Effects of Process Parameters in Friction Stir Welding of Aluminium Matrix Composites - A Review

P.V.Rajesh[1*]

[1]Department of Mechanical Engineering, Saranathan College of Engineering, Trichy-620012, Tamilnadu, India

rajesh-mech@saranathan.ac.in*

Abstract. *Friction Stir Welding (FSW) is a solid-state joining process which is very efficient, effective and agile green manufacturing technique. FSW was first intended for aluminium alloys, but now it has found diversified usage for a variety of metals and metal-matrix composites (MMCs). This environment-friendly process causes audacious plastic deformation, homogeneous and thorough mixing of material and thermal exposure which results in significant micro structural refinement with the formation of oriented dendrites, densification and clear homogeneity across the processed zone. FSW has been employed in various high technology applications such as aerospace, automotive industry, high precision welding etc., for its intact and strong bondage. The important process parameters considered generally are the tool rotation speed, traverse speed, force and the tool geometry. The output responses typically analysed are the mechanical properties like tensile strength, hardness, tool wear, etc., and microstructure of the welded specimen. Particularly, the weldment area is normally taken to ensure the uniform distribution and orientation of metal particles. The objective of this review paper is to analyse the collection of literature on FSW process and associated optimization. Recently, a lot of researchers have shown interest in FSW and its applications. Now a days, FSW is employed in order to achieve reduced time and cost of the product and increased strength of the weld.*

Received by	25 May 2020
Revised by	2 July 2020
Accepted by	22 August 2020

Keywords:

Friction stir welding, Input process parameters, Output responses, Optimization, Weld test.

1. Introduction

A metal matrix composite (MMC) is a joint of two or more materials at varied proportions. It may be a combination of two or more constituent parts, where the major constituent which also called as matrix is predominantly a metal and the minor constituents, which are called reinforcements like metals, ceramics or polymers. The most popular and widely used matrix material is aluminium due to its attractive properties. Henceforth, the term aluminium matrix composites is synonymously associated and in sometimes replacing MMCs. Various particle reinforcements, particularly ceramics being used are graphite, SiC, TiC etc. FSW is used in a variety of industrial applications as problems associated with cooling from the liquid phase are avoided. The main purpose of any process is to increase its productivity by varying the input process parameters to obtain desired outcomes. Optimization is generally adopted to obtain the best results under given circumstances. Many researchers had been worked in this area with different concepts and their research findings are discussed below.

2. Literature Review

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 [1]. The process parameters were rotational and transverse speeds. The Scanning Electron Microscope (SEM) was used to observe the microstructure. Rotational speed was 1500rpm and transverse speed was 100mm/min. The results showed that the maximum joint efficiency obtained was 75% at 1500rpm rotational speed and 25% at 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[2]. The effect of process parameters on temperature distribution, micro hardness and tensile strength of joints was studied. High speed steel tool used in this experiment. Tool transverse speed were 40,50,80 and 100mm/min, respectively. Tilting angle was 2°. The tool rotational speed was 365 and 1400rpm under clock wise rotational. The results showed that the maximum tensile strength obtained at rotational speed of 1400rpm and transverse speed of 40mm/min, temperature distribution was up to 15mm for the weld centre. It is also found that the temperature decreased as transverse feed rate increased.

Daniel Solomon et al. applied friction stir processing to reinforced composite material [3]. The main objective was to study the micro structure of welded joint at HAZ, TMAZ and weld nugget. The results showed that at weld nugget due to high temperature the reinforced particles dissolved in the matrix at weld nugget due to high temperature. Then, grain refinement took place.

B.Vijaya Ramnath et al. reviewed the friction stir welding of aluminium metal matrix composite [4]. Taguchi method and Grey relational analysis were used in this work. The effect of process parameters like transverse speed, rotational speed, axial force and volume fraction of reinforcement were clarified. By Taguchi method, it was found that the UTS and hardness of weld are 310MPa and 126HV, respectively and they were closer to the predicted value. As for Grey relational analysis, the UTS was 318MPa and hardness was 132HV. When compared with Taguchi method, it was very closer to the predicted values of UTS and hardness. From ANOVA analysis, the percentage of influence of process parameters are as follows; 24% for reinforcement, 23% for load and 22% for feed and 65% for rotational speed.

X. X. Zhang et al. investigated the effects of welding speed on the multiscale residual stresses in friction stir welded Al 2009/T4[5]. The samples were tested via Neutron diffraction (ND) and Decoupled hierarchical multimodal analysis which included a constant coefficient of friction based thermal model. The results showed that increasing of welding speed led to lower value of residual stresses at the retreating side i.e., the residual stresses were inversely proportional to the transverse speed.

N. Moham Kumar et al. investigated the effect of process variables in FSW of Aluminium alloy A356[6]. The tool used was high carbon steel and the process parameters involved were transverse speed, rotational speed and axial load of 50kN. The results showed that defects like porosity, cracks, blowholes etc., were observed. The welded component showed poor mechanical properties and low elongation in failure was observed.

Sonal Khurana et al. used ANOVA to optimize the process parameters. The graphite powder with 400 mesh size was used as reinforcement in aluminium matrix [7]. The UTS and hardness of specimens were measured. The process parameters were speed of 800 to 1400rpm, transverse speed of 0.6 to 1.2m/min and tool diameter of 5 and 5.5mm. One and two ways ANOVA table were used to predict the UTS and hardness. The results showed that UTS increased with an increase in the rotational speed and heat input in insufficient below 1000rpm and excess above 1400rpm. The hardness increased when the transverse speed decreased. A slow transverse speed resulted in tunnelling effect.

Samah Mohammed et al. used Taguchi method for the optimization of FSP of AA 2024/ Alumina [8]. The prediction model analysis showed that the maximum hardness value obtained at rotational speed of 1120 rpm and transverse speed of 14 mm/min for 3 passes. The process parameters taken for study were rotational speed from 900 to 1400 rpm and that transverse speed from 10- 20mm/min. Micro-Vickers hardness testing was employed to measure the hardness across the processed region. The readings were taken at close proximity distance. The results showed that the hardness values increase by 40% compared with base metal.

3. Selection of Materials

The most commonly used materials in FSW are various grades of aluminium alloys and their composites due to their attractive properties such as ease of forming, flexibility, low melting point and good machinability.

Santha Rao Dakarpu et al. attempted to optimize the process parameters for producing Al6061/TiB2 composite by FSW [9]. Taguchi method was adopted for analysis of mechanical properties. The results revealed that the influence of process parameters on the mechanical properties are rotational speed contributing to 35%, axial load to 23%, feed to 22% and addition of reinforcement to 20%.

G. Raja Kumar et al. attempted to weld two individual specimens of similar AMCs with Al7075 as matrix material and tungsten carbide (WC) as reinforcement [10]. This paper extensively focussed on the preparation procedure of Al-WC metal matrix composite. The results clearly indicated that the mechanical properties of the composite such as tensile strength, hardness, impact strength, etc., are far more superior than that of the individual Al7075.

R. Arokiadass et al., in their paper attempted to predict and optimize the FSW parameters for Al6061 metal matrix composite reinforced with Titanium Carbide (TiC). 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 [11]. Response Surface Methodology (RSM) was adopted. Five types of pin were used (square head, hexagonal head, pentagonal head, triangular head and tapered head). The results showed that at first, wear rate decreases with increase in tool rotational speed. But, further increase in rotational speed leads to increase in wear rate. The increase in axial force increases the heat generation.

V. Seshagiri Rao et al. attempted to optimize the process parameter of FSW using RSM based Grey–Fuzzy approach in Al 6061 based composites [12]. The main objective was to improve the tensile properties, UTS and tensile strength. The results showed a maximum elongation of 10.92% and ultimate tensile strength of 140.11MPa are achieved during tensile test.

B. Ram Gopal Reddy et al. fabricated Al/SiC metal matrix composite and joined two such specimens by FSW [13]. This paper exclusively focussed on the preparation procedure of Al/SiC composite and testing. AMC was produced by stir casting method. From the results, it was clear that the tensile strength and impact strength decrease with increasing percentage of reinforcement.

V. J. Badheka et al. fabricated Al7073/B4C surface composite by novel friction stir process and investigated the wear properties. The samples are combined together by

FSW [14]. 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. The results indicated that micro hardness and transverse speed are inversely proportional, a hardness value of 144HV is recorded at transverse speed of 50mm/min and range of improvement in hardness is 1.3 to 1.6 times the base metal.

G. Rambabu et al. attempted to optimize the FSW process parameters for improved corrosion resistance of AA2219 alloy joint. The main objective was to develop a mathematical model to predict the corrosion resistance [15]. Corrosion resistance is measured by Dynamic polarization testing. The results indicated that the optimized parameters were: tool profile to be hexagonal, rotational speed of 1307rpm, transverse speed of 880.50mm/min and axial force of 12.20kN for a corrosion rate of 604.52mV.

Shanmuga Sundaram et al. attempted in parameter designing and analysis of continuous drive friction welding of Al6061/SiC composites [16]. 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. As a result, optimized results obtained from TOPSIS and GRA were compared and summarized.

4. Process Parameters

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 [17]. Tools of cylindrical, threaded cylindrical and tapered cylindrical are used. Process parameters are rotational speed (1100rpm), transverse speed (22mm/min), axial load (12kN), tool material (HSS) and tool inclination (2 degree). The results showed that the threaded cylindrical head pin gave the highest tensile strength and highest micro hardness, whereas threaded and tapered pins gave defect free weld joint.

N. Murugan et al. attempted to synthesis and characterise TiC particulate reinforced AA6082 Al-alloy composite via FSW[18]. Process parameters taken were transverse speed (60mm/min), rotational speed (1200rpm), axial force (12KN) and volume fraction of reinforcement from 0 to 24% with 6% steps. Only we were varying the volume fraction of reinforcement. Optical and Electron Microscope were used for study. From the results, it was revealed that the tensile strength, micro hardness and wear resistance increase with increase in volume fraction of reinforcement.

I. Dinaharan et al. investigated the influence of transverse speed on the microstructure and mechanical properties of AA6082-TiC surface composite fabricated by FSW [19]. Transverse speed was varied from 40 to 80mm/min in steps of 20mm/min. Higher transverse speed result in poor distribution of TiC particles.

D. R. Ni et al. studied the tensile properties and strain hardening behaviour of friction stir welded AA2009/SiC composite joints[20]. Tensile properties and work hardening behaviour of FSW joints were studied at strain rates from 1/100 to 1/100000 (per second). The results showed that, when strain rate increases yield strength and UTS decrease.

A. Thangarasu et al. fabricated AA6082-TiC surface composites by FSW and analysed the wear characteristics [21]. The process parameters were rotational speed of 1200rpm, transverse feed of 60mm/min with 10kN axial force and 0 to 24% volume fraction of reinforcement. The results showed that the wear rate reduces by increasing volume fraction. The wear rate was 0.00693mg/m at 0% and 0.00303mg/m at 24%. 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. This paper discussed 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 [22]. The process parameters were rotation speed, welding speed, axial force. Visible defects were tunnel defects, pinhole, cracks etc.,. The results showed that rotational speed more than 1000rpm led to tunnel defect at middle of retreating side of weld region due to high heat generation. When rotational speed more than 1440rpm, piping defect occurred at top retreating side due to turbulence by high rotational speed. At Transverse speed less than 22mm/min, tunnel defect was observed at retreating side. At over Transverse speed of 75mm/min, piping was less than 2 kN promoted pinhole defect due to absence of vertical flow material. When axial force more than 4kN, by contrast, tunnel defect was found in both retreating sides.

S. Chainarong et al. fabricated SSM356 Al alloy by FSW. The main objective of this experiment was to improve the mechanical properties of SSM Al alloy by FSW [23]. Process parameters were traverse feed (80, 60 and 120mm/min) and rotational speed (1320rpm,1480rpm and 1750rpm). Results showed that proper and continuous stirring of tool contributes to fine grain size of the welded alloy.

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 [24]. The results showed that, when rotational speed increases, tensile strength decreases and when transverse speed increases, tensile strength decreases.

V.Jeganathan et al. processed aluminium alloy by FSW for defence applications [25]. The process parameters are rotational speed of 800 to 2000rpm and transverse feed of 31 to 68mm/min. Temperature during FSP was 870°C to 900°C. Results inferred that increase in the rotation speed leads to finer grains and increase in transverse speed increases the wear resistance.

Prashant Prakash et al. studied the process parameters of FSW on AA6061. This joining technique was energy efficient, environment friendly and versatile [26]. Process parameters were tool material, tool design, tool rotation speed, down force and weld speed. Rotational speed range was 41-1800rpm. Travel speed range was 5-800mm/min. Tool material is H13 steel with cylindrical profile of 18mm diameter and 6mm pin diameter. The results were: Tensile strength of 142MPa was obtained at a spindle speed of 1120rpm and feed of 20mm/min and 182MPa was obtained at 1400rpm and 25mm/min respectively with a joint efficiency of 60%.

K. Kalaiselvan et al. characterized the friction stir welded boron carbide particulate reinforced AA6061 aluminium alloy stir cast composite [27]. The process parameters were rotational speed of 1000rpm, transverse speed of 80mm/min, axial load of 10kN. Tool material made of high carbon and high chromium steels and tool pin profile was Square. The results clearly revealed that the micro hardness and tensile strength are higher at the weld nugget due to refinement of grains when compared to the parent material.

Mohsen Bahrami et al. investigated the effects of SiC reinforcement incorporation on mechanical properties of friction stir welded Al7075 alloy [28]. Process parameters were 20% Volume fraction SiC particle, rotational speed of 1250rpm and transverse speed of 40mm/min. Scanning Electron Microscope (SEM) and Atomic Force Microscopy (AFM) was used for study. Results obtained were as follows: Dynamic Re-crystallization takes place at SZ, X-ray diffraction shows the existence of 20% SiC, SiC cluster size is revealed as 90nm to 430nm, Optimum Mechanical properties obtained were: UTS of 270MPa, elongation of 10.04%, impact energy of 4750J, fatigue life of 24310 cycles, grain size of 3.85 micro meter and cluster size of 262nm.

The process parameters which are more widely used with their values are represented below in Table 1.

Author of the paper	Process parameter(s)	Value/Range
Omar S.Salih et.al	Rotational speed	1500 rpm
	Traverse feed	100 mm/min.
Halil Ibrahim Kurt et.al	Rotational speed	365 and 1400 rpm
	Traverse feed	40,50,80 and 100 mm/min.
Halil Ibrahim Kurt et.al	Tool tilting angle	2°
	Direction of tool rotation	Clockwise
Sonal Khurana et.al	Rotational speed	800-1400 rpm
	Traverse feed	0.6-1.2 mm/min.
	Tool diameter	5 and 5.5 mm
Samah Mohammed et.al	Rotational speed	900-1400 rpm
	Traverse feed	10-20 mm/min.
Santhu rao dakarpu et.al	Rotational speed	800-1700 rpm
	Traverse feed	20-80 mm/min.
	Axial load	4-7 N
	reinforcement	0-12 %
V.Seshagiri Rao et.al	Axial load	3,6 and 9 kN
	Pin shape	Tapered, squared and cylindrical
G.Rambabu et.al	Welding speed	600-1000 rpm
	Pin shape	Threaded, triangular and hexagonal

Table 1 Commonly used process parameters

5. Experimental Work and Results

N.Murugan et al. studied the welding parameters to join AMC AA6061/ZrB2 for the automation of the process[29]. This research found that the factors were rotational speed(1000-1500rpm), welding speed(30-70mm/min), axial force(4-8kN), fraction of ZrB2(0% to 10 wt% in steps of 2.5%) and tool material(high carbon steel with square profile). The UTM is used for tensile testing. The model was developed by statistical software (SYSTAT 12) and prediction was done by ANOVA technique. The results showed that the optimized parameters were tool rotational speed of 1132rpm, 10 wt% ZrB2, UTS of 226MPa, Axial force of 5.8kN and welding speed of 5mm/min. The joint showed high tensile strength, ductility and wear resistance.

M.Puviyarasan et al. attempted to optimize FSW process parameters for AA6061/SiC composite. Taguchi Method, design mathematical model and optimize parameters were done [30]. The optimized process parameters were tool rotational speed of 1200rpm, weld speed of 40mm/min with 4kN axial force.

Adel Mohammed Hassan et al. statically analysed some mechanical properties of FSW AMC [31]. This work aimed to statistically analyze the factors affecting hardness and tensile strength. 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 [32]. 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 contributed to 60% of overall contribution.

Adel Mohammed Hassan et al. investigated the process parameters in FSW of AMC which influence the wear behaviour [33]. The experimental results indicated that the wear resistance of joint increase at high welding speeds more than 45mm/min.

N. Murugan et al. fabricated AA6061 matrix titanium particulate reinforced composite by enhanced stir casting method and investigated on the wear characteristics [34]. The results showed that the wear rate decreased with rising TiC content. The wear rate increased with an increase in the travel speed. However, the wear rate decreased when normal load increased.

N. Murugan et al. investigated the effect of FSW on microstructure and wear properties of AA6061/ZrB2 in stir cast composites[35]. ZrB2 varied from 0 to 10 wt% in steps of 5 wt%. Microstructure of welded joints revealed dendritic structure. Micro hardness was found to be 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 [36]. The main objective was to make a weld so that beyond HAZ no change in properties of material. Moreover, Taguchi method could be controlled in way both HAZ to weld line and maximum temperature in weld were minimized simultaneously. This work also studied yield stress of the material at different welding temperature. The results showed that the variation of rotational speed of tool resulted in 51% contribution of HAZ distribution in weld line. A minimum process temperature of 458°C showed 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 [37]. At higher welding speeds, there would be no metallurgical deformation and also low heat input, therefore, AMC did not flow easily. As axial force increased, UTS decrease steadily. The UTS was highest at 0.5mm/s speed for tapered square pin and2.25mm/min for tapered hexagonal pin profile with joint efficiency 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 [38]. This paper mainly clarified the effect of tool pin profiles on properties of material. Results showed that the maximum joint efficiency and tensile strength obtained were 99% and 281MPa respectively for Square profile pin.

Huseyin Uzun et al. fabricated the AA2124/SiC by FSW. This work analysed the macro and micro-structure. The hardness was measured. The EDS (Electron Dispersive Spectroscopy) and electrical conductivity were tested [39]. The results showed that the reduction in hardness, high electrical conductivity at weld nugget was found. The results of EDX and SEM confirmed that the fine and coarse SiC particles were observed.

Watanabe et al. applied FSW which was developed by TWI to weld aluminium magnesium alloy to steel [40]. The maximum tensile strength of a joint was obtained at the pin offset of 0.2mm toward steel. 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 [41]. 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 [42]. Lesser tool wear occurred when using threaded tool. TEM analysis showed little difference in the dislocation, density from the base material to weld zone.

The most commonly used process parameters and their effect over material properties are given below in Table 2.

Effect of process parameter(s)	Result(s)
Increase in Traverse feed	Reduction in residual stresses
Increase in rotational speed	Increase in tensile strength and decrease in hardness
Increase in % reinforcement	Increase in hardness
Increase in axial load	Increased heat generation and increased wear rate
Threaded cylindrical pin	High tensile strength and high hardness
High traverse feed	Increased wear resistance and poor distribution of reinforcement
Increase in axial load	Homogeneous weld zone and high hardness at the nugget compared to parent metals

Table 2 Effect of process parameters and results

6. Recommendation by the Researchers

From the various research works, the researchers have recommended the following important points for higher efficiency and performance in the friction stir welding process.

- The tool-spindle angle can be altered during processing to follow the surface curvature using a multi-axis computer-controlled machine with feedback loop.
- Problem of eutectic melting can be avoided by selecting welding conditions that limit the maximum temperature attained during welding.
- The effects of FSP parameters on the super plastic behavior and the responsible deformation mechanism in his paper.
- Surface hardening coating of a steel tool might be an alternate approach to increase wear resistance.

7. Problems Identified

Based on the Literature survey, the following problems are identified:

- Tensile strength and elongation are very low in alloys. Hence a suitable composite material is needed to increase tensile strength.
- Spindle speed, traverse speed and axial force are the input process parameter which should be high for alloy materials.
- High contents of ceramic in composites lead to decrease in tensile strength but increase in hardness.
- Strength of the material which is obtained by the composite is far more superior compared to that of alloys.

8. Conclusion

In this paper, friction stir welding (FSW) process was reviewed. It was found that FSW could be used to weld soft materials like, Aluminium (Al), Nickel (Ni), Copper (Cu), Titanium (Ti), etc., successfully. However, it depends on various parameters such as welding speed, traverse speed, axial force etc. These parameters influence the heat input and properties of the weld.

Based on the reviews, following conclusions are drawn:

- Dimensions of work piece and tool geometry influenced the welding capability.
- Tool wear rate and tool melting were important factors that caused submerged FSW.
- Mechanical properties of the material depended on process parameters of FSW.
- Hardness of the material was based on composition and grain size of the reinforcement.

References

[1] Omar S. Salih, Hengan ou, Xingguo wei and W. Sun, Microstructure and mechanical properties of Friction Stir Welded AA6092/SiC Material Matrix Composite, *Journal of Material Science and Engineering, 742,* 2019, 78-88.

[2] Halil Ibrahim Kurt, Yahya bozkurt, Sedar salaman and Heuseyin uzun, Application of friction stir welding technique to AA2124%25 SiCp-T4 Aluminium matrix composites, *International journal of materials and engineering technology, 2(1),* 2019, 16-24.

[3] Daniel Solomon, Yong X. Gan and Reinbolt Michael, Friction Stir processing of particle reinforced composite material, *an article in Materials, 3(1),* 2019, 2010.

[4] X.X. Zhang, L. H. Wu, Heiko Andrae and Weimin Gan, Effects of Welding speed on the multiscale residual stresses in friction stir welding of Metal Matrix Composites, *Journal on Material Science and Technology, 35(5),* 2019, 824-832.

[5] B. Vijaya Ramanath, S. Abishek Subramanian, R. Rakesh, S. Sharun Krishnan and A. L. Ashwin Ramanathan, A Review on Friction Stir Welding of Aluminium Metal matrix composites, *3rd International conference on Material and Manufacturing Engineering, 390(1),* 2018, 012103.

[6] N. Moham kumar, R. Mani, R. Krishnarao and L. Karthikeyan, Effect of process variable during the friction stir processing of cast Aluminium alloy A356, *International Journal of Engineering Research and Technology, 6(2),* 2018, 1-4.

[7] Gaurav Makkar, Sonal Khrana and Surabhi lata, Optimization of process parameters in Friction Stir Welding using Analysis of Variance (ANOVA), *IOSR Journal of Mechanical and Civil Engineering, 15(3),* 2018, 51-57.

[8] Santha Rao Dakarpu and Ramanaiah nallu, Process parameters optimization for producing AA6061/TiB_2 composite by Friction Stir Processing, *Journal of Mechanical Engineering, 67(1),* 2017, 101-118.

[9] Babu Naik Banoth, B. Ravi, G. Raja Kumar and Arun Baby nallabelli, Fabrication and Friction Stir Welding of Aluminium 7075/wc metal matrix composites, *International Journal of Advance Research in Science and Engineering,* 2017, 367-374.

[10] K.Palaniraja, R.Arokiadass and D. Ommurugdhasan, Prediction and Optimization of Friction Stir Welding parameters of Al6061/TiC metal matrix composite, *International journal of Advances in Mechanical and Civil Engineering, 4(1),* 2017, 94-99.

[11] D.Vijayan and V.Seshagiri rao, Optimization of Friction Stir Welding process parameter using RSM based Grey-Fuzzy approach, *Saudi journal of Engineering and Technology, 2(1),* 2017, 12-25.

[12] Essan B. Moustafa, Samah Mohammed, Sayed Abdelwanis and M. S. Abd-Elwahad Tamer Mahmoud, Taguchi optimization for AA2024/Al_2O_3 surface composite hardness fabrication by Friction Stir Processing, *International Journal of Engineering and Technology, 3,* 2016, 7-10.

[13] B. Ram Gopal Reddy and O. Sailaja, Fabrication and Friction Stir Welding of Aluminium SiC metal matrix composites, *IJIRSET, 5(7),* 2016, 13153-13159.

[14] H. G. Rana, V. J. Badheka and A. Kumar, Fabrication of Al7075/B_4C surface composite by novel friction stir processing and investigation on wear properties, *Journal of Materials Engineering, 23,* 2016, 519-528.

[15] G. Rambabu, D. Balaji nair, C. H. Venkata rao, K. Srinivasa rao and G. Madhusudhan reddy, Optimization of Friction Stir Welding parameters for improved corrosion resistance of AA2219 Al alloy joint, *Journal of Defence Technology, 11(4),* 2015, 330-337.

[16] R. Adalarasan and A. Shanmuga Sundaram, Parameter design and analysis of continuous drive friction welding of Al6061/SiC composite, *Journal of Mechanical Science and Technology 29(2),* 2015, 769-776.

[17] M. Ilangovan, S. Rajendra Boopathy and V. Balasubramanian, Effect of tool pin profile on microstructure and tensile properties of friction stir welded dissimilar AA6061-AA5086 aluminium alloy joints, *Journal of Defence Technology, 11(2),* 2015, 174-184.

[18] A. Thangarasu, N. Murugan, Isaac Dinaharan and Vijay Joseph Santhiyagu, Synthesis and Characterization of titanium carbide particulate reinforced AA6082 aluminium alloy composites via friction stir processing, *Journal of Civil and Mechanical Engineering, 15(2),* 2015, 324-334.

[19] A. Thangarasu, N. Murugan, I. Dinaharan and S. J. Vijay, Influence of transverse speed on Microstructure and mechanical properties of AA6082-TiC surface composite fabricated by friction stir processing, *Journal on Procedia Materials Science, 5,* 2014, 2115-2121.

[20] D. R. Ni, Daolun Chen, D. Wang and Z. Y. Ma, Tensile properties and Strain hardening behaviour of friction stir welded SiCp/AA2009 composite joints, *Journal of Materials Science and Engineering, 608,* 2014, 1-10.

[21] A. Thangarasu, N. Murugan and Isaac Dinaharan, ,Production and Wear Characterization of AA6082-TiC surface composites by friction stir processing, *an article in procedia Engineering, 97,* 2014, 590-597.

[22] S. Chainarong, S. Suthummanon and P. Muangjunburee, Friction Stir Processing of SSM356 Aluminium alloy, *an article in procedia Engineering, 97,* 2014, 732-740.

[23] B. Ashok kumar and N. Murugan, Optimization of Friction Stir Welding process parameters to maximize tensile strength of stir cast AA6061/T6 Aluminium Matrix Composite, *Journal of Material and Design 57,* 2014, 383-393.

[24] V. Jeganathan Arulmoni and R. S. Mishra, Friction Stir Processing of Aluminium alloy for defense application, *International Journal of Advance Research and Innovation, 2(2),* 2014, 337-341.

[25] Mohsen Bahrami, Nader Helmi, Kamran Dehghani and Mohammed Kazem Besharati Givi, Exploring the effects of SiC reinforcement incorporation on mechanical properties of friction stir welded 7075 aluminium alloy: fatigue life, impact energy, tensile strength, *Journal of Materials Science and Engineering, 595,* 2014, 173-178.

[26] Prashant Prakash, Sanjay Kumar Sha and Shree Prakash Lal, A Study of process parameters of friction stir welded AA6061 Aluminium alloy, *International Journal of Innovative Research in Science Engineering and Technology, 2(6),* 2013, 2304-2309

[27] Kalaiselvan and N. Murugan, Role of Friction Stir Welding Parameter and Tensile Strength AA6061-B_4C of composite matrix, *Journal of Transaction of Non-ferrous Metals society of China, 23(3*), 2013, 616-624.

[28] I. Dinaharan and N. Murugan, Automation of friction stir welding process to join Aluminium Matrix Composite by Optimization, *Journal of Procedia Engineering, 38(1),* 2012, 105-110.

[29] M. Puviyaraan and V. S. Senthil kumar, Optimization of friction stir process in fabricating AA6061/SiCp composite, *Journal of Procedia Engineering, 38,* 2012, 1094-1103.

[30] Adel mohamood tassan, Mohammed Almonzam, Tarek Qasim and Amed M Ghaithan, Statistical analysis of Some mechanical properties of friction stir welding of Aluminium Matrix Composite, *International Journal of Experimental Design and Process Optimization, 3(1),* 2012, 91-109.

[31] M. Koilraj and S. R. Koteswara Rao, Friction Stir welding of dissimilar aluminium alloys AA2219 to AA5083, *Journal of Materials and Design, 42,* 2012, 1-7.

[32] Adel Mohmood Hassan, Mohammed Almomani, Tarek Qasim and Ahmed M Ghaithan, Processing parameters effect on friction stir welded aluminium matrix composite wear behavior, *an article in Materials and Manufacturing processes, 27(12),* 2012, 1414-1423 .

[33] S. Gopalakrishnan and N. Murugan, Production and wear characteristics of AA6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method, *an article in composites, 43(2),* 2012, 302-308.

[34] I. Dinaharan and N. Murugan, Effect of friction stir welding on microstructure, mechanical and wear properties of AA6061/ZrB_2 in situ cast composites, *Journal of Materials Science and Engineering, 543,* 2012, 257-266 .

[35] Mohamadreza Nourani, Abbas S.Milani and Spiro Yannacopoulos, Taguchi optimization of process parameters in friction stir welding of 6061 aluminium alloy A Review and Case Study, *Journal of Engineering, 3(2),* 2011, 144.

[36] S. GopalaKrishnan and N. Murugan, Prediction of tensile strength of friction stir welded aluminium matrix TiCp particulate reinforced composite, *an article in Materials and Design, 32(1),* 2011, 462-467.

[37] Vijay joseph santhiyagu and N. Murugan, Influence of tool pin profile on the metallurgical and mechanical properties of friction stir welded Al-10Wt.% TiB_2 metal matrix composite, *an article in Materials and Design, 31(7),* 2010, 3585-3589.

[38] M. Jayaraman, R. Sivasubramanian, V. Balasubramanian and A. K. Lakshmi narayanan, Optimization of process parameters for friction stir welding of cast aluminium alloy A319 by Taguchi Method, *Journal of Scientific and Industrial Research, 68,* 2009, 36-43.

[39] Huseyin uzun, Friction stir welding of SiC particulate reinforced AA2124 aluminium alloy matrix composite, *Journal of Material and Design, 28(5),* 2007, 1440-1446.

[40] Takehiko watanabe and Hirofumi takayama, Atsushi yanagisawa, Joining of aluminum alloy to steel by friction stir welding, *Journal of material processing technology, 178(1-3),* 2006, 342-349.

[41] L. M. Marzoli, A. V. Strombeck, J. F. Dos Santos, C. Gambaro and L. M. Volpone, Friction stir welding of AA6061/Al_2O_3/20SiCp reinforced alloy, *Composites science and technology, 66(2),* 2006, 363-371.

[42] G. J. Fernandez and Laurence, Characterization of tool wear and weld optimization of friction stir welding of cast aluminium 359+20%SiC metal matrix composite, *Journal on Material Characterization, 52(1),* 2004, 65-75.

Biography

Rajesh P V received his Master of Engineering Degree in Manufacturing Engineering from M.I.E.T Engineering College, India in 2016. Presently, he is working as an Assistant Professor in the Department of Mechanical Engineering, Faculty of Engineering, Saranathan College of Engineering, India. His current research interests include composites, bio ceramics, optimization and MCDM.