Joining of dissimilar aluminium alloys AA2014 T651 and AA6063 T651 by friction stir welding process

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Abstract: - In this work joining of two dissimilar aluminium alloys AA2014 T651 and AA6063 T651 was carried out using friction stir welding. The weld was obtained by varying its tilt angle (2°-4°), tool offset (0.5mm towards AS, centre line, 0.5mm towards Rs) and Pin diameter (5mm – 7mm). Tensile strength & %Elongation was carried out to evaluate the strength of the weld. Optical microscope study was carried out to study the uniform stirring of materials. The result shows that better interlocking and bonding of materials occurs at 4 degree tilt angle. The tensile strength is better when the tool is offset towards AA2014 side because of complete fusion of harder material. When, it is offset towards AA6063 side results in insufficient heat generation on advancing side. This leads to incomplete fusion of AA2014. Pin diameter has greatest impact on heat generation. The 6 mm pin diameter, 4 degree tilt angle and 0.5 mm offset towards advancing side give the optimum tensile strength of 371 MPa.

Key-Words: - Friction Stir Welding, Dissimilar Alloy, Stirring of Materials, Tensile Strength.

1 Introduction

Friction stir welding was invented at the welding institute UK in December 1991. It is solid state joining process in which metal undergoes deformation state and by applying external pressure weld obtains. The process is primarily used on aluminium and by this process the original material properties remains unchanged. In this process the material to be welded is clamped tightly. The friction stir welding consists of pin and the shoulder. The rotating tool which is harder than the material to be welded is rotating at the speed. The tool is tilted for the certain angle and it is plunged until the tool shoulder touches the surface of the material in the centre line of the material that is to be welded. Once it is plunged in the tool is rotated for certain time without any feed for heat generation and this time is called indentation time. Once the feed is given the material gets soften and flow towards the tool rotating direction and welding occurs.

Aluminium alloys AA2014T651 and AA6063T651 is selected for study. AA2014T651 has widely used for aircraft structural application has weldable issues such as hot cracking, voids, precipitates dissolution while welded by fusion welding[1]. Increase in tool rotation speed increases heat generation and increase in welding speed decreases generation of heat, when the heat input is high fracture occurred at heat affected while fracture occurred on weld nugget for low heat input [2]. For dissimilar joints the shifting of tool towards high strength material gives

better weldability [3]. The larger pin diameter stirs more material but in the case of smaller pin diameter the heat input was high, the shoulder contact area decides the frictional heat generation [4,5]. The weld strength decreases when the thickness of the plates increases [6,7]. The harder material should be kept on advancing side [8, 9]. The proper back plate should be provided whose thermal conductivity is lesser than that of the welded material. Using of both threaded and unthreaded tool results in similar stirring action [10].Tool offset towards the higher strength material side increases weld strength [16]. The plunging of rotating tool in lower strength material side results in increased tool life [18]. From literature survey it is revealed that more work had been carried out by varying the various aspect of friction stir welding such as varying rotating speed and feed [15,19], varying the tool position [20,22]. It has been observed that few papers exist on the varying the following combination tilt angle, tool position and tool geometry on dissimilar aluminium alloy. An investigation on Effect of tool position on the fatigue properties of dissimilar 2024-7075 sheets and found that better weld strength obtains when the tool is offset toward harder material side[23]. In present work, various investigation are carried out to find the effect of varying tilt angle, tool geometry and tool position on mechanical and microstructure of dissimilar friction welded joints of AA2014T651 and AA6063T651.

2 Experimental Procedure

The extruded plates of AA2014 and AA6063 of 6mm thickness in T651 condition were friction stir welded in butt joint configuration. The size of the plates was 210mm x 55mm. The chemical composition of the AA6063 and AA2014 is shown in Table1 and Table2. Throughout the experiment AA2014 is kept on the advancing side. The experiments were conducted in vertical end milling machine. The friction stir tool is made of HSS of various pin diameter 5mm, 6mm and 7mm respectively. The friction stir pin length is 5.8mm and diameter of the shoulder is 20mm. the tool has the constant rotational speed of 2000rpm and welding feed of 16mm/min. The tilt angle of the tool was varied between 3 to 5 degrees. The position of the tool is varied form +0.5mm to -0.5mm with respect to the centre line. The tool was rotated in the clock wise direction. The unthreaded tool was plunged at centre line until the shoulder touches the surface of the plate, the indentation time is kept constant i.e. 30sec. and then the tool is moving towards so that weld can obtained. In case of offset the tool is plunged in once after it is positioned.

component	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	Others
Weight %	0.434	0.339	0.0580	0.0290	0.384	0.00790	0.152	0.0120	98.6	Remaining

Table 1. Composition of aluminium alloy AA6063 T651

component	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	Others
Weight %	0.770	0.237	4.43	0.650	0.660	0.0310	0.0480	0.0520	93.1	Remaining

Table 2. Composition of aluminium alloy AA2014 T651

From each joint, a tensile specimen was extracted from the mid length of the joint. ASTM E8M-04 guide lines (gauge length 50 mm, width 12.5 mm, and overall length 200 mm) were followed to prepare the specimen. The tensile strength specimen was prepared by cutting in band saw and then it is milled for obtaining gauge length width. For the microstructure the specimen is polished and etched in Keller's reagent. Microstructure analysis was carried out using a light optical microscope.

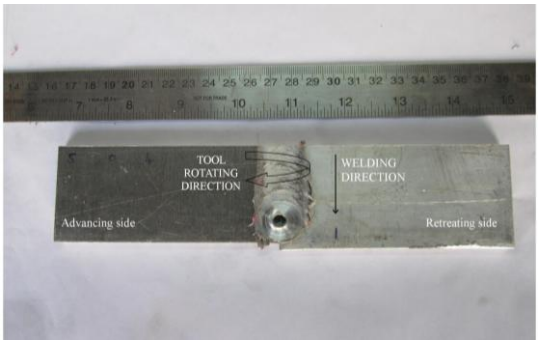

Fig. 1 Friction Stir Welded plates AA2014 & AA6063

3 Results and discussion

3.1 Mechanical properties

Tensile properties of friction stir welded joints were measured by performing tensile tests on transverse tensile samples containing weld nugget zone at the center. The testing is carried out in 1000N universal testing machine

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Exp no	Pin dia (mm) (Ø)	Tool offset (mm) (H)	Inclination (deg) (θ)	Displacement (mm) (Δ)	TS MPa (σ)	%Elongation (δ)
1	5	0	3	4.7	254.34	9.4
2	7	0.5	2	3.2	264	6.4
3	7	-0.5	4	6.3	313.34	12.6
4	7	-0.5	2	9.7	313.34	19.4
5	5	-0.5	2	9.7	305.34	19.4
6	7	0	3	9.5	335.34	19
7	6	0	3	11.2	328	22.4
8	6	-0.5	3	10.9	341.34	21.8
9	6	0	3	10.6	329.34	21.2
10	7	0.5	4	11.2	360	22.4
11	6	0	4	11.2	344	22.4
12	6	0	3	10.4	309.34	20.8
13	6	0	3	10.2	330.67	20.4
14	6	0	2	12	319.34	24
15	5	0.5	2	3.2	259.34	6.4
16	6	0.5	3	11.2	346.67	22.4
17	5	-0.5	4	10.3	126.67	20.6
18	6	0.5	4	11.2	371.34	22.4
19	5	0.5	4	8.5	209.34	17
20	6	0	3	10.8	331.34	21.6

Table 3. Experimental result of tensile strength and % elongation

3.1.1 The effect of pin diameter on the tensile strength of the joint

The pin diameter influences heat generation which has greater impact on the plasticization of material. The pin diameter also accounts for the flow of plasticized material from the advancing side to the retreating side. When shoulder diameter is kept constant, increase in pin diameter is inversely proportional to the heat generation i.e when pin diameter increases amount of heat generated decreases. It is directly proportional to the area of the welded region.

i) For the joints welded at the pin diameter of 5mm, the volume of material stirred is low but the heat generated by the pin is high. This will lead to the turbulent material flow. The distance travelled by the material from advancing side to retreating side is also low which leads to poor bonding of materials. This results in lower tensile strength of welded joints. In such cases failure always occurred at the weld region.

ii) The joints fabricated with the pin diameter of 6mm shows better tensile strength. The pin generates sufficient amount of heat, hence material attains its

deformation state. This enhances uniform flow of material from advancing side to retreating side which results in superior tensile strength.

Fig. 2a Failure occurred at 6063 side.

3.1.2 The effect of tool inclination on the tensile strength of the joint

When the tool rotates due to the centrifugal force the material tries to come up once after it reaches its plasticized state. When tilt angle is provided it refills the material which leads to effective bonding of materials. When the joints are welded with the tilt angle of 2degree the contact between the tool shoulder and plate surface is good that results in better co-efficient of friction.

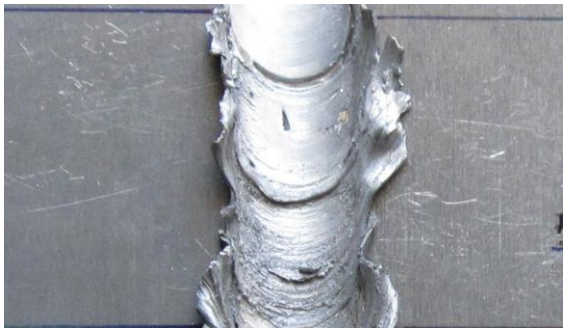

Fig. 2c Skimming of material at lower tilt angle

When tool passes on the material comes out and deposited on either side of the weld zone as shown in fig2c. The joint fabricated with the tilt of 3&4 degrees doesn't show skimming effect as shown in fig 2d. Further increase in tilt angle leads to incomplete fusion because of reduced coefficient of friction.

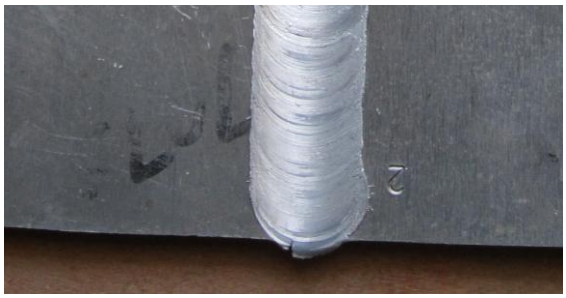

Fig. 2d No skimming of materials at higher tilt angle

iii) For the joints welded at the pin diameter of 7mm, the heat developed by the pin is low and the heat is distributed to large volume of material which leads to incomplete fusion of material.

Fig. 2b Failure occurred at the welded region

3.1.3 The effect of tool offset on the tensile strength of the joint

The material in the advancing side offer more resistance to plastic flow when compared to that of material in the retreating side. When the tool is plunged at the centre line of the weld the heat developed by the pin is equally distributed to the advancing and retreating side. When the tool is plunged 0.5mm distance from centre line towards advancing side, more heat is distributed to advancing side. This results in complete fusion of AA2014 which results in better tensile strength. When the tool is offset towards the retreating side, the tensile strength is comparatively low for all the cases because of the incomplete fusion of the AA2014.

i) The weld strength increases when it is welded by the pin diameter 5mm, tilt angle 2degree and offset towards retreating side compared to the other welds fabricated by 5mm pin dia. This is because heat developed in AA6063 is very high almost above its melting point which results in materials flow freely towards the direction of the rotation tool. Due to insufficient heat generated at advancing side stirring of AA2014 is incomplete. When the tensile test is performed a defect called tunneling occurs and failure occurred towards the direction of the defect as shown in fig2h.
ii) At 7mm pin diameter when the tool is offset towards retreating side a material cluster is formed and travels in the direction

Fig. 2e Failure occurred due to incomplete fusion

Fig. 2g Failure occurred due to tunneling defect

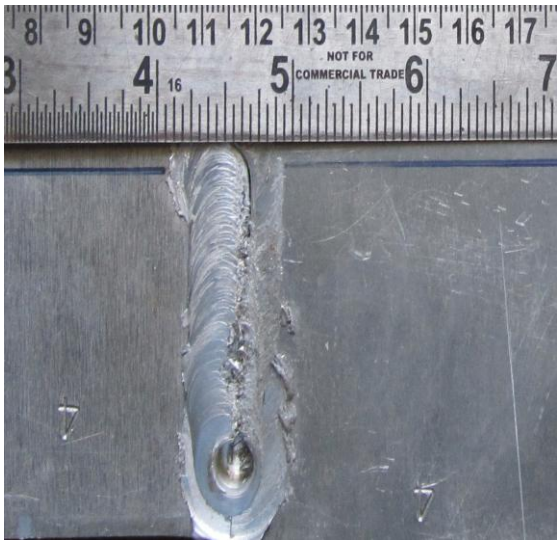

Fig. 2f Incomplete fusion of material

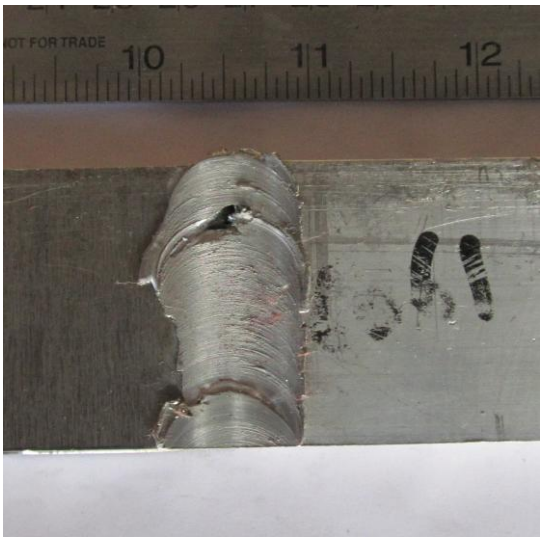

Fig. 2h Tunneling defect

of tool which is the clear evidence of incomplete fusion as shown in fig2f.

iii) When the tool is offset towards the advancing side at 6mm pin diameter, the complete fusion of material occurs that results in the superior tensile properties. When it is offset towards retreating side tensile strength slightly decreases.

Microstructure

The onion layers in the microstructure are because of the flow of materials. It is observed that when the tool is rotated the material flow towards the rotating direction of the tool. When welded at the pin diameter of 5mm, 3degree tilt angle at the centre line of the weld the stirring of materials didn't take place completely due to the insufficient heat generation in the advancing side as shown in fig3a. The breakage occurred at the welded region due to the incomplete fusion of AA 2014 aluminium alloy. When the tool is offset towards advancing side and the angle of inclination is 4degree, most part of the tool was in AA2014 hence heat generated in the advancing side is high. Because of the smaller pin diameter the distance traveled by the material was low results in lower tensile strength. When the tool offset of 0.5mm towards the retreating side at 4degree tilt angle a tunneling is obtained through out weld. The defect is obtained because of incomplete fusion of AA2014 and lesser co-efficient of friction between the material and the tool. For 2degree tilt angle the tensile strength increases. In this case heat generation increased as a result of better co-efficient of friction between material and the tool. When it is welded at the pin diameter of 6mm, 3degree tilt angle at the centre line of the weld, complete stirring of materials takes place, which means sufficient heat generation. While doing tensile strength breakage occurs on the AA6063T651 side. When it is welded at the 6mm, 4degree tilt angle the tensile strength further increases. This is because when the tool rotates, the material attains it deformation state because of its rotary action of the tool the deformed material try to come out. When the tilt angle is low the materials are deposited on the either side of the welded zone which is nothing but the loss of material in the welded zone. If the tilt angle is too high then the surface contact between the tool and the material is low, lower co-efficient of friction

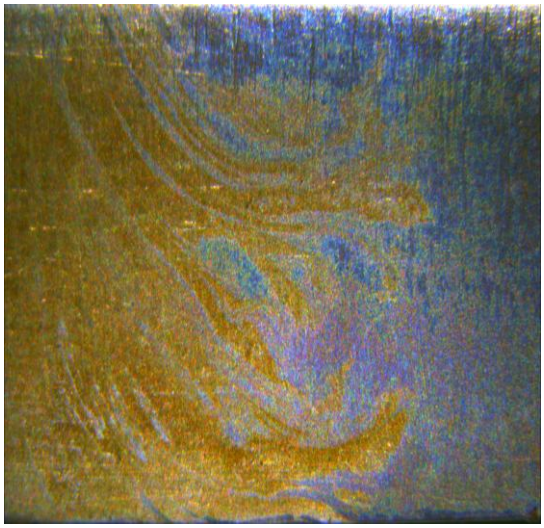

Fig. 3a Microstructure of Parameters
(Pin Diameter 5, Tool offset 0, tilt angle 3)

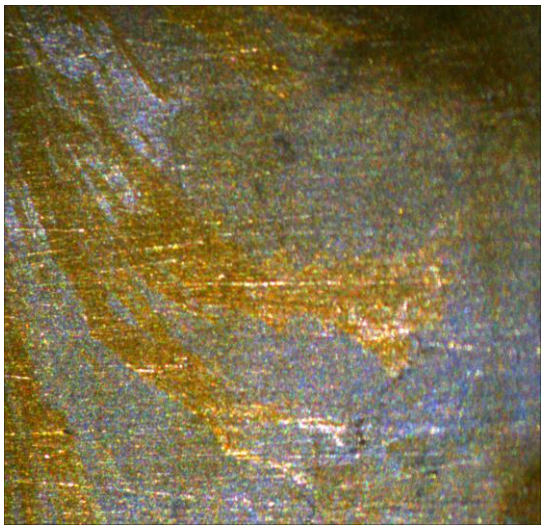

Fig. 3b Microstructure of Parameters
(Pin Diameter 5, Tool offset 0.5, tilt angle 4)

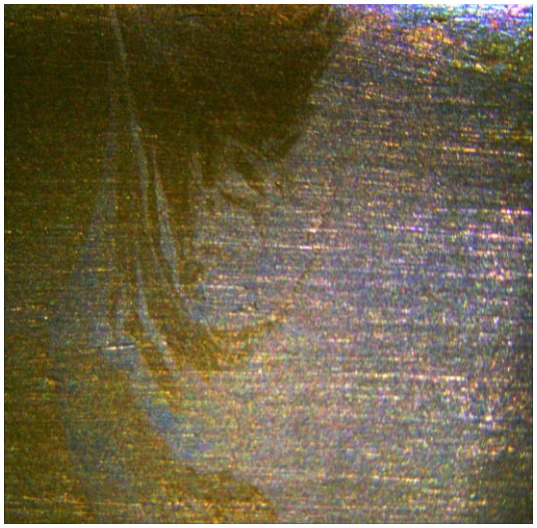

Fig. 3c Microstructure of Parameters
(Pin Diameter 6, Tool offset 0, tilt angle 4)

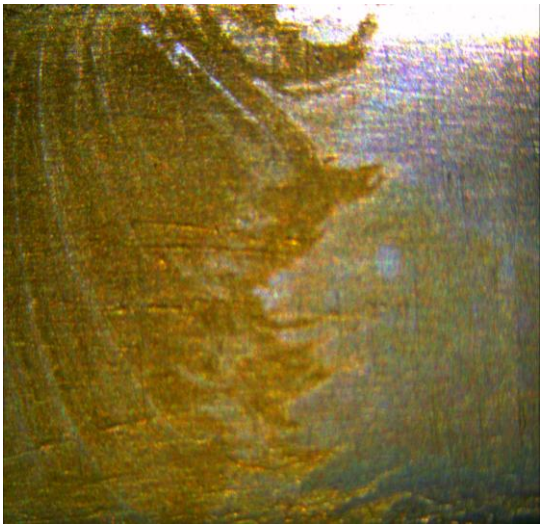

Fig. 3d Microstructure of Parameters
(Pin Diameter 6, Tool offset -0.5, tilt angle 3)

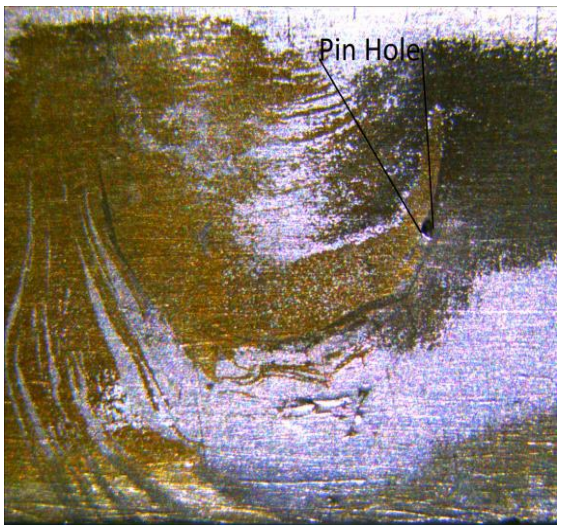

Fig. 3e Microstructure of Parameters
(Pin Diameter 7, Tool offset 0.5, tilt angle 4)

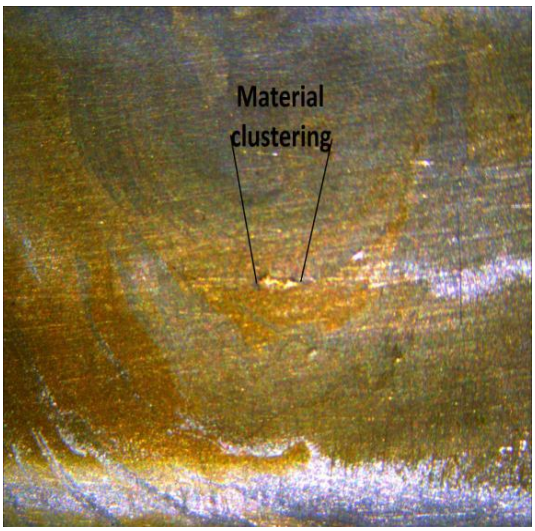

Fig. 3f Microstructure of Parameters
(Pin Diameter 7, Tool offset -0.5, tilt angle 2)

results in lesser heat generation**.** If we provide the tilt angle it interlock the materials and backfills it. So the interlocking of material at the 4degree tilt angle is optimum.

The microstructure reveals that the material had flow till the end. The onion rings was pretty clear so it reveals the complete stirring of materials has obtained. When the offset of 0.5mm towards the AA2014 is given for the tilt angle of 4 degree gives the better tensile strength of all the combined experiments.

When the tool offset is 0.5mm towards the advancing side at 4degree tilt angle, at 7mm pin diameter, pinhole defect was found in the advancing side as shown in fig3e. When the tensile test is performed the failure occurs at the AA6063T651 side. It reveals that better stirring of material. Despite of defect the tensile strength obtain was high because of the reasons, 4degree tilt angle gives the better interlocking and bonding of material and the heat generated was sufficient for the complete fusion of materials. The microstructure also reveals the materials are completely stirred till the end. At 0.5mm offset towards the retreating side at 2degree tilt an island like structure found at the weld region as shown in fig3f. This reveals that incomplete fusion of metal at that particular region.

Conclusion

Aluminum alloy AA2014T651 and AA6063T651 was successfully friction stir weld employing different process parameters. Their influence on mechanical properties of developed joints was investigated. Following conclusion can be drawn from the present work.

1) At Lower Pin Diameter heat generation was high but material stirred region was low. Increasing pin diameter increases welded region. If the pin diameter is too high the heat generation was low results in welding defects such as tunneling defect, pinhole and insufficient fusion of materials.
2) Material skimming occurred when the tilt angle was low. At 4degree tilt angle the material interlocking and refilling rate was high, hence tensile strength increases.
3) When the tool is offset towards advancing side AA2014 alloy completely plasticized because of high heat input on that side, offset of tool towards retreating side results in incomplete fusion of metal because of lesser heat input on harder material i.e. on aluminium alloy AA2014T651.
4) 6mm pin diameter when it is offset towards the advancing side at 4degree tilt angle gives the tensile strength of 371MPa which is 87.7% strength of the base metal.
5) Optimum tensile strength was found when pin diameter is equal to the thickness of the plate. The future work can be done on welding of dissimilar aluminum alloys AA6082 & AA5083 on higher pin diameters.

References:

[1] Chaitanya Sharma, Dheerendra Kumar Dwivedi , Pradeep Kumar, Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of AA7039 aluminum alloy,*Materials and Design* Vol.36 (2012) pp.379–390.

[2] S.Tutunchilar, M. Haghpanahi, M.K. Besharati Givi, P. Asadi, P. Bahemmat, Simulation of material flow in friction stir processing of a cast Al–Si alloy *Materials and Design* Vol.40 (2012) pp.415–426.

[3] Takehiko Watanabe, Hirofumi Takayama, Atsushi Yanagisawa, Joining of aluminum alloy to steel by friction stir welding,*Journal of Materials Processing Technology* Vol.178 (2006) pp.342–349.

[4] S. Rajakumar, C. Muralidharan, V. Balasubramanian, Influence of friction stir welding process and tool parameters on strength properties of AA7075-T6 aluminium alloy joints, *Materials and Design* (2010) article in press.

[5] Y.K.Yousif, K.M.Daws, B.I.Kazem, Prediction of Friction Stir Welding Characteristic Using Neural network , *Jordan Journal of Mechanical and Industrial Engineering* Vol.2 (2008) pp.*151 – 155.*

[6] Y. M. Hwang, P. L. Fan, C . H. Lin, Experimental study on Friction Stir Welding of copper metals, *Journal of Materials Processing Technology* Vol.210 (2010) pp.1667–1672.

[7] Cemal Meran, The joint properties of brass plates by friction stir welding, *Materials and Design* Vol.27 (2006) pp.719–726.

[8] K.L. Harikrishna, J.J.S. Dilip, K. Ramaswamy Choudary, V.V. Subba Rao, S.R. Koteswara Rao, G.D. Janaki Ram, N. Sridhar and G. Madhusudhan Reddy, Friction stir welding of magnesium alloy ZM21,

Transactions of The Indian Institute of Metals Vol. 63, Issue 5, October 2010, pp. 807 – 811.
[9] Hasan Okuyucu , Adem Kurt , Erol Arcaklioglu, Artificial neural network application to the friction stir welding of aluminum plates, *Materials and Design* Vol.28 (2007) pp.78–84.
[10] Olivier Lorraina, Véronique Favier, Hamid Zahrouni, Didier Lawrjaniec, Understanding the material flow path of friction stir welding process using unthreaded tools, *Journal of Materials Processing Technology* Vol.210 (2010) pp.603–609.
[11] K. Surekha, A. Els-Botes, Development of high strength, high conductivity copper by friction stir processing, *Materials and Design* Vol.32 (2011) pp.911–916.
[12] Y.C. Chen, K. Nakata, Effect of tool geometry on microstructure and mechanical properties of friction stir lap welded magnesium alloy and steel, *Materials and Design* Vol.30 (2009) pp.3913–3919.
[13] X. Cao, M. Jahazi, Effect of welding speed on the quality of friction stir welded butt joints of a magnesium alloy, *Materials and Design* Vol.30 (2009) pp.2033–2042P.
[14] Heurtier, M.J. Jones, C. Desrayaud, J.H. Driver,*F. Montheillet, D. Allehaux*, Mechanical and thermal modelling of Friction Stir Welding, *Journal of Materials Processing Technology* Vol.171 (2006) pp.348–357.
[15] Qingfeng Zeng, Jiakui Zu, Litong Zhang, Guanzhong Dai, Designing expert system with artificial neural networks for in situ toughened Si3N4, *Materials and Design* Vol.23 (2002) pp.287-290.
[16] *P. Cavaliere, F. Panella*, Effect of tool position on the fatigue properties of dissimilar 2024-7075 sheets joined by friction stir welding, *Journal of materials processing technology* Vol.206 (2008) pp.249–255.
[17] M.Sarvghad Moghaddam, R.Parvizi, M, Haddad-Sabzevar, A.Davoodi, Microstructural and mechanical properties of friction stir welded Cu–30Zn brass alloy at various feed speeds: Influence of stir bands, *Materials and Design* Vol.32 (2011) pp.2749–2755
[18] Huseyin Uzun, Claudio Dalle Donne , Alberto Argagnotto, Tommaso Ghidini,Carla Gambaro, Friction stir welding of dissimilar Al 6013-T4 To X5CrNi18-10 stainless steel, *Materials and Design* Vol.26 (2005) pp.41–46.
[19] L. Ceschini , I. Boromei , G. Minak , A. Morri , F. Tarterini, Effect of friction stir welding on microstructure, tensile and fatigue properties of the AA7005/10 vol.%Al2O3p composite, *Composites Science and Technology* Vol.67 (2007) pp.605–615.
[20] 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* Vol.40 (2012) pp.7–16.
[21] M. Geigera, F. Micarib, M. Merkleina, L. Fratinib, D. Contornob, A. Gieraa,, D. Stauda, Friction Stir Knead Welding of steel aluminium butt joints, *International Journal of Machine Tools & Manufacture* Vol.48 (2008) pp.515–521.
[22] K.L. Harikrishna, J.J.S. Dilip, K. Ramaswamy Choudary, V.V. Subba Rao4, S.R. Koteswara Rao,G.D. Janaki Ram, N. Sridhar and G. Madhusudhan Reddy, Friction stir welding of magnesium alloy ZM21, *Transactions of The Indian Institute of Metals* Vol. 63, Issue 5, October 2010, pp. 807 – 811
[23] J. A. Esparza, w. C. Davis, e. A. Trillo, l. E. Murr, Friction-stir welding of magnesium alloy az31b, J*ournal of materials science letters* Vol.21, 2002, pp.917– 920.
[24] M. Abbasi Gharacheh, A.H. Kokabi, G.H. Daneshi, B. Shalchi, R. Sarrafi, The influence of the ratio of ‘‘rotational speed/traverse speed’’ (o/v) on mechanical properties of AZ31 friction stir welds, *International Journal of Machine Tools & Manufacture* Vol.46 (2006) pp.1983–1987
[25] M. Ericsson, R. Sandstro m, Influence of welding speed on the fatigue of friction stir welds and comparison with MIG and TIG *International Journal of Fatigue* Vol.25 (2003) pp.1379–1387.