
Increase or reduction in hardness of the composite depends on the composition (wt %) of the reinforcement added.

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