International Journal of Research in Engineering and Innovation (IJREI)

journal home page: http://www.ijrei.com

ISSN (Online): 2456-6934

Friction stir welding/processing studies of aluminum alloy & titanium 64

R.S. Mishra & Preeti Rani

Department of Mechanical Production and Automobiles Engineering, Delhi Technological University Delhi-110042 India

Abstract

The main objective of this research paper is to consider and show a detailed study of friction stir welding/processing conducted by most of the researchers on aluminum alloy & titanium 64. The study is consist of influence of process parameters on response parameters, material flow during welding, and effect of reinforcement on the weld joint by friction stir welding, microstructure study to define the effect of different parameters on the grain structure of aluminum alloy. And the study showed that the effect of welding parameters like tool rotation speed, welding speed, tool pin diameter, shoulder diameter and tool pin profile have a significant effect on the tensile strength, micro hardness, yield strength and strain rate of FSW/FSPed aluminum alloy & titanium 64.

Key words: Friction stir welding, Aluminum alloy, Titanium 64

1. Introduction

Friction Stir Welding is a solid-state process, which means that the Parent materials are to be joined without melting during the welding process due to which the original characteristics of parent material remains unchanged after welding as much as possible. Friction stir welding is conducted with the help of a designed cylindrical tool consisting of a cylindrical shouldered and a profiled pin that rotates and plunged into the interface between two plate materials those are need to join. When tool pin and work-piece comes in contact friction takes which generates heat for the welding that causes softening of work-piece without melting and allows traversing of the tool along the weld line under pressure. Due to rotation of tool intermixing of work-piece material takes place and work-piece plates joined together. Friction stir processing is a local thermo-mechanical metal working process used to modify microstructure of metallic materials based on the principle of friction stir welding and it also used to increase ductility, improve corrosion resistance properties and helps to produce super-plastic materials by microstructure refinement.

2. Literature Review of Aluminium Alloy &Titanium 64 Metals

A comprehensive review of various research data which shows the effect of different process parameters on friction stir welded / processed of dis-similar metals has been discussed. This review consist of published papers of dis-similar metals has been presented in tabular form. The review table given below explains the details of parameters considered by earlier authors.

Corresponding author: R.S. Mishra
Email Id: rsmishra@dce.ac.in

S.No	Author	Title of Paper	Material	Tool and Groove size	Input Parameter	Output Parameter	Conclusion
1	Bahrami.M , et al (2014)	A novel approach to develop Al matrix nano composite employing FSW technique	7075-O Al plate thickness 6 mm	H13 hot working steel	➢ Tool shoulder diameter 16 mm. ➢ Threaded taper pin profile height - 5.7 mm. ➢ Tool Rotational speed - 800, 1000, and 1250 rpm 4) Traverse speed -30.5, 40, and 50 mm/min	➢ Microstructural observation ➢ Mechanical properties	(1) 7075 Aluminum matrix nano-composite reinforced with SiC particles was developed in the stir zone. (2) At high rotational speed (1250 rpm) powder dispersion improved due to effective stirring action of the pin. (3) UTS of specimen FSWed with powder at 1250 rpm and 40 mm/min was 31% superior to that of the specimen FSWed without powder. (4) The addition of SiC particles led to 76.1% enhancement of elongation.
2	Chen, Y. (2015).	Interface characteristic of friction stir welding lap joints of Ti/Al dissimilar alloys	TC1 Ti alloy and LF6 Al alloy plates thickness 2 mm 250 mm×100 mm	Lap joint	➢ Tool concaved shoulder diameter - 15mm. ➢ Cone-threaded pin diameter 4 mm. ➢ Tool Rotational speed 600, 950 and 1500 rpm ➢ Traverse speed 60, 95, 118 & 150 mm/min. ➢ Tilt angle - 2 ^{0}	➢ Interface macrograph of lap joints with different parameters. ➢ Failure loads of lap joints ➢ Microstructure and element distribution on interface. ➢ Micro hardness distribution	(1) At the welding speed of 60 mm/min and the tool rotation rate of 1500 r/min, the interfacial zone of lap joint can be divided into three kinds of layers. When the welding speed increases to 150 mm/min, groove-like crack occurs on the interface. (2) The failure loads of the lap joints decrease with the increase of welding speed. (3) The micro hardness of the lap joint presents an uneven distribution, the maximum value of hardness reaches HV 502 in the middle of the stir zone.
3	Aonuma.M ., et al (2010)	Dissimilar Metal Joining of 2024 and 7075 Al- Alloys to Ti-Alloys by Friction Stir Welding	Al Alloy - 2024-T3 & 7075-T651 Titanium Ti-6Al-4V	Tool Material - SKD61	➢ Tool shoulder diameter (mm) 15. ➢ Pin diameter (mm) – 6. ➢ Tool pin length (mm) - 1.9. ➢ Tool rotating speed (rpm) - 850 ➢ Welding Feeds (mm/min) - 100, 200, 300. ➢ Tilt angle - 3 ^{0}	➢ Macrostructures ➢ Microstructures ➢ Tensile strength ➢ Hardness	(1) In joining Ti and Al alloys by friction stir welding, the weldability of the Ti and 2024 Al alloy was better than of the Ti and 7075 alloy, and the tensile strengths of the Ti/2024 joints were higher than the other joints under the same joining conditions in this study. (2) Increasing the travel speed tends to increase the tensile strength of the Ti and Al alloy joint. The tensile strength of the Ti-6Al-4V and Al alloy joint is lower than the Ti and Al alloy joint.

4	Wang.J., et al (2014)	Tool wear mechanisms in friction stir welding of Ti–6Al–4V alloy	Ti–6Al–4V sheets Thickness - 2.5mm	Tool Material - W–La, CY16 and WC411	➢ Tool of a cylindrical pin with an increased pin tip diameter - 6.3mm. ➢ Tool rotating speed (rpm) 900, 1000, 1100. ➢ Welding Feeds (mm/min) - 25, 50	➢ Microscope images	(1) Friction stir welding (FSW) of titanium alloy Ti–6Al–4V was performed using three types of tools made of W–1.1%La2O3 and two different grades of WC–Co based materials. (2) Deformation was reduced by introducing a larger cylindrical pin designing the W–1.1%La2O3 tool. Among the cermets tools, fracture was observed in CY 16 grade WC–Co tool with 8wt %Co but was not found in WC411 grade WC–Co tool with 11wt%Co. Adhesive wear mechanism was related to the result of chemical affinity between WC–Co andTi–6Al–4V alloy.
5	Bang.H., et al (2013)	Joint properties of dissimilar Al6061-T6 aluminum alloy /Ti-6%Al-4%V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding	Al6061-T6 aluminum alloy and Ti-6%Al-4%V titanium alloy Thickness - 3.5 millimeters	Tool Material - WC-12% CO BUTT JOINT	➢ Tool shoulder diameter (mm) – 18. ➢ Pin diameter (mm) – 5. ➢ Tool pin length (mm) - 3.3. ➢ Tool rotating speed (rpm) - 300~450. ➢ Welding Feeds (mm/min) - 1.0~1.4 mm/sec. ➢ Tilt angle - 3 ^{0}	➢ Surface and cross-section characteristics in FSW and of HFSW welds. ➢ Mechanical characteristics in FSW and of HFSW welds. ➢ Microstructure in FSW and of HFSW welds. ➢ Thermal history in FSW and of HFSW welds	(1) The ultimate tensile strength was approximately 91% in HFSW welds by that of the Al alloy base metal, which was 24% higher than that of FSW welds without GTAW under same welding condition. (2) Elongation in HFSW welds increased significantly compared with that of FSW welds, which resulted in improved joint strength. (3) The ductile fracture was the main fracture mode in tensile test of HFSW welds.
6	Squillace.A ., et al (2011)	Effect of welding parameters on morphology and mechanical properties of Ti–6Al–4V laser beam welded butt joints	Ti–6Al–4V (ASTM B265 Grade5) Thickness - 1.6 mm	butt configurat ion using a Nd-YAG laser was studied.	➢ Tool shoulder diameter (mm) 18. ➢ Pin diameter (mm) – 5. ➢ Tool pin length (mm) - 3.3. ➢ Laser power 0.8,1.0,1.2 KW ➢ Welding Feeds - 17, 25, 34, 42, 50 and 58 mm/s ➢ Tilt angle - 3 ^{0}	➢ Morphology of the welds. ➢ Microstructures ➢ Micro hardness ➢ Tensile test ➢ Fatigue tests	(1) The interface between Al and filler metal became curved in shape with increasing bonding time due to capillary force at grain boundaries. The bonding at the interface between Ti and filler metal proceeds by the formation of two different intermetallic compound layers.

7	Ji.Y., et al (2016)	Microstructure and Mechanical Properties of Friction Welding Joints with Dissimilar Titanium Alloys	LFW joint with Ti-6Al-4V (Ti64) and Ti-5Al-2Sn-2Zr-4Mo-4Cr (Ti17) 130*75 * 20 mm			➢ Macro and Microstructure ➢ Compositional Analysis ➢ Microhardness ➢ Tensile Properties	(1) The microstructure across the linear friction welding dissimilar joints with titanium alloys displayed marked change, mainly consisting of a re-crystallized grain zone in the weld center, deformed grains and partial re-crystallization in the thermo-mechanical affected zones. (2) The maximum hardness is located in the weld metal, which may result from the fine grains arising from the rapid cooling during the welding process. (3) The linear friction welding dissimilar joints obtained higher tensile strength than base metal Ti64 with lower strength. The failure located in the Ti64 side approximately 1.2 mm away from the welding interface.
8	Sohn.w., et al (2014)	Microstructure and bonding mechanism of Al/Ti bonded joint using Al /10Si /1Mg filler metal	1050 Al alloy and cp-Ti alloy using filler metal(Al /10Si /1Mg) with a thickness of 100 mm Thickness 3 mm			➢ Characterization of micro structures at Al/filler metal interface during diffusion bonding. ➢ Characterization of microstructures at filler metal/Ti interface during diffusion bonding ➢ Characterization of interfacial bond strength at Al/Ti diffusion bonded joint	(1) The results show that the bonding at the interface between Al and filler metal proceeds by wetting the Al with molten filler metal, and followed by removal of oxide layer on surface of Al. (2) The interface between Al and filler metal moved during the isothermal solidification of filler metal by the diffusion of Si from filler metal into Al layer. (3) The interface between Al and filler metal became curved in shape with increasing bonding time due to capillary force at grain boundaries. The bonding at the interface between Ti and filler metal proceeds by the formation of two different intermetallic compound layers.
9	Aonuma.M ., et al (2012)	Dissimilar metal joining of ZK60 magnesium alloy and titanium by friction stir welding	Titanium and Mg–Zn–Zr alloy Thickness - 2.0 mm	Tool Material - SKD61 alloy steel Butt joint	➢ Tool shoulder diameter (mm) – 15. ➢ Pin diameter (mm) - 6. ➢ Tool pin length (mm) - 1.9 ➢ Tool rotational speed - 850 rpm ➢ Tool traverse speed - 50, 100 mm/min ➢ Tilt angle - 3 ^{0} ➢ Probe offsets of 1.0 and 1.5 mm	➢ SEM image ➢ Fractured surface of Mg and Ti joint	(1) Alloying elements of ZK60 Mg–Zn–Zr alloy on the microstructure of the dissimilar joint interface with titanium and the joint strength in comparison with pure magnesium and titanium has been investigated. (2) The fracture of the joint by tensile test occurred mainly in the stir zone of Mg–Zn–Zr alloy and partly at the joint interface. The tensile strength of the Mg–Zn–Zr alloy and titanium joint was higher than that of the pure magnesium and titanium .

10	Chen.Y.C., et al (2009)	Microstructural characterization and mechanical properties in friction stir welding of aluminum and titanium dissimilar alloys	ADC12 cast aluminum alloy sheet& Pure titanium sheet	Tool Material - (made of WC–Co)	➢ Tool shoulder diameter (mm) 15. ➢ Pin diameter (mm) - 5 mm. ➢ Tool pin length (mm) - 3.9. ➢ Tool rotational speed - 850 rpm. ➢ Tool traverse speed - 50, 100 mm/min. ➢ Tilt angle - 3 ^{0}	➢ Failure loads and fracture locations of joints. ➢ Qualitative EDS map analysis of mixture structure. ➢ XRD spectrums from different fracture surfaces	(1) ADC12 Al alloy and pure Ti can be successfully lap welded using friction stir welding technology. (2) The maximum failure load of lap joints can reach 62% that of ADC12 Al alloy base metal. The transient phase TiAl3 forms at the joining interface by Al–Ti diffusion reaction. (3) The formation of TiAl3 is strongly dependant on welding speeds (heat inputs) during FSW and thus affects the mechanical properties of joints.
11	Liu.H.J.,et al (2010)	Microstructural characteristics and mechanical properties of friction stir welded joints of Ti–6Al–4V titanium alloy	Ti–6Al– 4V plates Thickness - 2 mm	Tool Material - Tungsten–rhenium	➢ Tool rotational speed - 400 rpm. ➢ Tool traverse speed - 25, 50 and 100 mm/min. ➢ Tilt angle - 2.5 . ➢ Plunge depth - 0.2 mm	➢ Features of the microstructural zones. ➢ Effect of welding speed on the SZ microstructure. ➢ Hardness profile. ➢ Transverse tensile test	(1) Defect-free welds were successfully obtained with welding speeds ranging from 25 to 100 mm/min. (2) A bimodal microstructure was developed in the stir zone during friction stir welding, while microstructure in the heat affected zone was almost not changed compared with that in the base material.
12	Bang.H., et al (2013)	Joint properties of dissimilar Al6061-T6 aluminum alloy/Ti–6%Al–4%V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding	Al6061-T6 aluminum alloy and Ti–6%Al–4%V titanium alloy Thickness - 3.5 mm	Tool Material - F113 WC-12% CO	➢ Tool shoulder diameter (mm) 18. ➢ Pin diameter (mm) – 5. ➢ Tool pin length (mm) - 3.3. ➢ Tool rotational speed - 850 rpm. ➢ Tool traverse speed - 50, 100 mm/min. ➢ Tilt angle - 3^{0} ➢ Probe off sets of 2 mm	➢ Surface and cross-section characteristics in FSW and of HFSW welds. ➢ Mechanical characteristics in FSW and of HFSW welds. ➢ Microstructure in FSW and of HFSW welds. ➢ Thermal history in FSW and of HFSW welds	(1) The ultimate tensile strength was approximately 91% in HFSW welds by that of the Al alloy base metal, which was 24% higher than that of FSW welds without GTAW under same welding condition. (2) Notably, it was found that elongation in HFSW welds increased significantly compared with that of FSW welds, which resulted in improved joint strength. The ductile fracture was the main fracture mode in tensile test of HFSW welds.

13	Xie.G.M., et al (2008)	Effect of microstructural evolution on mechanical properties of friction stir welded ZK60 alloy	ZK60 alloy Thickness - 8mm		➢ Tool shoulder diameter (mm) – 20. ➢ Pin diameter (mm) -6 . ➢ Tool pin length (mm) - 5.7. ➢ Tool rotational speed - 800 rpm. ➢ Tool traverse speed - 100 mm/min. ➢ Tilt angle -2.5 ^{0}	➢ XRD patterns obtained. ➢ Microstructure ➢ SEM images of ZK60 Mg-alloy	(1) Under a rotation rate of 800 rpm and a traverse speed of 100 mm/min, 6mm thick extruded ZK60 magnesium alloy plate was successfully friction stir welded and defect-freenweld was obtained. (2) The UTS, YS and elongation of the FSW joint reached 87%, 77%, and 65% of the PM, respectively. After aging treatment, UTS, YS and elongation were increased to 94%, 92%, and 77% of the PM, respectively. 3) During FSW, fine and equiaxed recrystallized grains of 5.3 m were generated and MgZn2 particles were broken up and dispersed with most of them being dissolved into the magnesium matrix.
14	Dressler.U. , et al (2009)	Friction stir welding of titanium alloy TiAl6V4 to aluminium alloy AA2024-T3	TiAl6V4 and Al-alloy 2024-T3 Thickness 2 mm	Tool material - Standard tool steel butt joints	➢ Tool concave shoulder diameter (mm) – 18. ➢ Pin threaded and tapered diameter (mm) -6 ➢ Tool pin length (mm) - 5.7. ➢ Tool rotational speed - 800 rpm. ➢ Tool traverse speed - 100 mm/min 6) Tilt angle -2.5 ^{0}	➢ Microstructure ➢ Hardness profile ➢ Stress–strain curves	(1) Titanium alloy TiAl6V4 and aluminium alloy 2024-T3 were successfully joined by friction stir welding. (2) Hardness and tensile strength of the butt joint were investigated. (3) The weld nugget exhibits a mixture of fine recrystallized grains of aluminium alloy and titanium particles. (4) Hardness profile reveals a sharp decrease at titanium/aluminium interface and evidence of microstructural changes due to welding on the aluminium side. The ultimate tensile strength of the joint reached 73% of A2024-T3 base material strength.
15	Zhang.Yu , et al (2008)	Microstructural characteristics and mechanical properties of Ti–6Al–4V friction stir welds	Ti–6Al–4V plate thickness- 3 mm.	Tool material - Mo-based alloy tool	➢ Tool convex shoulder diameter (mm) -15. ➢ Pin threaded and tapered diameter (mm) -5.1. ➢ Tool tapered pin length (mm) -3. ➢ Tool rotational speed - 300 and 600 rpm. ➢ Tool traverse speed - 2mm and 1 mm/s	➢ Microstructural features of welds ➢ Microstructural evolution in the 400 rpm weld. ➢ Heat affected zone (HAZ). ➢ Effect of rotational speed on the SZ microstructure. ➢ Vickers hardness profile of weld. ➢ Transverse tensile test	(1) The microstructural evolution of these regions during FSW can be reasonably explained by taking into account solid-state transformation and the annealing effect of the microstructure. (2) Mechanical properties were heterogeneously distributed in the weld, which were directly related with the heterogeneous distribution of microstructure. (3) The SZ exhibited much higher mechanical properties than the base material, while the HAZ was the weakest in the weld, and its properties were representative of the transverse tensile properties of the weld.

16	Aonuma.M., et al (2009)	Effect of alloying elements on interface micro structure of Mg–Al–Zn magnesium alloys and titanium joint by friction stir welding	Mg–Al–Zn alloy plates of AZ31B, AZ61A and AZ91D, and a Ti plate Thickness-2.0 mm	Tool Material - SKD61 alloy tool steel. Square butt joints	➢ Tool shoulder diameter (mm) – 15. ➢ Tool screw-type Pin diameter (mm) -5.0. ➢ Tool screw-type pin length (mm) - 1.9. ➢ Tool rotational speed - 850 rpm ➢ Tool traverse speed - 50 mm/min ➢ Tilt angle - 3 ^{0}	➢ Microstructure in stir zone of Mg–Al–Zn alloy. ➢ Effect of aluminum on joint interfacial microstructure and tensile strength	(1) An Al-rich layer was formed at the joint interface. Increasing the aluminum content of the Mg–Al–Zn alloy, Ti–Al intermetallic compound layer was observed clearly on the joint interface. (2) The joint fractured in the intermetallic compound layer in the tensile test. The intermetallic compound plays an important role in making a Ti/Mg joint, but the increased thickness of this compound tends to reduce the tensile strength.
17	Ragu Nathan.S., et al (2017)	Failure analysis of tungsten based tool materials used in friction stir welding of high strength low alloy steels	High strength low alloy (HSLA) steel Thickness- 5 mm thick	Tool Material – 3 different grades of tungsten based alloy W90, W95 and W99	➢ Tool rotational speed - 600 rpm. ➢ Tool traverse speed - 30 mm/min	➢ Thermo-mechanical analysis. ➢ Microscopic observations. ➢ EBSD analysis. ➢ Evaluation of transfer layer	(1) Three tungsten base tool materials used in this investigation, W99 (W–1%La2O3) tool exhibited better microstructural stability without undergoing physical (dimensional) changes in tool configuration. (2) The W/matrix de-cohesion, matrix tearing and W-cleavage in the W90 and W95 tools are mainly due to formation of Fe–Co– Ni phase (softer phase) in the matrix. (3) It was found that the tool made of 99% W and 1% La2O3 withstood high strain rate, temperature and flow stresses generated during FSW of HSLA steel. This is mainly due to the microstructural stability of the tool materials and formation of protective transfer layer during FSW of HSLA steel.
18	Husain Mehdi et al (2016)	Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy – a review	7050-T651, Al-4Mg-1Zr, Al- Alloy F357	CY16, W-La, WC-411 tool	➢ 350 rpm and 15 mm/min ➢ 2236 rpm to 1500 rpm	➢ Mechanical Properties ➢ Wear Property ➢ Microstructure ➢ Macrostructure	Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints. Microstructure evaluation of FSW joints clearly shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter

19	Husain Mehdi et al (2017)	Influences of Process Parameter and Microstructural Studies in Friction Stir Welding of Different Alloys: A Review	7475 Al 7050-T65 cast A356 aluminum Al-4Mg-1Zr	CY16, W-La, WC-411 tool	➢ 2236 rpm and travel speed of 2.33 mm/s ➢ 700 rpm and a traverse speed of 203 mm/min ➢ Tool rotation rate of 300,700, 900 and 1100 rpm and a traverse speed 2 and 8 ipm	➢ Mechanical Properties ➢ Microstructure ➢ Macrostructure ➢ Wear Properties	The mechanical properties of welded joint by friction stir welding are largely dependent on the combined effect of both the composition of alloying element and processing parameter.
20	Mironov.S. , et al (2009)	Development of grain structure during friction stir welding of pure titanium	Purity a-titanium (ASTM Grade, Thickness- 3 mm thick Butt-welded Joint	Tool Material - Mo-based alloy	➢ Tool convex shoulder diameter (mm) – 15. ➢ Pin threaded and tapered diameter (mm) -5.1 ➢ Tool tapered pin length (mm) -3 ➢ Tool rotational speed - 200 rpm ➢ Tool traverse speed -	➢ Base material ➢ Low-magnification overview ➢ TMAZ ➢ Stir zone	(1) The global straining state during the process was deduced to be close to the simple shear with the shear surface being nearly along the truncated cone having a diameter close to that of the tool shoulder in the top part of the SZ and the pin diameter in the bottom part of the SZ. (2) The material flow was shown to arise mainly from the prism slip, giving rise to the pronounced P-fiber fhk i lgh11 20i simple shear texture in the SZ. (3) The grain structure evolution was shown to be a complex process driven mainly by the texture-induced grain convergence, but also involving the geometrical effects of strain and limited discontinuous recrystallization.
21	Buffa.G., et al (2012)	On the Choice of Tool Material in FSW of Titanium Alloys	Ti–6Al–4V titanium alloy sheets 100 mm x 200 mm Thickness- 3 mm thick	Tool Material – 3 different Tool (two WC based materials) K10-K30 and W25Re.	➢ Tool shoulder diameter (mm) - 16 mm. ➢ Tool conical Pin diameter (mm) -5 ➢ Tool conical pin length (mm) -2.6 ➢ Tool rotational speed - 300, 700 and 1000 rpm ➢ Tool traverse speed - 35 mm/min	Numerical Model	(1) All the tools failures were observed between the end of the sinking stage and the first few mm of welding. According to the numerical results, (2) Although characterized by a large hardness value, the K10 material revealed as inadequate for FSW of titanium alloys as brittle fractures occur. No weld could be obtained with the low rotational speed and unsatisfying tool life values were observed at the increasing of the tool rotation.

3. Conclusions & Recommendations

- It was difficult to weld aluminum alloy & titanium 64 because of high strength and large difference of melting point.
- Improve the strength of weld joint reinforcements is going to add in the weld joint to enhance the weld quality and to check the effect of reinforcement on the microstructure and mechanical properties of weld joint .

References

[1] Bahrami, M., Kazem, M., Givi, B., Dehghani, K., & Parvin, N. (2014). On the role of pin geometry in microstructure and mechanical properties of AA7075 / SiC nano-composite fabricated by friction stir welding technique. Journal of Materials & Design, 53, 519–527.

[2] Chen, Y. (2015). Interface characteristic of friction stir welding lap joints of Ti / Al dissimilar alloys, 632 6 (February 2015).

[3] Aonuma, M., & Nakata, K. (2011). Dissimilar Metal Joining of 2024 and 7075 Aluminium Alloys to Titanium Alloys by Friction Stir Welding *, 52(5), 948–952.
[4] Wang, J., Su, J., Mishra, R. S., Xu, R., & Baumann, J. A. (2014). Tool wear mechanisms in friction stir welding of Ti – 6Al – 4V alloy. Wear, 321, 25–32.
[5] Bang, H., Bang, H., Song, H., & Joo, S. (2013). Joint properties of dissimilar Al6061-T6 aluminum alloy / Ti-6%Al-4%V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding. JOURNAL OF MATERIALS&DESIGN.
[6] Squillace, A., & Prisco, U. (2012). Effect of Welding Parameters on Morphology and Mechanical Properties of Ti-6Al-4 V Laser Beam Welded Butt Joints. Journal of Materials Processing Tech., 212(2), 427–436.
[7] Ji, Y., Wu, S., & Zhao, D. (2016). Microstructure and Mechanical Properties of Friction, 1–11.
[8] Sohn.w. (2014). Microstructure and bonding mechanism of Al / Ti bonded joint using Al – 10Si – 1Mg filler metal Microstructure and bonding mechanism of Al / Ti bonded joint using, (August 2003).
[9] Aonuma, M., & Nakata, K. (2012). Dissimilar metal joining of ZK60 magnesium alloy and titanium by friction stir welding. Materials Science & Engineering B, 177(7), 543–548.
[10] Chen, Y. C., & Nakata, K. (2009). Microstructural characterization and mechanical properties in friction stir welding of aluminum and titanium dissimilar alloys. Materials and Design, 30(3), 469–474.
[11] Liu, H. J., Zhou, L., & Liu, Q. W. (2010). Microstructural characteristics and mechanical properties of friction stir welded joints of Ti – 6Al – 4V titanium alloy. Materials and Design, 31(3), 1650–1655.
[12] Bang, H., Bang, H., Song, H., & Joo, S. (2013). Joint properties of dissimilar Al6061-T6 aluminum alloy / Ti – 6 % Al – 4 % V titanium alloy by gas tungsten arc welding assisted hybrid friction stir welding. Materials and Design, 51, 544–551.
[13] Xie, G. M., Ma, Z. Y., & Geng, L. (2008). Effect of microstructural evolution on mechanical properties of friction stir welded ZK60 alloy, 486, 49–55. https://doi.org/10.1016/j.msea.2007.08.043.
[14] Dressler, U., Biallas, G., & Mercado, U. A. (2009). Friction stir welding of titanium alloy TiAl6V4 to aluminium alloy AA2024-T3, 526, 113–117.
[15] Zhang, Y., Sato, Y. S., Kokawa, H., Hwan, S., Park, C., & Hirano, S. (2008). Microstructural characteristics and mechanical properties of Ti – 6Al – 4V friction stir welds, 485, 448–455.
[16] Aonuma, M., & Nakata, K. (2009). Effect of alloying elements on interface microstructure of Mg – Al – Zn magnesium alloys and titanium joint by friction stir welding, 161, 46–49.
[17] Nathan, S. R., Malarvizhi, S., Balasubramanian, V., & Rao, A. G. (2016). Failure analysis of tungsten based tool materials used in friction stir welding of high strength low alloy steels. EFA, 66, 88–98.
[18] Husain Mehdi, R.S. Mishra, Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy- A Review, Journal of Achievements in Materials and Manufacturing Engineering 77/1 (2016) 31-40.
[19] Husain Mehdi, R.S. Mishra, Influences of Process Parameter and Microstructural Studies in Friction Stir Weldingof Different Alloys: A Review, International Journal of Advanced Production and Industrial Engineering, IJAPIE-SI-MM 509 (2017) 55–62.
[20] Mironov, S., Sato, Y. S., & Kokawa, H. (2009). Development of grain structure during friction stir welding of pure titanium. Acta Materialia, 57(15), 4519–4528.
[21] Buffa, G., Fratini, L., Micari, F., & Settineri, L. (2012). Politecnico di Torino Porto Institutional Repository on the Choice of Tool Material in Friction Stir Welding of Titanium Alloys.