RESEARCHERID
THOMSON REUTERS

[Bhaskara, 6(4): April 2019] ISSN 2348 – 8034
DOI- 10.5281/zenodo.2654634 Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

CHARACTERIZATION OF FRICTION STIR WELD JOINT FOR ALUMINUM ALLOY (AA6061) COATED WITH MG PARTICLES

P. Bhaskara[*1] & V. Venkata Ramana[2]

[*1]Asst. Prof. Dept. of Mechanical Engg., VEMU Institute of Technology, P.Kothakota, Andhra Pradesh, India

[2]Assoc. Prof. Dept. of Mechanical Engg., VEMU Institute of Technology, P.Kothakota, Andhra Pradesh, India

ABSTRACT

Friction stir welding (FSW) is a solid-state welding process which is having broad scope of joining materials which are relatively hard to be welded by fusion welding process. FSW process is highly energy-efficient and eco friendly as compared to the fusion welding. The purpose of this experimental work is to investigate and analyze the mechanical properties like Tensile Strength, Hardness and Impact strength by using Universal Testing Machine, Rockwell Hardness Tester and Charpy Impact Test Machine respectively on butt joint. Friction stir welding operation is performed on Aluminium alloy 6061 coated with magnesium particles. The optimum values were optimized by developing a Taguchi optimization technique .The experimental results have been analyzed by using ANOVA statistical technique to know the effect of process parameters. During this experimental work it is observed that AA 6061 has higher values of Tensile Strength and Hardness due to its strain hardening effect.

Keywords: *Friction Stir Welding (FSW), Aluminium Alloy 6061, Magnesium Particles, ANOVA, & Taguchi method.*

I. INTRODUCTION

Joining of dissimilar materials has been under study since the past decades. Many applications require a combination of different metals to achieve better mechanical and metallurgical properties. The density of Aluminium is 2.7 g/cm^3.The use of Aluminium and steel in a structure can reduce the total weight drastically. These materials can be used for designing various structures for automobile, cryogenic and many other industries [1–4]. Aluminium alloys such as AA6061 possess good formability and light weight. Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing work pieces without melting the work piece material. This process is competent enough to weld materials which are relatively difficult to be welded or almost unweldable by fusion welding (FW) process. The major aspect of this process is that the temperature remains below the solidus temperature, i.e., melting of the material does not take place. As the welding takes place below the solidus temperature, various defects associated with the FW process are not present in FSW. FSW leads to fine grain structure in the stir region due to dynamic recrystallization owing to severe plastic deformation, resulting in substantial micro structural evolution [5-8]. Due to this fine microstructure, good mechanical properties are observed in FSW. The complete information about the process of FSW was explained by many researchers in the past in different publi- cations[8–12].The chemical percentage of AA 6061 is shown in table 1.1.The schematic representation of FSW is shown in figure 1.1.[13]

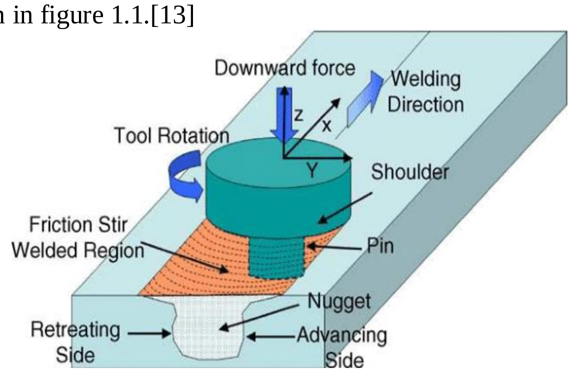


Fig. 1.1: Schematic representation of FSW process

[Bhaskara, 6(4): April 2019] **ISSN 2348 – 8034**
DOI- 10.5281/zenodo.2654634 **Impact Factor- 5.070**

Table1.1: Chemical composition of AA6061 in weight %.

Alloy	**Cu**	**Si**	**Mn**	**Mg**	**Fe**	**Zn**	**Ti**	**Cr**	**Al**
6061	0.15-0.4	0.4-0.8	0.15	0.8-1.2	0.7	0.25	0.15	0.04-0.35	Balance

FSW has been successful in joining many of the commercial aluminium alloys including 1xxx, 2xxx, 3xxx, 5xxx, 6xxx 7xxx, 8xxx and in 3xx and 4xx of cast aluminium alloys. It is also successfully employed in dissimilar welding. It is not only successful in dissimilar combinations of aluminium alloys but also in aluminium - steel, aluminium –copper and aluminium – magnesium alloys.

II. LITERATURE SURVEY

The important aspect of formulating a problem in the research work with clear objective is to have a deep insight into the literature survey. M. A. Tashkandi, J. A. Al-Jarrah, M. Ibrahim[14] it has been reported that the volume fraction of alumina particles incorporated in this study were 2, 4, 6, 8 and 10% were added on both sides of welding line. Hema pothur, Gangadhar S.M. and Ravindranath.K [15], the investigation carried on “Influence of Friction Stir Welding Parameters on the Micro Structural and Mechanical Properties of Aluminium Alloy 6061. Krishnan K.N et al. [16] the solution and ageing treatments to produce high hardness resulted in failure in the bending. P Jagadeesh Chandra Prasad et al. [17] FSW Minimum defects were observed for the highest tool rotation speed. P. Ferro and F. Bonollo [18] Explains the fundamental unknown parameter, under the assumption of sticking between the tool/matrix interface, is the yield shear stress, which is temperature dependent.

III. EXPERIMENTAL SETUP

Then the coating of magnesium particles is done on the welding line of the base aluminium metals that are to be welded. Then the plates were welded by using Friction Stir Butt Welding process with 18 different level combinations of welding parameters. The welded plates are cut to the dimensions to suit Tensile test, Hardness test and SEM analysis by following ASME code book and tests were performed accordingly.

Coating of Mg particles on Al

The magnesium slurry (0.25gm up to 1.5gms) in homogeneous form were mixed with n-methyl pyrrolidine and grinded again in order to increase the cohesiveness or bonding strength of the magnesium particles shown in the figure 3.1.1. Then this mixture is mixed with a chemical bonding agent polyvinylidene fluoride (pvdf) in order to increase the adhesiveness and to stick firmly on to the substrate material shown in the figure 3.1.2.

Figure: 3.1.1 Preparation of Mg slurry

Figure: 3.1.2 Coating of the magnesium slurry on the base metal

Then the coated material is allowed to dry under the solar lamp, until the dry coated layer forms on to the substrate material or base material as shown in the figure 3.1.3.

[Bhaskara, 6(4): April 2019] ISSN 2348 – 8034
DOI- 10.5281/zenodo.2654634 Impact Factor- 5.070

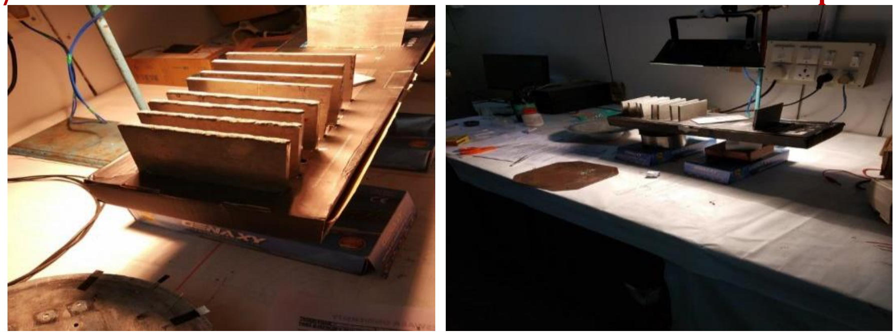


Figure: 3.1.3 drying of the magnesium coating under the solar lamp

The FSW is performed on the vertical milling machine with specifications of 10 Hp, and speed of 3000rpm as shown in figure 3.1.4. The Fixture setup on milling machine is shown in figure 3.1.4.

Fig. 3.1.4: Vertical Milling Machine (Make HMT)

Fig. 3.1.5: Fixture setup on milling machine

Tool Design

A Non-consumable tool of H13 tool steel is used for the joints. The tool is shown in Figure. 3.2.1. The process parameters of Friction stir welding is shown in table 3.2.1

Figure: 3.2.1 FSW circular pin profile

Table: 3.2.1 Main Process Parameters in FSW with their Effects

Parameter	Effects
Tool Rotational Speed	Frictional heat, "stirring", oxide layer breaking and mixing of material.
Welding Speed	Appearance, heat control.
Tool profile	Frictional heat, maintaining contact conditions.

Mechanical testing

Tensile testing

The tensile tests provide information about the materials under uniaxial tensile stresses on the strength in terms of ultimate tensile strength (UTS), yield strength (YS) and ductility in terms of percentage of elongation (% E). This information helps to compare the material and quality of the joint. The tensile specimens are machined to a standard dimension as per the standard from the selected portions of the welded part as shown in Figure 3.6. The results of the tensile tests may not represent the strength and ductility properties of the entire product or its service behavior under different environments but are accepted as satisfactory under standard testing conditions. The tensile tests are evaluated for each welding condition. The tensile tests are conducted for two set of welding conditions. The Universal Testing Machine (UTM) is shown in figure 3.3.1.1.

Figure: 3.3.1.1Universal Testing Machine (TUE-C-200)

Specimen Preparation

The testing procedure involves Hardness test and Impact test accordingly the specimen is prepared as shown in the figure 3.3.2.1. The figure below shows a typical Tensile Test specimen. Tensile testing of butt welds has been the major method used for evaluating strength of FSB welds in literature. This test method was adopted in this study. Test samples, 20 mm wide, perpendicular to the welding direction were machined from the weld plates.

ISSN 2348 – 8034
Impact Factor- 5.070

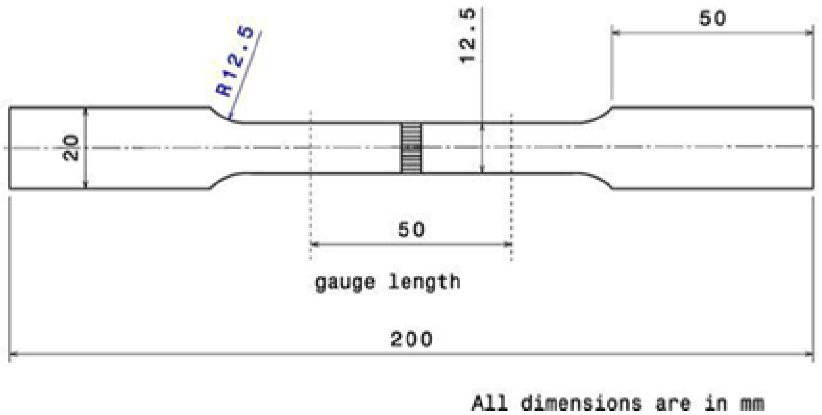


Figure: 3.3.2.1Test Specimen

The specimen was prepared by cutting the base metal sheet of dimensions 100mm x 100mm x6.00mm by using wire EDM. The methodology for joint considered in FSW process consist 6061 Al Alloy of 6.00mm thickness plates (100mm x 100 mm) length plate are prepared for the similar joint configuration is shown in Figure 3.3.2.2. The tool made of H13 has Cylindrical Pin with flat shoulder was used to fabricate the joints. The initial joint configuration was obtained by securing plates in position using proper clamps. Based on the literature coupled with availability of speeds on the machine, three different Tool Rotational Speeds and Welding Speeds and with and without magnesium were selected to carry out the experiment. Then the testing of the specimen enhanced to evaluate the impact strength by conducting impact test on Charpy impact testing machine as shown in the figure 3.3.2.3.Testing of specimen for tensile test on UTM illustrated in figure 3.3.2.4.The figure 3.3.2.5(a) and figure 3.3.2.5(b) show the specimen before testing and after testing.

Figure: 3.3.2.2Welded Specimen

Figure: 3.3.2.3 Charpy impact testing machine

RESEARCHERID
THOMSON REUTERS

[Bhaskara, 6(4): April 2019]
DOI- 10.5281/zenodo.2654634

ISSN 2348 – 8034
Impact Factor- 5.070

Figure: 3.3.2.4: Testing of Specimen in UTM

Figure: 3.3.2.5 (a & b): specimen before & after testing

IV. RESULTS AND DISCUSSION

The below table 4.1 shows the experimental results for Tensile test, Hardness test and impact test of AA6061.

Table: 4.1 Experimental Results of Tensile strength, hardness and impact test of AA6061

S No	Magnesium	Speed (Rpm)	Feed (Mm/Min)	Tensile Strength (N/Mm2)	Hardness	Impact Strength (Joules)
1	0.25	1000	40	95.008	63.2	2
2	0.25	1200	50	83.14	63.8	4
3	0.25	1400	60	71.192	64.9	2
4	0.5	1000	40	91.32	59.9	2.5
5	0.5	1200	50	73.96	61.0	2
6	0.5	1400	60	75.93	62.8	4
7	0.75	1200	40	68.96	63.1	4.5
8	0.75	1400	50	70.43	63.5	3
9	0.75	1000	60	66.93	62.4	2.5
10	1	1400	40	78.13	62.1	4.5
11	1	1000	50	67.39	61.3	3
12	1	1200	60	70.62	60.2	3
13	1.25	1200	40	75.36	61.9	4
14	1.25	1400	50	71.05	63.4	3
15	1.25	1000	60	19.19	62.0	2.5
16	1.5	1400	40	89.52	61.9	4
17	1.5	1000	50	22.34	64.2	2.5
18	1.5	1200	60	25.53	63.2	2

ANOVA Analysis

ANOVA is employed to optimize the Tensile Strength, Hardness and Impact strength of the AA6061 material for Friction Stir Butt Welding. The testing results were analyzed with their presses parameter individually. The tables4.2 given below shows the process parameters and their design levels. These values are considered for carrying the project work, such as Tool Rotational Speed (N), Welding Speed (F) and with and without Magnesium, different joint profiles.

ISSN 2348 – 8034
Impact Factor- 5.070

Table: 4.2 Process Parameters and their design levels used in FSBW

Process Parameters	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Tool Rotational	1000	1200	1400			
Welding Speed	40	50	60			
Magnesium in gms	0.25	0.5	0.75	1	1.25	1.5

From the experiment it can be concluded that experiment number 1is having highest tensile strength the parameters are with 0.25gm of magnesium, speed 1000 rpm, feed 40mm/min. From the above graph we can say that by adding magnesium particles to the weld pool, the tensile strength of weld join is increased. ANOVA results for Tensile test, Hardness test & Impact test are shown in tables 4.3,4.4 and 4.5 respectively. And the S/N Ratio of Tensile test , hardness and impact test are shown in the graph 4.1,4.2 & 4.3 respectively.

Table: 4.3 ANOVA Results of tensile Strength for AA 6061

Factor	Degrees of Freedom DOF	Sum of Squares SS	Mean Squares MS	Percentage of Contribution
Mg	5	3164.6	632.9	37.1
Speed	2	2449.9	1224.9	28.7
Feed	2	752.6	376.3	8.8
Error	8	2155.8	269.5	
Total	17	8522.9	-----	

From the Table 4.3, the Percentage of Contribution values for Magnesium in gms (37.1%), Tool Rotational Speed (28.7%), Welding Speed (8.8%) is obtained. It is observed that the with Magnesium coating have great influence. Since this analysis is a parameter-based optimization design, from the above values with Magnesium coating is the Major Factor to be selected effectively to get the good Tensile strength.

Table: 4.4 ANOVA Results of Hardness for AA6061

Factor	Degrees of Freedom DOF	Sum of Squares SS	Mean Squares MS	Percentage of Contribution
Mg	5	45.73	9.147	28.93
Speed (rpm)	2	16.99	8.405	10.75
Feed	2	27.61	13.807	17.47
Error	8	67.70	8.463	
Total	17	158.04		

From the ANOVA Table 4.4, the Percentage of Contribution values for With Magnesium (28.93%) Tool Rotational Speed (10.75%), Welding Speed (17.47%) is obtained. It is observed that the Magnesium in gms have great influence on Hardness. Since this analysis is a parameter-based optimization design, from the above values Magnesium in gms is the Major Factor to be selected effectively to get the good Hardness.

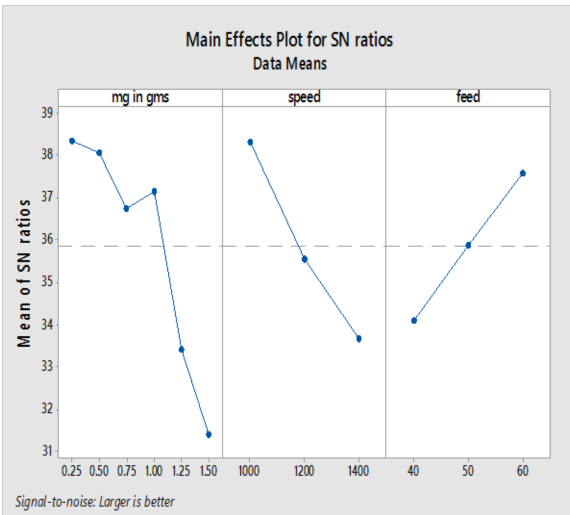
Table: 4.5 ANOVA Results of Impact strength for AA6061

Factor	Degrees of Freedom DOF	Sum of Squares SS	Mean Squares MS	Percentage of Contribution
Mg	5	1.611	0.322	11.98
Speed	2	2.694	1.3472	20.38
Feed	2	2.861	1.4306	21.28

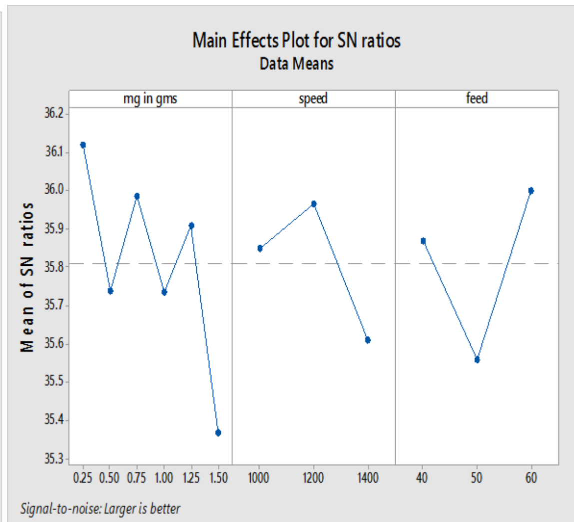
 ISSN 2348 – 8034
Impact Factor- 5.070

Error	8	6.278	0.7847	
Total	17	13.444		

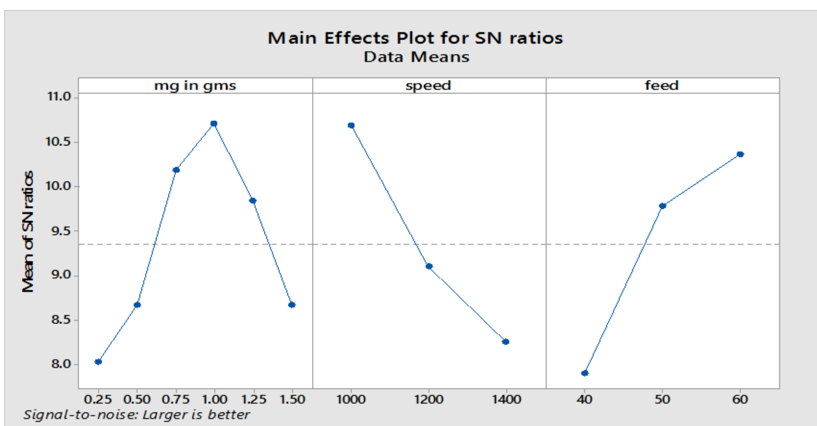
From the ANOVA Table 5.6, the Percentage of Contribution values for Magnesium in gms(11.98%) Tool Rotational Speed (20.38%), Welding Speed (21.28%) is obtained. It is observed that the Welding speed have great influence on Impact strength. Since this analysis is a parameter-based optimization design, from the above values Welding speed is the Major Factor to be selected effectively to get the good Hardness.



Graph: 4.1S/N ratios for Tensile strength of AA 6061



Graph: 4.2 S/N ratios for Hardness of AA 6061



Graph: 4.3 S/N ratios for Impact Strength of AA 6061

The aim is to identify the most influencing significant parameters and percentage contribution of each parameter on responses of FSBW joints by conducting minimum number of experiments using TAGUCHI.

SEM Analysis

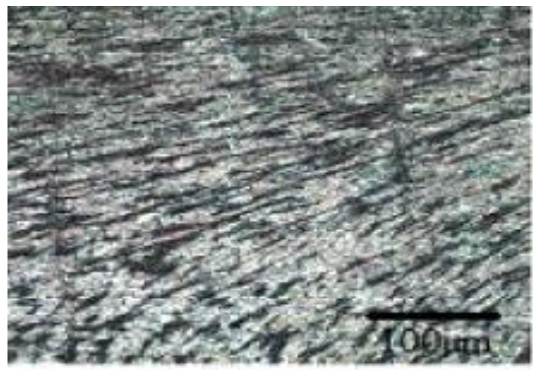
A scanning electron microscope (SEM) analysis is carried during this work in order to observe the Specimen high vacuum in conventional SEM or in low vacuum or wet conditions in variable pressure or environmental SEM and at a wide range of cryogenic or elevated temperatures with specialized instruments. The images captured of the specimen at different speed and feed parameters are shown in figures in figure 4.2.1.

[Bhaskara, 6(4): April 2019] ISSN 2348 – 8034
DOI- 10.5281/zenodo.2654634 Impact Factor- 5.070

(a) Micro structure
(0.25gm of mg, 40 mm/min Feed, 1000 RPM)

(b) Microstructure
(0.5 gm of mg, 60 mm/min Feed, 1400 RPM)

(c) Microstructure
(1gm of mg, 60 mm/min Feed, 1200 RPM)



(d) Microstructure
(1.5gm of mg, 40 mm/min Feed, 1000)

Figure: 4.2.1 Scanning Electron Microscope Images

V. CONCLUSIONS

The present work, friction stir Butt welding was conducted to join AA 6061. The Analysis of Taguchi for orthogonal array shows that, for the Tensile Strength, Magnesium is most influence parameter while the Feed (welding speed) is the least influence parameter. The remaining parameters have a moderate effect. For Hardness, Magnesium is highly influenced while speed least influence. The remaining parameters have a moderate effect. For Impact strength, the high influenced parameter is feed and least influence parameter is Magnesium by weight and also concluded that magnesium coating along the weld line has a great influence in the joint strength of friction stir welding. It was observed that at first as the percentage of magnesium is increased the tensile strength is decreased, this is because it requires more heat input in order to completely stir the magnesium particles along with the aluminium base metal (alloying).The complete alloying of Magnesium coating with the aluminium base metal was happening due to the higher heat input. AA 6061 has higher values of Tensile Strength and Hardness due to its strain hardening effect and magnesium particles on AA6061.With the increase of Tool Rotation Speed, the Hardness increases first and then decreases, but as the Welding Speed increases, the Hardness also increases with the addition of magnesium. With the increase of Tool Rotation Speed, the Impact strength decreases first and then increases, but as the Welding Speed increases and at lower feed, due to the higher heat input the impact strength increases even with the increase in the weight of magnesium.

REFERENCES

1. Song KH, Chung YD, Nakata K. Investigation of microstructure and mechanical properties of friction stir lap jointed Monel 400 and Inconel 600.Met Mater Int 2013;19:571–6.
2. Chen C, Kovacevic R. Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding. Int J Mach Tools Manuf 2004(44):1205–14.
3. Kusuda Y. Honda develops robotized FSW technology to weld steel and aluminum and applied it to a mass-production vehicle. Ind Robot An Int J 2013;40:208–12.
4. Haghshenas M, Abdel-Gwad A, Omran AM, Gökçe B, Sahraeinejad S, et al. Friction stir weld assisted diffusion bonding of 5754 aluminum alloy to coated high strength steels. Mater Des 2014;55:442–9.
5. RHODES C G, MAHONEY M W, BINGEL W H, SPURLING R A, BAMPTON C C. Effects of riction stir welding on microstructure of 7075 aluminum [J]. Scripta Materialia, 1997, 36(1): 69-75.
6. ZHAO J, JIANG F, JIAN H G, WEN K, JIANG L, CHEN X B. Comparative investigation of tungsten inert gas and friction stir welding characteristics of Al-Mg-Sc alloy plates [J]. Materials and Design, 2010, 31: 306-311.
7. CAVALIERE P, CABIBBO M, PANELLA F, SQUILLACE A. 2198 Al-Li plates jointed by friction stir welding: Mechanical and microstructural behaviour [J]. Materials and Design, 2009, 30: 3622-3631.
8. THOMAS W M, NICHOLAS E D. Friction stir welding for the transportation industries [J]. Materials and Design, 1997, 18: 269-273.
9. Esparza , W.C. Davis , L.E. Murr , J. Mater. Sci. Mater. Electron. 38 (2003) 941–952 .
10. H.J. Zhang , H.J. Liu , L. Yu , Mater. Des. 32 (2011) 4402–4407 .
11. J.A. Esparza , W.C. Davis , E.A. Trillo , L.E. Murr , J. Mater. Sci. Lett. 21 (2002) 917–920 .
12. Y. Zhao , Q. Wang , H. Chen , K. Yan , Mater. Des. 56 (2014) 725–730 .
13. Umasankar das,Rathnesh kumar,vijay toppo "effect of process parameters on mechanical properties of friction stir welded joint of two dissimilar Al- Alloys" international journal of technical research.- v4(08)-Aug 2015.
14. M. A. Tashkandi, J. A. Al-Jarrah, M. Ibrahim "increasing mechanical properties of friction stir welded joints of 6061 aluminum alloy by introducing alumina particals''.
15. Hema pothur,Gangadhar S.M. and Ravindranath.K(2012) "Influence Of Friction Stir Welding Parameters on The Micro Structural And Mechanical Properties Of Aluminum Alloy 6061'',.International Journal Of Applied Engineering Research. Vol 7, no.8(2012) Pp. (907-916).
16. Krishnan K.N(2002) on the formation of onion rings in friction stir welds, Material Science and Engineering, Vol.327, pp (246-251).
17. P Jagadeesh Chandra Prasad1, P Hema2 and K Ravindranath3- "Optimization of Process Parameters for Friction Stir Welding of Aluminum Alloy Aa6061 Using Square Pin Profile", International Journal for Mechanical Engineering Volume 3, Issue No. 2, April-2014.
18. P. Ferro And F. Bonollo, "A Semi Analytical Thermal Model for Fiction Stir Welding".
19. H. Bidasi, M. Tour, A. Tavakoli "The influence of process parameters on microstructure and mechanical properties of friction stir welded Al 5083 Alloy Lap Joint" in American Journal of Material Science 2011.
20. L. E. Murr, G. Liu, J. C. Mcclure "Dynamic recrystallization in friction-stir welding of aluminium alloy 1100, Journal of materials science letters 16 (1997) 1801-1803". Gene Mathers, "The welding of Aluminum and its alloys", 2002.
21. Koilraj et al (2012) optimized FSW process with respect to tensile strength of the dissimilar welds AA2219 and AA5083 using five different tool profiles.
22. Ali, M.W. Brown, C.A. Rodopoulos, and S. Gardiner, "Characterization of 2024-T351 Friction Stir Welding Joints".
23. Takao Okada & Masako Suzuki &Haruka Miyake & Toshiya Nakamura & Shigeru Machida &Motoo Asakawa, "Evaluation of crack nucleation site and mechanical properties for friction stir welded butt joint in 2024-T3 aluminum alloy".
24. M. Garware, G.T. Kridli, and P.K. Mallick "Tensile and Fatigue Behavior of Friction-Stir Welded Tailor-Welded Blank of Aluminum Alloy 5754"