ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Friction Stir Welding Processes: A Review

Naveen Kumar *, Manjit Singh, Amit Handa
*M.Tech Research Scholar, RIMT College of Engineering & Technology, Mandigobindgarh, Punjab, India
Associate Professor, RIMT College of Engineering & Technology, Mandigobindgarh, Punjab, India
Associate Professor, RIMT College of Engineering & Technology, Mandigobindgarh, Punjab, India

Abstract

Friction Stir Welding is a novel green solid state joining process particularly used to join high strength aerospace aluminum alloys which are otherwise difficult to weld by conventional fusion welding. Unlike other solid state joining technique, in Friction stir welding a third body contact by tool will generate the additional interface surfaces and finally all the surfaces are coalesced with each other by applied pressure and temperature and form solid state weld. This review paper addresses the overview of Friction stir welding which includes the basic concept of the process, microstructure formation, influencing process parameters, typical defects in FSW process and some recent applications. The paper will also discuss some of the process variants of FSW such as Friction Stir Processing, Friction Welding processes

Keywords: Friction stir Welding; dissimilar Al alloy; Al and cu alloys ; AISI 1021 steels

Introduction

Friction Stir Welding (FSW) is a solid state joining process that utilizes the heat produced between the material and a non-consumable rotating pin to join the desired materials or work pieces. This rotation causes a plasticized region of material to rotate about the tool. As the tool is moved through the material, the material on the leading edge enters the plasticized region and is swept around to the back of the tool where the lagging material is left to form a solid joint. In order to obtain a properly consolidated weld it is also necessary for there to be a shoulder above the pin, typically 1.5-2 times the diameter of the pin, which rides along the surface of the work piece in intimate contact, while pin is submerged in work piece providing the stirring and heating.It is important to note that while the process is named Friction Stir Welding, friction is not main source of energy for the weld but rather the shearing of the material at the interface between the tool and the material is.FSW presents numerous advantages over conventional fusion welding techniques such as eliminating the need for a shielding gas, requiring less energy per weld, and the lack of a flame or arc making it safer in the work place. Another advantage of FSW is its ability to join materials that are extremely difficult, or impossible to weld with 2 conventional fusion techniques. Also, since FSW is a solid state process there is no melting of the parent material which can lead to the formation of unwanted and detrimental intermetallic compounds often present during the welding of dissimilar metals such as Magnesium and Aluminium. FSW is able to successfully join materials such as aerospace high alloy aluminium (2000 and 7000series), magnesium, metal matrix composites, and dissimilar metals. Thermal heating and mechanical stirring originated by the rotational tool with probe join two pieces of alloy plates. For light metal alloys, welding by FSW is expected in transport industries due to the high quality of the joint because of the low temperature processing without melting. It is considered by many to be the most significant development in metal joining in a decade.[1]

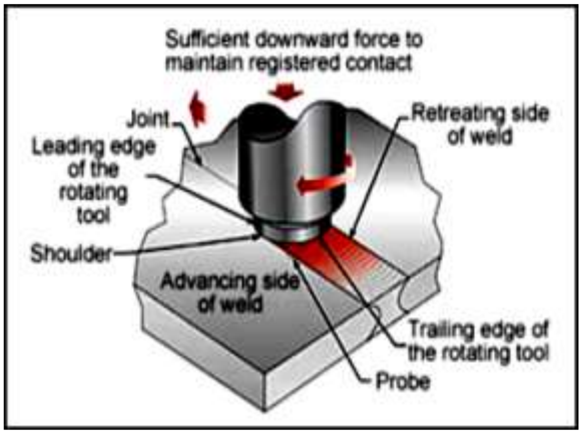

Fig.1. Schematic diagram of the Friction Stir Welding(1)

Friction stir welding Research studies and characteristics

A. Friction stir Welding of dissimilar aluminium alloy.

Koilraj et al [2] optimized FSW process with respect to tensile strength of the welds and the optimum settings.Furthermore, the optimum values of the rotational speed, transverse speed, and D/d ratio are 700 rpm, 15 mm/min and 3 respectively. In addition, they concluded that the cylindrical threaded pin tool profile was the best among the other tool profiles considered. Palanivelet al [3] examined the influence of tool rotational speed and pin profile on the microstructure and tensile strength of the dissimilar friction stir welded aluminum alloys AA5083-H111 and AA6351-T6. The welds fabricated using straight tool profiles had no defects while the tapered tool profiles caused a tunnel defect at the bottom of the joints under the experimental considered conditions. Furthermore, three different regions namely unmixed region, mechanically mixed region and mixed flow region were observed in the weld zone [3]. Furthermore, Palanivel et al [4] joined AA5083-H111 and AA6351-T6 using tool rotational speed of 950 rpm and straight square pin profile which resulted into obtaining the highest tensile strength of 273 MPa. Moreover, the variation in the tensile strength of the dissimilar joints was attributed to material flow behaviour, loss of cold work in the HAZ of AA5083, dissolution and over aging of precipitates of AA6351 and formation of macroscopic defects in the weld zone. Da Silva et al [5] investigated the mechanical properties and microstructural features as well as the material flow characteristics in dissimilar 2024-T3 and 7075-T6 FSW joints. The welds were produced at fixed feed rate (254 mm/min) varying the rotation speed in three levels (400, 1000 and 2000 rpm).Da Silva et al [5] clearly stated that, typical microstructural features of FSW welds such as SZ, TMAZ and HAZ regions were seen. A sharp transition from the HAZ/TMAZ to the SZ has been observed in the advancing side; while in the retreating side, such transition is moregradual. They found that the minimum hardness value of naturally aged samples in the HAZ at the retreating side was about 88% of 2024-T3 base material. Furthermore, 96% ofefficiency in terms of tensile strength was achieved using 1000 rpm rotational speed. Fracture of the weld specimens occurred in the HAZ at the retreating side (2024-T3).Aval et al [6] investigated the microstructures and mechanical propertiesin similar and dissimilar friction stir welding of AA5086-O andAA6061-T6 using thermomechanical modeland experimental observations. They concluded that the hardness in AA5086 side mainly depends on recrystallization and generation of fine grains in the weld nugget whereas hardness in the AA6061 side varies with the size, volume fraction and distribution of precipitates in the weld line and adjacent heat affected zone as well as the aging period after welding. Aval et al [6] further observed grainrefinement in the stirred zone for all their samples; however, the finer grain size distribution is achieved within the AA6061 side where higher strain rates are produced. Shen et al [7] in their investigation on microstructures and electrochemical behaviors of the friction stir welding dissimilar welds observed that the microstructure of the FSW weld consist of finer grains in comparison to that of the parent material.Furthermore, intense plastic deformation and frictional heating during welding resulted in the generation of a dynamically recrystallized fine grained microstructure within the stirred zone. Tran et al [8] investigated the behavior of friction spot welding between AA 5754-O and AA 7075-T6.They showed that, under cyclic loading conditions, the micrographs show that the 5754/7075 and 7075/5754 welds in cross-tension specimens mainly failed from the fatigue crack along the interfacial surface and from the fracture surface through the upper sheet material[8].Jun et al [9] investigated residual strains in dissimilar friction welds. The research was conducted using the Eigen strain Reconstruction Method in FSW between AA5083 and AA6082-T3.They further observed that full-field residual stress–strain distributions can be reconstructed relatively easily based on limitedexperimental data sets using transparent and straight forward FE modeling framework. Another study was conducted by Ghosh et al [10], they joined A356 and 6061 aluminum alloys using FSW under different tool rotation and traversing speeds. They found that the interface microstructure within the weld nugget is dominated by the retreating side alloy as the signature of Si rich particle distribution and it was evident for all the samples produced. They further observed that welds fabricated at the lowest tool rotational and traversing speed exhibited superior mechanical properties when compared to the remaining welds produced.

Sundaram et al [11] friction stir welded AA2024-T6 and AA5083-H321 using five different pin profiles developed successfully and suitable for the dissimilar FS welding of aluminum alloys. They further observed that increasing the tool rotational speed or welding speed led to the increase in the tensile strength; and it reachesa maximum value and then decreases. Additionally, the increase in the tool axial force led to the increase in the tensile strength of the dissimilar FS welded joints. The tensile strength decreases after it attains a maximum value. Muruganandam et al [12] in FS Welding of dissimilar 2024 and 7075 aluminum alloys, investigated the microstructures, the results revealed that the process led to recrystallized grain structure and precipitates distribution.Moreira et al [13] produced friction stir butt welds of AA6082-T6 with AA6061- T6. The welds exhibited intermediate properties and the tensile tests failures occurred near the weld edge line where a minimum value of hardness was observed. Furthermore, microstructural changes induced by the friction stir welding process were clearly identified. Leitao et al [14] used AA5182- H111 and AA6016-T4 sheet samples and joined them using FSW. Welds between both alloys exhibited a hardness variation consistent with the microstructure evolution across the TMAZ and no significant decrease in the hardness was observed for the welds and its strength efficiency is about 90%. Still, its ductility seriously decreases relative to the base materials due to the heterogeneous characteristics of these welds. Cavaliere et al [15] studied the mechanical and microstructural behaviour of FSW between AA6082 and AA2024. They noticed that the vertical force increased as the travel speed for all the produced joints increases. They also achieved the best tensile and fatigue properties for the joints with the AA6082 on the advancing side and welded with anadvancing speed of 115 mm/min. Leitao et al [16] joined AA5182-H111 and AA 6016-T4 using friction stir welding process. They found in the dissimilar welds the presence of small defects at the weld root of the dissimilar welds induced rupture of some of the blanks during the formability tests. Hatamleh and DeWald [17] joined AA 2195 and AA 7075 and investigated the peening effect on the residual stresses of the produced welds. Results showed that the surface residual stresses resulting from shot peening on both AA 2195 and AA 7075 were higher compared to the laser peening due to the high amount of cold work exhibited on the surface from shot peening. Furthermore, high values of tensile stresses were noticed in the mid-thickness on the laser peened samples. Recent studies on friction stir welding of dissimilar aluminum and its alloys have been reviewed and acomprehensive summary of the results have been presented

A. Friction stir welding between aluminium and copper alloys

The development of laboratory work on the friction stir welding of dissimilar materials will provide a good insight on their possible industrial application and therefore enhance industrial development. Liu et al [18] observed while welding copper (T2) to AA 5A06 that the distribution between the Copper (Cu) and Aluminium (Al) has an evident boundary and the material in the stir zone shows obvious plasticcombination of both materials. Furthermore, they observed clearly an onion ring structure in the stir zone indicating good material flow. Additionally, they indicated that the metal Cu and Al close to the copper side in the Weld Nugget (WN) zone showed a lamellar alternating structure characteristic [18]. However, a mixed structure characteristic of Cu and Al existed in the aluminium side of the weld nugget (WN) zone. The stir action of the tool, frictional heat and heat conductivity of Cu and Al could have induced the different structures of both sides in the weld nugget zone. The X-ray diffraction (XRD) analysis showed that there were no new Cu–Al intermetallics in the weld nugget zone. Consequently, the structure of the weld nugget zone was largely plastic diffusion combination of Cu and Al [18]. However, Xue et al [19] successfully welded AA1060 and 99.9% pure commercial copper (annealed), they conducted XRD analysis and their results revealed the existence of distinct characteristic diffraction peaks of Al2Cu and Al4Cu9. Hence, they stated that the Al2Cu and Al4Cu9 were generated around the larger Cu particles, and for the smaller Cu particles most of the copper were transformed into these two intermetallics (IMCs). However, the microstructures of the nugget zone consisted of a mixture of the aluminium matrix and Cu particles. The distribution of the Cu particles with irregular shapes and various sizes was inhomogeneous in the nugget zone and a particles-rich zone (PRZ) was formed near the bottom of the weld [19]. Furthermore, they examined the presence of the particles in the aluminium matrix of the nugget zone and attributed that to the stirring action of the tool pin that worn out the Cu pieces from the bulk copper, breaking up and scattering them during the FSW process [19]. AA5083 and commercially pure copper were joined using FSW by Bisadi et al [20]. They observed that a very low welding temperature led to some defects like channels that showed up at a region near the sheets interface especially in the Cu sheet. Also, extremely high process temperature leads to some cavities appearance at the interface of the diffused aluminium particles and the copper sheet material. Additionally, they found that increasing the process temperature reportedly leads to higher amounts of copper particles diffusion to the aluminium sheet, increase in the intermetallic composition]/'s and a number of micro crackswere present.On the other hand, Xue et al [20] welded AA 1060aluminium to commercially pure copper. They identified many defects in the nugget zone at the lower rotation speed of 400 rpm considered; whereas at higher rotation speeds of 800 and 1000 rpm, good metallurgical bonding between the Cu pieces and Al matrix was achieved. Furthermore, a large volume defect was observed when the soft Al plate was placed at the advancing side. They attributed that to the hard copper bulk material which was hard to transport to the advancing side during FS welding [21]. Esmaeili et al [22] joined AA 1050 and 70%Cu–30% Zn brass, the results showed that the structure of the sound joint at the nugget zone of aluminium is made up of a composite structure, consisting of intermetallics and brass particles, mainly at the upper region of the weld cross section. Furthermore, a multilayer intermetallic compound was formed at the interface at rotational speeds higher than 450 rpm. This layer is mainly composed of CuZn, CuAl2 and Cu9Al4. Thedistribution, shape and size of the particles are irregular and inhomogeneous in the nugget zone of aluminium [22]. Ouyang et al [23] also conducted dissimilar FSwelds using AA 6061(T6) to copper. They demonstrated that the direct FSW of AA 6061 to copper has been difficult due to the brittle nature of the intermetallic compounds formed in the weld nugget. Moreover, the mechanically mixed region in the dissimilar AA 6061 to copper weld consisted mainly of several intermetallic compounds such as CuAl2, CuAl, and Cu9Al4 together with small amounts of α-Al and a facecentered cubic solid solution of Al in Cu [23].Abdollah-Zadeh et al [24] friction stir welded AA 1060 to a commercially pure copper. They observed intermetallic compounds of Al4Cu9, AlCu and Al2Cu near the Al/Cu interface, where the crack can be initiated and propagated preferentially during the tensile tests. They also observed that higher rotational speeds increased the amount of intermetallic compounds formed at the aluminium / copper interface while low rotational speed resulted in imperfect joints. Saeid et al [25] stated that the interface in the central region moved considerably into the bottom plate while joining 1060 aluminium alloy to commercially pure copper. The vertical transport of the interface is attributed to the ring-vortex flow of materials created by the tool pin threads [25]. At higher welding speeds, less vertical transport of the interface was observed on the retreating side [25]. Akinlabi et al [26] investigated the microstructure of the joint interface of AA 5754 and C11000 copper welds. The mixing of both materials was observed leading to good metallurgical bonding at the joint interface. The aluminium rich region was black/silver while golden yellow showed copper rich regions. Furthermore, Akinlabi, et al [27] observed a thickness reduction in the joint interface but good mixing was achieved in the weld produced at a constant rotational speed of 600 rpm and feed rates of 50 and 150 mm/min. They attributed the reduction in thickness at the joint interfacial regions to heavy flash observed during the welding process [27]. In addition, a good material mixing was achieved in welds produced at lower feed rate due to high heat generated while the welds produced at highfeed rates resulted in worm hole defect formation [27]. On the other hand, Galvao, et al [28] observed that increasing the heat input, by performing welds under higher ω/v ratio, resulted in the formation of mixed material zones with increasing dimension and homogeneity. Furthermore [28], the morphology of the mixing zones and the type and amount of the intermetallic phases, which they found to result from a thermomechanically induced solid state process, are also strongly dependent on the welding parameters.

Galvao et al [29] friction stir welded oxygen free copper with high phosphorous content (Cu-DHP, R240) and AA 5083-H111. They observed that the welds performed with the aluminium placed at the advancing side of the tool were morphologically very irregular, being significantly thinner and exhibiting flash formation due to the expulsion of the aluminium from the weld area. Furthermore, the aluminium, which is expelled, gave rise to the flash displayed for the welds performed with aluminium at the advancing side [29]. It was observed that when the aluminium plate is located at the retreating side of the tool, the material was dragged by the shoulder to the advancing side, where the harder copper plate is located [29]. In FSW of dissimilar metals, the pin offset is a very important factor. Agarwal et al [30] joined AA 6063 and 99.9% pure commercially copper using FSW. They observed that as the pin offset is increased there is improper mixing of the Al-Cu metals that resulted in the tunnelling defect. Singh et al [31] observed that there were different microstructure features in the different zones. At the weld centre line, mix region of aluminium and copper were found. Small particles of aluminium and copper were distributed in the opposite side by the stirring forces of the tool. The Thermo Mechanically Affected Zone (TMAZ) is clearly obtained in Copper but it was not found in aluminium. Thus, in both the metals, the Heat Affected Zone (HAZ) was not clear [31]. Ratnesh and Pravin [32] successfully joined AA 6061 and copper by FSW. They produced sound joints by shifting the centre line of the tool towards the copper plate on the advancing side. A presence of a ‘‘transition zone’’ was observed by Guerra et al [33] while friction stir welding thick AA 6061 plates with a thin high purity copper foil. This transition zone was found to be about twice as thick on the retreating side as it is on the advancing side. They believed that the material in this zone rotates, but its velocity decreases from the rotational velocity of the pin at the inner edge of the transition zone to zero at its outer edge [33]. Xue et al [34] joined 1060 aluminium alloy and commercially pure copper with success through friction stir lap welds. They found that the nugget zone consisted of pure Al material and a composite structure in the upper and the lower parts respectively. They found that the Al/Cu interface was characterised by a thin, continuous and uniform intermetallic layer, producing a good interface bonding. Furthermore, good metallurgical bonding was achieved between the Al matrix and the Cu particles in the composite structure due to the formation of a small number of intermetallics [34]. Akinlabi et al [35] observed that the joint interfaces are characterised by mixed layers of aluminium and copper as evident in the microstructures resulting from the heat input into the welds by the stirring action of the tool during the FSW process. Furthermore, they observed that the percentage decrease in the grain sizes increases towards the stir zones of the welds. LI et al [36] used pure copper and AA 1350 and successfully joined them through FSW with the pin offset technique. They found that both copper and aluminium are greatly refined after FSW compared to the base materials. No intermetallic compound was found according to the XRD results. Esmaeili, et al [37] friction stir welded brass to AA 1050 at different rotation speeds. At low rotation speeds and due to low levels of heat inputs, no detectable intermetallic compound was observed. As the rotation speeds increases, the gradual formation of intermetallics is initiated at the interface.Additionally, the increase in the rotational speed resulted in the thickening and development of intermetallic layers.

A. Friction welding Processes AISI 1021 steel

Handa et al[38] study, an experimental set-up was designed in order to achieve friction welding of plastically deformed AISI 1021 steels. Low alloy steel (AISI 1021) was welded under different welding parameters and afterwards the mechanical properties such as tensile strength, impact strength and hardness were experimentally determined. On the basis of the results obtained from the experimentation, the graphs were plotted. It is the strength of welded joints, which is fundamental property to the service reliability of the weldments and hence present work was undertaken to study the influence of axial pressure and rotational speed in friction welded joints. Axial pressure and rotational speed are the two major parameters which can influence the strength and hence the mechanical properties of the friction welded joints. Thus the axial pressure and rotational speed were taken as welding parameters, which reflect the mechanical properties.

Handa et al[39] investigated that Joining of dissimilar metals is one of the most essential needs of industries. There are various welding methods that have been developed to obtain suitable joints in various applications. However, friction welding is a joining process that allows more materials and material combinations to be joined than with any other welding process. Continuous drive friction welding studies on austenitic stainless steel and ferritic steel combinations has been attempted in this investigation. Friction welding process parameter optimization, mechanical characterization and fracture behavior is the major contribution of the study. The microhardness across the weld interface was measured and the strength of the joint was determined with tensile tests and impact tests. Also the tensile fractured specimens were examined by scanning electron microscopy so as to study its fracture behavior. The experimental results indicate that axial pressure has a significant effect on the mechanical properties of the joint and it is possible to increase the quality of the welded joint by selecting the optimum axial pressure. Handa et al[40] studies that austenitic stainless steel needs to be welded specially in power generation industries. Unfortunately the austenitic stainless welding has several fabrication and metallurgical drawbacks when welded by using conventional fusion welding methods, which can often leads to in-service failure. The most pronounced fabrication faults are hot cracks due to inadvertent use of incorrect welding electrodes, primarily carbon steel electrodes. The use of carbon steel electrode results in the formation of very hard, crack-susceptible bulk structure on the stainless steel side. Such hard and brittle zones may render to localized pitting corrosion attack, hydrogen embrittlement, sulfide stress cracking, and stress rupture. Thus conventional fusion welding of many metalsare not feasible owing to the formation of brittle and low-melting inter-metallic. Solid state welding processes that limit extent of intermixing are generally employed in such situations. Friction welding (FRW) is one such solid state welding process that can be employed in such situations. In the present investigation an experimental set-up was made in order to achieve friction welding of plastically deformed AISI 304 steels.In this experimental study austenitic stainless steel (AISI 304) was welded under different welding parameters and afterwards the mechanical properties such as tensile strength, impact strength and hardness were experimentally determined. It is the strength of welded joints, which is fundamental property to the service reliability of the weldments and hence present work was undertaken to study the influence of axial pressure and rotational speed in friction welded joints.

Conclusion

The basic conclustion of friction stir welding of dissimilar materials focusing on aluminum to other materials has been conducted. The latter focuses on dissimilar aluminium alloys, aluminum to magnesium, aluminum to steel and titanium. Furthermore, this paper review showed that there is asignificant progress in FSW of dissimilar materials. Most of the cited research studies are more focused on understanding the microstructure and physical properties of various welds. FSW technology need to be more developed to enable the technique to be employed industrially. The full understanding of the dissimilar FSW process is needed to accommodate the huge demand in the industries including manufacturing andthe aerospace industry.

The conclustion of friction welding is that mechanical properties were found to vary with the applied axial pressure, which indicates that axial pressure is an important welding axial pressure could be successfully optimized for the friction welding process on the basis of the results of the current investigation.

Reference

1. T. Morishige1, A. Kawaguchi, M. Tsujikawa1, M. Hino, T. Hirata and K. Higashi, “Dissimilar Welding of Al and Mg Alloys by FSW. Materials Transactions, Vol. 49, 2008, pp. 1129 -1131.
2. M. Koilraj, V. Sundareswaran, S. Vijayan, S.R. Koteswara Rao,“Friction stir welding of dissimilar aluminum alloys AA2219 to AA5083– Optimization of process parameters using Taguchi technique” Materials and Design , 2012, pp. 1–7.
3. R. Palanivel, P. Koshy Mathews, N. Murugan, I. Dinaharan, “Effect of tool rotational speed and pin profile on microstructure and tensile strength of dissimilar friction stir welded AA5083-H111 and AA6351 T6 aluminum alloys”, Materials and Design ,2012 , pp. 7–16.
4. R. PalaniveI, P. Koshy Mathews, “Mechanical and microstructural behaviour of friction stir welded dissimilar aluminum alloy”, IEEE International Conference On Advances In Engineering, Science And Management , 2012, pp. 7- 11.
5. A.A.M. da Silva, E. Arruti, G. Janeiro, E. Aldanondo, P. Alvarez, A. Echeverria, “Material flow and mechanical behaviour of dissimilar AA2024-T3 and AA7075-T6 aluminum alloys friction stir welds”, Materials and Design ,2011 , pp. 2021–2027.
6. H. Jamshidi Aval, S. Serajzadeh, A.H. Kokabi, “Evolution of microstructures and mechanical properties in similar and dissimilar friction stir welding of AA5086 and AA6061”, Materials Science and En’gineering A 528 ,2011, pp. 8071– 80853.
7. Changbin Shen, Jiayan Zhang, Jiping Ge, “Microstructures and electrochemical behaviors of the friction stir welding dissimilar weld”, Journal of Environmental Sciences, 2011, 23(Supplement) S32–S35.
8. V.-X. Tran, J. Pan, T. Pan, “Fatigue behavior of spot friction welds in lap-shear and cross-tension specimens of dissimilar aluminum sheets”,International Journal of Fatigue,2010, pp. 1022–1041.
9. T-S. Jun, K. Dragnevski, A.M. Korsunsky, “Microstructure, residual strain, and eigenstrain analysis of dissimilar friction stir welds”, Materials and Design ,2010 , pp. S121–S125.
10. M. Ghosh, K. Kumar, S.V. Kailas, A.K. Ray, “Optimization of friction stir welding parameters for dissimilar aluminum alloys” Materials and Design ,2010 , pp. 3033–3037.
11. N. Shanmuga Sundaram, N. Murugan, “Tensile behavior of dissimilarfriction stir welded joints of aluminum alloys” Materials and Design ,2010 , pp. 4184–4193.

12. D. Muruganandam, S. Ravikumar, Sushil Lal Das "Mechanical and Micro Structural Behavior of 2024–7075 Aluminum Alloy Plates joined by Friction Stir Welding", IEEE , pp. 247- 251.
13. P.M.G.P. Moreira, T. Santos, S.M.O. Tavares, V. Richter-Trummer, P. Vilaca, P.M.S.T. de Castro, "Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 wit AA6082-T6" Materials and Design ,2009, pp. 180–187.
14. C. Leitao, R.M. Leal, D.M. Rodrigues , A. Loureiro, P. Vilaca, "Mechanical behaviour of similar and dissimilar AA5182-H111 and AA6016-T4 thin friction stir welds" Materials and Design ,2009 , pp. 101–108.
15. P. Cavaliere, A. De Santis, F. Panella, A. Squillace, "Effect of welding parameters on mechanical and microstructural properties of dissimilar AA6082–AA2024 joints produced by friction stir welding" Materials and Design ,2009, pp. 609–616.
16. C. Leitao, B. Emilio, B.M. Chaparro, D.M. Rodrigues, "Formability of similar and dissimilar friction stir welded AA 5182-H111 and AA 6016- T4 tailored blanks" Materials and Design ,2009 , pp. 3235–3242.
17. O. Hatamleh, A. DeWald, "An investigation of the peening effects on the residual stresses in friction stir welded 2195 and 7075 aluminum alloy joints", Journal of Materials Processing Technology ,2009, pp. 4822–4829.
18. P. Liu , Q. Shi, W. Wang, X. Wang, Z. Zhang,"Microstructure and XRD analysis of FSW joints for copper T2/aluminium 5A06 dissimilar materials" Materials Letters , 2008, pp 4106–4108.
19. P. Xue, B.L. Xiao, D.R. Ni, Z.Y. Ma, "Enhanced mechanical properties of friction stir welded dissimilar Al–Cu joint by intermetallic compounds" Materials Science and Engineering A,
    2010, pp 5723–5727.
20. 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 2013, pp 80–88.
21. P. Xue, D.R. Ni, D. Wang, B.L. Xiao, Z.Y. Ma, "Effect of friction stir welding parameters on the microstructure and mechanical properties of the dissimilar Al–Cu joints" Materials Science and Engineering A, 2011, pp 4683–4689.
22. A. Esmaeili,M. K. BesharatiGivi, H. R. Zareie Rajani , " A metallurgical and mechanical study on dissimilar Friction Stir welding of aluminum 1050 to brass (CuZn30)" Materials Science and
    Engineering, 2011, pp. 7093– 7102.
23. Jiahu Ouyang, Eswar Yarrapareddy, Radovan Kovacevic, " Microstructural evolution in the friction stir welded 6061 aluminum alloy (T6-temper condition) to copper" Journal of Materials Processing Technology, 2006, pp 110–122.
24. A. Abdollah-Zadeh, T. Saeid, B. Sazgari , "Microstructural and mechanical properties of friction stir welded aluminum/copper lap joints" Journal of Alloys and Compounds, 2008, pp. 535–538.
25. T. Saeid, A. Abdollah-zadeh, B. Sazgari, " Weldability and mechanical properties of dissimilar aluminum–copper lap joints made by friction stir welding" Journal of Alloys and Compounds, 2010, pp 652–655.
26. E.T. Akinlabi, D. M. Madyira , S.A.Akinlabi ,"Effect of Heat Input on the Electrical Resistivity of Dissimilar Friction Stir Welded Joints of Aluminium and Copper" The Falls Resort and Conference Centre, Livingstone, Zambia, 2011, pp.13 – 15.
27. Esther T. Akinlabi, Randall D. Reddy, Stephen A. Akinlabi,"Microstructural Characterizations of Dissimilar Friction Stir Welds" Proceedings of the World Congress on Engineering (WCE), 2012,
    ISBN: 978-988-19252-2-0, pp. 4 - 6
28. I. Galvao, J. C. Oliveira, A. Loureiro and D. M. Rodrigues,"Formation and distribution of brittle structures in friction stir welding of aluminium and copper: influence of process parameters"Science and Technology of Welding and Joining, 2011, pp.681- 689.
29. I. Galvao, R. M. Leal, A. Loureiro and D. M. Rodrigues, "Material flow in heterogeneous friction stir welding of aluminium and copper thin sheets" Science and Technology of Welding and Joining, 2010, pp. 654- 660.
30. S. Pratik Agarwal, Prashanna Nageswaran, N. Arivazhagan, K. Devendranath Ramkumar, "Development of Friction Stir Welded Butt Joints of AA 6063 Aluminium Alloy and Pure Copper" International Conference on Advanced Research in Mechanical Engineering, 2012 ,(ICARM), pp. 46-50.
31. R. K. R. Singh, R. Prasad, S. Pandey, "Mechanical Properties Of Friction Stir Welded Dissimilar Metals" Proceedings of the National

Conference on Trends and Advances in Mechanical Engineering, 2012, pp. 579- 583.

32. R. K. Shukla , P. K. Shah , " Investigation of Joint Properties of Friction Stir Welding of Aluminum 6061 Alloy to Copper" International Journal of Engineering Research and Technology, 2010, pp. 613—620.
33. M. Guerra, C. Schmidt, J.C. McClure, L.E. Murr, A.C. Nunes, "Flow patterns during friction stir welding" Materials Characterization , 2003, pp. 95– 101.
34. P. Xue, B. L. Xiao, D. Wang and Z. Y. Ma, "Achieving high property friction stir welded aluminium/copper lap joint at low heat input" Science and Technology of Welding and Joining, 2011, pp.657-661.
35. Esther T. Akinlabi, Stephen A. Akinlabi, "Effect of Heat Input on the Properties of Dissimilar Friction Stir Welds of Aluminium and Copper" American Journal of Materials Science, 2012, pp. 147-152.
36. L. Xia-wei, Z. Da-tong, Q. Cheng, Z. Wen"Microstructure and mechanical properties of dissimilar pure copper/1350 aluminum alloy butt joints by friction stir welding" Trans. Nonferrous MET. Soc. China 22, 2012, pp. 1298-1306.
37. A. Esmaeili, H.R Zareie Rajani, M. Sharbati, M.K. BesharatiGivi, M.Shamanian, 2011 "The role of rotation speed on intermetallic compounds formation and mechanical behavior of friction stir welded brass/aluminum 1050 couple" Intermetallics , pp. 1711-1719.
38. A. Handa, V. Chawla, "Experimental study of mechanical properties of friction welded AISI 1021 steels" Indian Academy of Sciences, 2013, Vol. 38, pp. 1407–1419.
39. A. Handa, V. Chawla, "Mechanical characterization of friction welded dissimilar steels at 1000 rpm, Materials Engineering - Materialove inzinierstvo, 2013, pp. 102-111.
40. A. Handa, V. Chawla, "Mechanical characterization of friction welded AISI 304 steels". international journal of engineering sciences & research technology". 2013, ISSN: 2277-9655.pp. 2818-2821.