Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

Experimental Study and Optimization of Friction Stir Welding of Dissimilar Aluminum Alloys AA6101- AA1200

[1]S. K. Aditya,
[1] Associate Professor
Mechanical Engineering Department,
NSHM Faculty of Engineering & Technology
Durgapur, West Bengal, India

[3] Dr. N. R. De
[3] Professor
Mechanical Engineering Department,
Dr. B. C. Roy Engineering College,
Durgapur.

Dr. M. C. Majumdar
Professor
Mechanical Engineering Department,
National Institute of Technology,
Durgapur. West Bengal, India

***Abstract*- Friction stir welding (FSW) is a novel solid state welding process in which the weld is completed without molten metal. This is an environment friendly process with high potential and proven method for welding high strength aluminum alloys. Today's manufacturing trend is to achieve the desired properties of material and to reduce the cost of production. Use of low price material and sometime dissimilar alloys are also used for cost reduction. It is very difficult to join dissimilar alloys than joining similar alloys due to the difference of their compositions. The goal of this research work can be broadly stated as to present a systematic approach in Modeling, Characterizing and optimizing the process parameters of friction stir welding for joining dissimilar alloys AA6101/AA1200 and optimizing, using Taguchi method.**

Key words :* *FSW, Aluminum alloys, Tensile strength, Taguchi method,

INTRODUCTION

Friction stir Welding (FSW) is a revolutionary solid state welding technique invented in 1991 at The Welding Institute (TWI). The process operates below the solidus temperature of the metals being joined hence no melting takes place during the process. This process is being used for plate fabrication .Friction Stir Welding is a hot shear joining process in which a non-consumable, rotating tool plunges into a rigidly clamped work-piece and move along the joint to be welded. The cylindrical rotating tool used in FSW has threaded/ unthreaded pin slightly less in length than the weld depth. The operating principle of FSW process is presented below.

Friction Stir Welding Process :

A rotating tool specially designed for the purpose to generate heat and material close to the tool is converted to super plastic nature. Then the tool is moved along the joint interface. The tool usually has a large diameter shoulder and a smaller threaded pin. The rotating tool develops frictional heating causing a thin plasticized zone around the pin and material is transported from front to the rear by a solid state key hole effect. The process is thus characterized by high strain rates and super plasticity near the rotating tool. This paper describe the process, and its effect on the parent metal as well as heat generation and thermal analysis its uses in various fields of engineering.

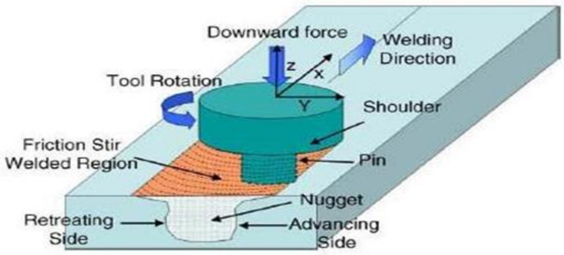


Fig: 1 Schematic diagram of Welding process

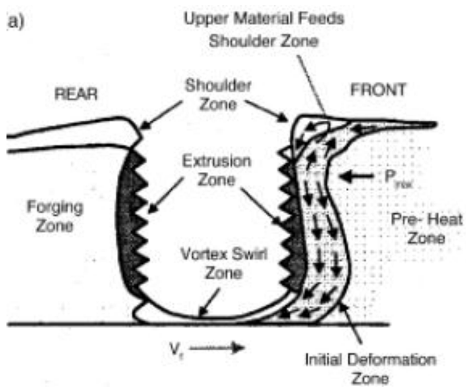


Fig:2 Cross section of Friction stir welding zone

Thermo-mechanical characterization of aluminum and its alloys have been produced over a period of time. Al-Mg-Si alloys (AA6xxx series) present an attractive properties with respect to high strength, welding performance, good corrosion resistance. These alloys are used in aircraft industries, automobile industries etc. Even though lot of research work are being done on several 6XXX grade of material but none explored AA6101 and AA6101/AA1200. Use of low price material and sometime dissimilar alloys are also used for cost reduction. It is very difficult to join dissimilar alloys than joining similar alloys due to the difference of their compositions. Joining of these alloys have very prospective market for Gas cylinders, Battery car body and structures, ladders, trolleys, domestic and office furniture etc. These are generally done by the small entrepreneurs. Further study will prove its applicability in real life. Keeping all these points in mind, the present investigation was carried out.

Chemical Composition:

	Copper	Magnesium	Silicon	Iron max	Manganese	Others Chromium etc.	Solidus temp °C	Liquidus temp °C
AA6101	0.1	0.7	0.5	0.5	0.1	0.1	635	658
AA1200	0.02	-	Si+Fe ≤ 0.8		0.03	-	611	675

Table-1

Mechanical Properties:

	Density gm/cc	Melting point °C	UTS MPa	Yield Strength MPa	Young's modulus GPa	Elongation %	Poisson's Ratio	Specific heat $10^{-6}/^0C$	Conductivity W/mK
AA6101	2.7	635	221	172	75	19	0.33	23	219
AA1200	2.7	621	105	75	68	12	0.25	23	211

Table-2

Experimental Study:

The machine used for friction stir welding was a conventional vertical milling machine which was transformed into a friction stir welding machine by designing a fixture that makes the milling machine capable of performing friction stir welding. The fixture was fitted on the milling machine table to do the friction stir welding. The tool used for welding was designed to fit the taper of the vertical head of the milling machine and clamped rigidly with a nut at the other end. The tool has a shoulder diameter 18 mm and cylindrical probe of 6 mm diameter. Friction stir welding was done by holding the plates to be welded securely in the fixture designed so that the plates stay in place and do not fly away due to the rotation of the tool. The plates were additionally secured with taper wedge to firmly hold the job on the fixture.

The rotational motion of the spindle was started and the tool is then got in contact with the surface of the plates and the probe is plunged at the butt welded zone to a depth so that the shoulder of the tool is firmly in contact with the plate to be welded. The vertical force is applied at predetermined amount. The tool is given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced, this time is called dwell time, and after the dwell time the tool is given forward motion which formed the weld. The tool is withdrawn after the weld is fabricated, the process leaves a hole and the design of the weld is done in such a way that the part with the hole in it is cut and not used for the further processes with the welded plates. Efforts are on the way so that the hole can be avoided at the end.

RESULTS AND DISCUSSION:

Temperature measurements were carried out during the FSW of the AA1200- AA6101-T6 joints. The assumptions regarding the approach of the thermal cycles in the HAZ/TMAZ interface and SZ, as mentioned were also assumed for the AA1200-AA6101-T6 joints, as well as considerations associated with the accuracy of the temperature measurements. The thermal history measured for the dissimilar AA1200- AA6101-T6 joints are shown in the Table -3

Samples	Temperature in Advancing Side °C				Temperature at Retreating Side °C			
	Stir zone	Thermo-mechanical zone	Heat affected zone	Base metal	Stir zone	Thermo-mechanical zone	Heat affected zone	Base metal
DM 1/1	397	292	257	60	392	282	252	50
DM 1/2	393	293	268	67	388	287	258	60
DM 1/3	410	303	275	72	397	277	269	62
DM 2/1	384	297	274	65	380	278	268	62
DM 2/2	398	287	273	67	387	280	268	57
DM 2/3	420	295	288	69	403	289	271	59
DM 3/1	392	294	280	61	384	286	265	54
DM 3/2	393	281	273	73	392	272	261	65
DM 3/3	422	310	277	76	399	298	270	67
Average temperature °C	401.0	294.7	273.9	67.8	391.3	283.2	264.7	59.6

Table- 3

Temperature Distribution on surface of joined plate

The peak temperature measured for the AA6101- T6 joints at different position. It is seen that it took 5 seconds to reach maximum temperature and cooling down to 50^0 C took about 78 seconds. Observation shows that maximum temperature is held at 9 mm from the weld line.

Tensile Test of Dissimilar Al-Alloys AA1200 - AA6101-T6

Transverse tensile specimens were tested in order to determine the tensile properties at room temperature for the dissimilar joints of Al-alloys AA1200 and AA6101-T6 alloy base metals by the FSW process, for different energy inputs applied. Following the same procedure used earlier, specimens are obtained from the butt joined plates of two different base metals along the same direction, with the testing load position transverse to the welding direction and and rolling direction. The tensile properties for the nine welding conditions studied. Test results are given in the following table for both UTS and % elongation.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

AA6101-T6 & AA1200

Force (kN)	Rotational speed (Rpm)	Speed (mm/min)	Tensile strength (Mpa)					Weld Performance	
			Trial 1	Trial 2	Trial 3	Average UTS(Mpa)	% elongation	Strength %	Elongation %
6	250	12	80.15	79.35	79.95	79.55	7.1	75.8	32.3
10	250	18	72.25	74.25	72.63	73.87	11.2	70.4	50.9
14	250	30	85.35	88.15	86.27	87.23	8.9	83.1	40.5
6	400	12	78.14	74.2	76.9	75.44	9.6	71.8	43.6
10	400	18	83.65	84.15	85.23	82.57	12.2	78.6	55.5
14	400	30	72.55	70.2	71.1	71.65	10.5	68.2	47.7
6	660	12	79.35	78.12	80.05	77.42	9.8	76.7	44.5
10	660	18	78.95	82.45	80.05	81.35	10.8	76.7	49.1
14	660	30	76.1	72.25	73.36	74.99	11.3	69.9	51.4

Table- 4

Tensile test results of Dissimilar Aluminum Alloys AA6101 and aa1200

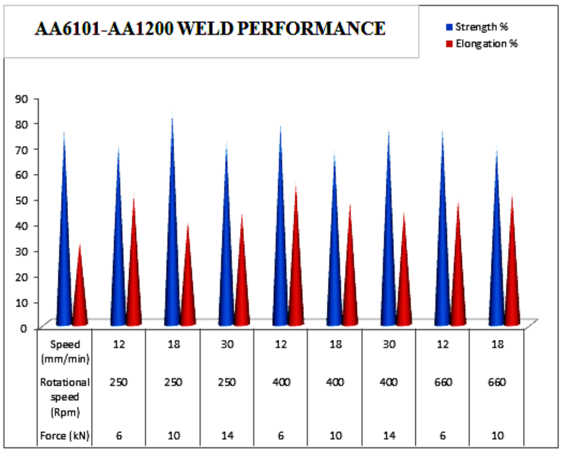


Fig- 3

Weld Performance of Dissimilar Aluminum Alloys AA6101 and AA1200

The results shows that high heat input gives better weld performance. This may be explained as at high heat input the weld interface is more plasticized. At high energy input level amount of strain energy develops at low level due to more plasticity of the material. At low energy input low rpm of the tool is unable to develop sufficient strain energy. This results lower welding efficiency. It is important to remark that fracture occurs in the retreating side and location close to the interface TMAZ/HAZ. The shift in falure location is basically to the stretching of the temperature gradient with the energy inputs. In this way critical temperature field shifts towards the base material AA1200 away from the SZ. In addition, it is reported for a friction stir welding that fracture never occurred close to the original joint line, but mostly near the line where shoulder of the tool had touched the top side of the weld at 45^0 fracture, at the bottom side of the weld.

It also may be noted that UTS is around 78% its base metal of lower strength of material. This may be explained as while welding the AA1200 was placed at the retreating side. Aluminum alloyAA6101 contains 0.7% Mg while AA1200 contains trace amounts of alloying elements. Hence, a study of FSW of these two alloys provides an excellent way to determine the nature of solute transport, which in turn is related to the plastic flow.Concentration profiles of Mg across the weld provides important insight about the nature of plastic flow and mixing of magnesium between the two alloys. The transport and mixing of Magnesium from Mg-rich AA6101 alloy into very low alloy containg AA1200 did not occur in the atomic level and the spatial variation of concentration profile between the two plates. The computed magnesium concentration profile based on its transport by convection and diffusion showed a gradual decrease of Mg in AA6101 to very small concetration in AA1200. Imperfect mixing of plasticized alloys during FSW where the materials seem to move in layers without significant diffusive interlayer mixing.

Hardness Test :

Hardness profiles are determined along the transversal cross section surface of the AA1200 and AA6101 dissimilar FSW joints for different conditions. Hardness measured transverse to the weld direction of dissimilar FSW joints produced with different conditions along three different lines i e near the starting point, middle of the length and lastly near the end point. Hardness also measured on both the sides of the weld i e of AA6101 on advancing side and of AA1200 on retreating side of the weld. The hardness is plotted as shown in the fig- 4 AA6101 & AA1200.

Reatreating Side BHN	Distance from Line of Welding (mm)	Advancing Side BHN
92	3	152
89	8	145
85	13	137
83	18	132
85	23	128
74	28	130
74	33	130
68	38	120
64	43	113
50	48	108

Table-5

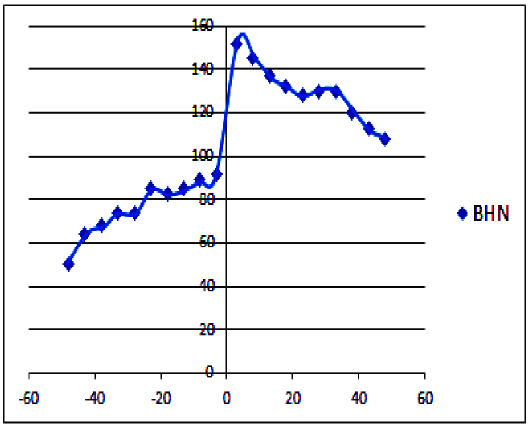


Fig- 4

Hardness distribution across the weld line

Optimization of Process Parameters:

There are quite a few methods for optimization.

1. Taguchi Method,
2. ANOVA Method,
3. Response surface method.

Taguchi & ANOVA methods can be performed best by MINITAB or DOE software.

Every experimenter has to plan and conduct experiments to obtain enough and relevant data so that he can infer the science behind the observed phenomenon. He can do so by,

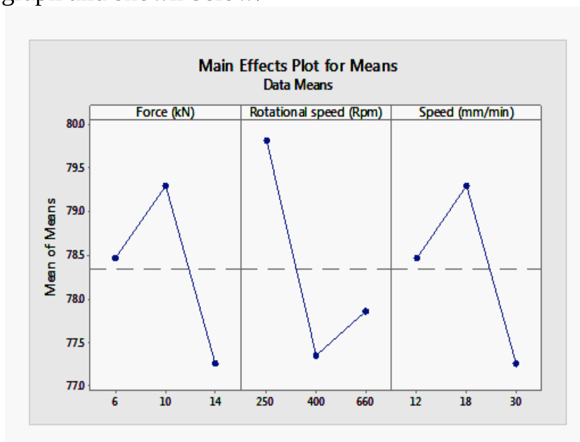
i) Trial-and-error approach:
ii) Design of experiments ;

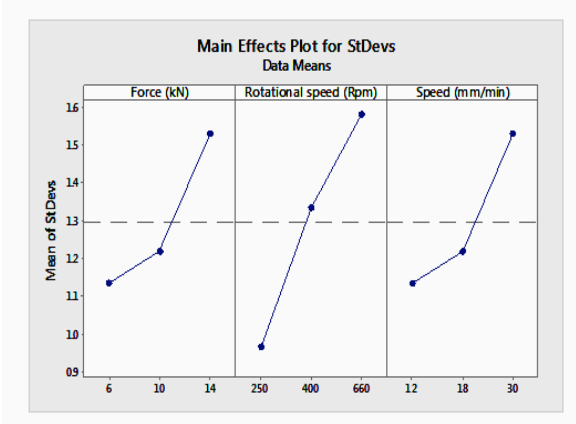
Design of experiments method is used where a well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources required are prohibitively large.

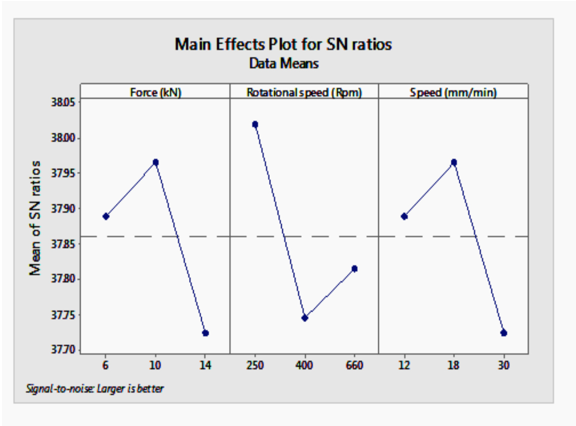
Taguchi Method:-

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY " experiments which gives much reduced " variance " for the experiment with " optimum settings " of control parameters to obtain BEST results. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Taguchi Analysis of Trial 1, Trial 2, Trial 3 versus Rotational speed, Axial Force, Welding Speed are plotted in graph and shown below.







Predictions from Taguchi Analysis for AA-6101 T-6 and AA-1200:-

The Optimum combination of parameters obtained from the main effect plot for the S/N ratio and mean with the best combination at 250 rpm Rotational Speed, 10 KN Axial Force and 18 mm/min Welding Speed and the Optimized Tensile Strength has been predicted as 80.05 MPa.

CONCLUSION:

Different process parameters were applied for welding dissimilar alloy AA6101 and AA1200 which is almost pure Aluminum. The results ie welding strength and % elongation is matching with the performances expected in case of AA6101. It is interesting to find that welding performance of dissimilar alloys are much lower than welding performance of AA6101 and higher than AA1200. During welding this set dissimilar alloys AA6101 is placed on the advancing side and during the process of welding some Magnesium are being transferred to retreading side from the advancing side resulting a Magnesium rich alloy in the retreading side. Due to this phenomenon welding performance is slightly improved than AA1200 on the Retreating side.

REFERENCES:

[1] Babu S. et al : Optimizing FSW parameters to maximize tensile strength of AA2219 Al- alloyjoints. Metals and Materials International, 2009. 15(2) : (pp321- 330)

[2] C. A. Weis Olea. Influence of Energy input in FSW on structure evolution and Mechanical behavior of Precipitation-hardening in Al-alloys (AA2024-T351, AA6013-T6 & Al-Mg-Sc) Institute of Materials research 2008, Geesthacht, Germany (pp 1- 159)

[3] Chao & Qi : Thermal and Thermomechanical modeling of friction stir welding of aluminum alloy6061-T6. Journal of Materials Processing & Manufacturing Science, 7(2): (pp215-233).

[4] Cem C Tutum et al : Optimization of the process parameters for controlling Residual stress & distortion in FSW, Research article, University of Denmark, 2009.(pp1- 4)

[5] Chen and Kovacevic : Finite Element Modeling of friction stir welding – thermal and thermomechanical analysis – Machine Tools and Manufacture, Jun 2003 (p1319-1326)

[6] Chi Hui Chien et al : Optimal FSW process parameters for Al-alloys AA5083, Journal of the Chinese institute of Engineers 2011, (pp1-8)

[7] C.Hamilton et al : Characteristic temperature curves for Al-alloys during Friction stir welding, Welding Journal, 2010, Vol 190, (pp189- 194)

[8] Deepa Reddy Akula**.** Characterization of mechanical properties & study of FSW joints fabricated from similar & dissimilar alloys of Aluminum, Dec 2007, (pp 1-92)

[9] Diogo Marino Neto, Pedro Neto : Numerical modeling of fsw process: a literature review. Research paper of Mechanical Engineering Deptt, University of Coimbra, Portugal, (pp1- 23)

[10] G. Cam et al : Mechanical properties of friction stir butt welded Al 5086- H32 plate, AMME journal vol 32, Issue 2, Oct 2008 (pp 151-156)

[11] Indira et al : A study of process parameters of Friction stir welded AA6061 Al alloy in O and T6 conditions, ARPN journal of Engineering and Applied science, vol 2, no 1, Feb2011, (pp 61- 66)

[12] Jawdat A Al-jarrah et al : Optimization of Friction stir welding parameters for joining of Al-alloys using RSM, Adv. Theor. Appl. Mech.2013 Vol 6, No 1, (pp13- 26)

[13] Jayaraman et al : Optimization of process parameters for friction stir welding of cast aluminum alloy A319 by Taguchi method. Journal of scientific & Industrial research 2009. 68(1) (pp36- 43).

[14] J. Adamowski, M. Szokodo, Friction stir welding of Al-alloy AW6082-T6 : AMME journal vol 20, Issue – 12, Feb 2007 (p 403-406)

[15] Khandekar et al : Prediction of temperature distribution and thermal history during friction stir welding : Input torque based model. Science and Technology of Welding and joining, 2003, 8(3): (pp165-174)

[16] K. Lenin et al : Process parameters optimization for Friction stir welding of Polypropylenematerial using Taguchi method, Journal of scientific & Industrial Research 2014, Vol 73, (pp369- 374)

[17] Kareem N .Salloomi. et al : 3-Dimentional non-linear finite element analysis of both thermal & mechanical response Friction stir welded 2024-T3 Aluminum plate, Journal of Information Engineering & applications, 2013, Vol 3, No 9 (pp6- 11)

[18] Lambda Lab: Characterization of Tensile Residual stresses in 7050-T7651 Aluminum FSW. 2002, cincinnati OH

[19] L.Cederqvist et al : Factors affecting properties of Friction stir welded Aluminum lap joint, Research at University of South Carolina. Colombia S. C. (pp1- 7)

[20] Lakshminarayanan et al : Process parameters optimization for frictionstir welding of RDE40 al-alloy using Taguchi technique. Transactions of nonferrous Metals society of China 2008, 18(3) : (pp548- 554)

[21] L. Karthikeyan et al : Experimental studies of FSW of AA2011 and AA6063 Al alloys, International Journal of Advanced Engineering Technology Dec 2012 (PP1-2)

[22] Liao T. W. et al : Model based optimization of friction stir welding processes. Science and Technology of Welding & Joining, 2009. 14(10): (pp426- 435)

[23] Milan Vukcevic et al :Forces optimization at Friction stir welding process, 16TH International research conference 2012, Dubai, UAE. (pp1- 4)

[24] M. Jayaraman et al : Optimization of process parameters for FSW of cast Al-alloy A 319 by Taguchi method , Journal of scientific & Industrial Research, vol 29, Jan 2009, (pp 36- 43)

[25] M. Jayaraman et al : Effect of process parameters of Tensile strength of Friction stir welded cast LM6 Al-alloy joints, J. Mater. Sci. Technol. Vol 25, no. 5, 2009, (pp 655- 664)

[26] MohamadrejaNoorani et al ; Taguchi optimization of process parameters in Friction stir welding of 6061 Aluminum alloy, A review and Case study, Scientific Research engineering, 2011, 3 (pp144- 155)

[27] M. S. Sidhu et al : Friction stir welding – Process and its variables : A Review, International journal of emerging technology and Advanced Engineering , vol 2, Issue 12, Dec 2012, (pp 275- 279)

[28] N. T. Kumbhar, K. Bhanumurthy. Friction stir welding of Al 6061 alloy : Asian J Exp. Sci. Vol 22, No. 2 (pp 63-74)

[29] N. T. Kumbhar, et al : Friction stir welding of Aluminum alloys, BARC News letter, 2011, Issue 321, (pp 11- 17)

[30] N. Bhanodaya Kiran Babu et al : A review of friction stir welding of AA6061 Al-alloy, ARPN journal of Engineering & applied science, 2011, vol 6 No 4 (pp61- 63)

[31] Okuyucu H. et al : Artificial neural network application to the friction stir welding of aluminum plates, Materials & Design, 2007. 28(1) : (pp78-84)

[32] P. Prasanna et al : Optimization & validation of Process parameters in Friction stir welding on AA6061 Al-alloy using Grey relation analysis, International journal of Engineering research & application 2013, Vol 3 Issue 1, (pp1471- 1481)

[33] R. Palanivel et al : Development of mathematical model to predict the mechanical properties of Friction stir welded AA6351 Al- alloy, Journal of Engineering Science & Technology review 2011, 4 (1) (pp25- 31)

[34] S. G. Dalu et al : Effects of various process parameters of Friction stir welded joints – A Review, International journal of Research in Engineering and Technology , vol 2, Issue 12, 2013. (pp 555- 558)

[35] Samir A. Emam& Ali EiDomiaty. A refined energy based model for Friction stir welding, World academy of science, engineering & technology, 53, 2009.(pp 1-7)

[36] Sang& Sang et al : Liquation cracking of dissimilar aluminum alloys during FSW, Material transactions, Japan Institute of Metals, 2011 vol 52 no 2 (pp54- 57)

[37] S. K. Tiwari et al **:** Friction stir welding of Aluminum alloys : A review, International journal of Mechanical, Aerospace, Industrial & Mechatronics Engineering 2013 , Vol 7 No. 12 (pp1342- 1347)

[38] Soundarajan et al : Thermo-mechanical model with adoptive boundary conditions for friction stir welding of Al 6061. International journal of Machine Tools & Manufacture, 2005. 45(14): (pp1577- 1587)

[39] T. Venugopal, K. SrinivasaRao,K. Prasad Rao. Studies on Friction stir welding of AA7075 Al-alloy, Indian Institute of metallurgy, vol 57, no 6 Dec 2004, (PP 659-663)

[40] V. Balasubramanium et al : Friction stir welding : Environmentally cleaner welding process, Manufacturing EngineeringDeptt , Annamalai University, 2012 (pp1-12)

[41] V. L. Srinivas et al :Parametric analysis of FSW on AA6061 Al-alloy, International journal of Mechanical Engineering & Research, 2013, vol 3 Issue 5, (pp557- 564)