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Process Optimization of Preheated Friction Stir Welded Ferrous and Non-Ferrous Materials

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Abstract:- Joining of Ferrous and Non-Ferrous materials, such as aluminum and steel alloys is very challenging which requires the efficient and economic processes. The Al/Steel combination have wide range of industrial application especially in automotive sector looking for lightweight materials and provides good strength. As we know aluminum and steel alloys have different metallurgical properties it is quite difficult to join them with fusion welding methods. Friction Stir Welding (FSW) process (also referred as green joining technology) is most suitable technology to join dissimilar materials like Al/Steel, which was developed way back in 1991 by The Welding Institute (TWI). Earlier FSW was used to join softer material such as aluminum alloys and the process has been expanded to weld the materials having higher strength. To join high strength materials large forces are required, due to this tool wear have become major issue. To resolve this issue, an additional heating source is introduced in front of the Friction Stir Welding tool which softens the base material to be welded and reduces the load on tool hence no mimized tool wear. Present work focused to join Ferrous and Non-Ferrous materials like A6082-T6 and Steel and evaluate the effect of parameters considered on tensile strength. Taguchi parametric design approach was used to determine process parameters, post welding the results are analyzed by using ANOVA statistical tools. The best welding quality is found out by comparing the result obtained from tensile testing showed that due to preheating of base metal, increase in material flow and quality of the weld.

Keywords:- Friction Stir Welding; Ferrous/Non-Ferrous Materials; Preheating; Optimization; SEM.

I. INTRODUCTION

The current industrial requirements are joining of dissimilar materials which have numerous industrial applications. This lead to the development of latest joining techniques capable to join dissimilar materials like aluminum and steel, which are among the most significant materials that are finding applications on the various industries from the miniature assemblies to extremely large earth-moving vehicles, more viable and sustainable products.

However, there are a certain number of methods to join these dissimilar metals but no one could establish a reliable or a sort of credible welding method for the industrial applications while quality, cost, human resources and facilities are taken into the main considerations.

As many of the metals, there are still many unsolved problems in the joining of different alloys which basically have different thermal and mechanical properties. The sound joint is the highest concern through the design of the parts especially for such places where the quality of the joints has more priority than other concerns.

It is assumed that the new replacement of the light materials is that it will help to reduce the fuel consumption, production cost and effectively reduces the amount of human-elemental energies on the heavier materials. For instance, the use of the aluminum/steel alloys and finding the surrogating material for some of the sensitive components is relatively influenced by the controlling forces like current regulations to encounter fuel efficiency standards by decreasing vehicle weight [1, 2].

There are, however, numbers of works on the application of different welding technologies to bond dissimilar alloys but the problem of losing the strength in the bond areas is always a big challenge because of the formation of the brittle intermetallics has not been solved [3,4].

Subsidiary precipitates created during solidification, different thermal properties, dissimilar thermal expansion, heat capacity and thermal conductivity, large difference between the melting points (around 650 °C for Al alloy and 1457 °C for steel) and nearly zero solid solubility of iron in aluminum are creating the large discrepancy between the metals leading to the reduction of the mechanical properties after the joining processes. Laser roll bonding [5], impact welding [6], friction welding [7], ultrasonic welding [8], diffusion bonding [9], explosive welding [10], laser brazing/welding [12, 13], magnetic pulse welding [14] and laser pulse welding [15, 16] are the typical welding processes that have been applied up to now to join different grades of the steels to the aluminum alloys.

In the present work Friction stir welding of A6082-T6 and Mild Steel plates with accepted strength is studied with the help of preheating. Steel plate is preheated to 100^{o}C, 150^{o}C and 200^o C before friction stir welding. Preheating improve mechanical properties such as tensile strength, cooling rate and residual stress. From the investigation it is found that preheating of base metals before welding will reduces the load on tool and tool wear. Also helps better mixing of the alloys at joint interface, which helps to get good joint strength. Optimizing the process will help to get best combination of parameters to achieve required objective.

II. LITERATURE REFERENCES

Watanabe and K. Kimapong [17] investigated Friction Stir Welding of Aluminum Alloy with Mild Steel plate. This study investigated the effects of pin rotation speed, position of the pin axis, and pin diameter on the tensile strength and microstructure of the joint. The main results obtained are as follows: Butt-joint welding of an aluminum alloy plate to a steel plate was easily and successfully achieved. Many fragments of the steel were scattered in the aluminum alloy matrix, and fracture tended to occur along the interface between the fragment and the aluminum matrix. A small amount of intermetallic compounds was formed at the upper part of the steel/aluminum interface, while no intermetallic compounds were observed in the middle and bottom regions of the interface. A small amount of intermetallic compound was also often formed at the interface between the steel fragments and the aluminum matrix.

M. Merklein et. al. [18] mentioned it is difficult to join steel-aluminium, since intermetallic phases appear during welding. Because of these phases joint may fail due to load. Laser assistance for preheated friction stir welding of steel is adapted in order to enhance the weldability as well as the welding feed and to reduce the wear at the tool.

Antonio José Ramirez Londoño et. al. [19] studied dissimilar joining of 2 mm thick butt joint involving AISI 1020 mild steel and aluminum alloy 6063-T6. To understand the effect of welding parameters on the joint microstructural evolution and mechanical performance of such welded joint.

Avinash S. et. al. [20] carried out a review on Optimization of Process Parameters by using Taguchi experiment design technique for maximizing tensile strength of friction welding Al (6061) and steel 304.An orthogonal array of L9 was; Using ANOVA and signal to noise ratio of robust design, effect of tensile strength of friction welding process parameter (Rotational speed, forging force, time) is evaluated and optimum welding condition for maximizing tensile strength is determined. Sundaravel Vijayan et. al. [21] Carried research on Multi objective Optimization of Friction Stir Welding Process Parameters on Aluminum Alloy AA 5083 Using Taguchi-Based Grey Relation Analysis. The L9 orthogonal array of Taguchi experimental design is used for optimizing the FSW process parameters on tensile strength of FSW welds and total input power required for the process.

Elena Scutelnicu. et. al. [22] studies shows that adding additional source of heat to preheat base metal provides added advantages such as quick and better plastic deformation of base material, also minimized tool failure and quality of weld would be better.

Maulik kumar Patel. et. al. [23] studied, Friction stir welding of Al 6061T-6 plate with accepted strength is studied with the help of preheating heat source of the al 6061 T-6 plate. Al 6061 T-6 plate is preheated to 100^{o}C, 125^{o}C and150^{o} C before friction stir welding. Preheating of friction stir welding joints is welded completely without any un-welded zone resulting from smooth material flow by equally distributed temperature in two sides of Al plates. Preheating improve mechanical properties such as tensile strength, cooling rate and residual stress. Preheating in friction stir welding help to improve welding speed, penetration depth, heat affected zone.

III. METHODOLOGY

A. Design of Experiment

The process parameters identified for the investigations are shown in Table I such as Preheating Temperature, Tool Rotation Speed and Tool Travel Speed. This is the design of experiment by which the present work has been carried out. Table II gives Friction Stir Welding tool details

Sl. No.	Process Parameters			
1	Tool Rotational Speed (rpm)	1000	1400	2000
2	Tool Travel Speed (mm/min)	16	20	25
3	Preheating Temperature (°C)	100	150	200

TABLE I. FSW PROCESS PARAMETER

Tool Material	Tungsten-Carbide
Pin Profile	Cylindrical Tapered
Shoulder Diameter	20 mm
Pin Top Diameter	5 mm
Pin Bottom Diameter	3 mm
Pin Length	3.4 mm
Shoulder Length	30 mm

TABLE II. FRICTION STIR WELDING TOOL DETAILS

B. Taguchi's Method

Taguchi approach attempts to extract maximum important information with minimum number of experiments. Taguchi techniques are experimental design optimization techniques which use standard Orthogonal Arrays (OA) for forming a matrix of experiments. Using an OA to design the experiment helps the designer to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way. OA's allow screening out few important main effects from the many less important ones.

In the present work operating parameters, each at three levels are selected to evaluate strength of the joint are mentioned in Table III. Based on Taguchi method, the L27-OA was constructed. The reason for using L27-OA is to evaluate the significance of interaction terms. Interaction means the influence of an operating variable on the effect of other operating variable.

C. Anova Analysis

Analysis of Variance (ANOVA) is a statistical method which is used to discuss the relative importance of the entire control factor. They are also used to find the contribution of each parameter. F-test proposed by Fisher is used as an auxiliary tool of inspection. Thus, the larger the value of f-test the more dominant the parameters are.

D. S/N Ratio

Taguchi also recommended to analyse the values using S/N ratio. It involves conceptual approach which graphs the effect and identifies the significant values.

L^{27} Array	Variable/levels x_1	x_2	x_3	Tensile Test (MPa)	SN Ratio
1	16	1000	100°	208.02	46.2902
2	16	1000	150°	214.60	47.3831
3	16	1000	200°	228.01	46.97762
4	16	1400	100°	227.65	47.15601
5	16	1400	150°	264.64	47.42072
6	16	1400	200°	245.60	47.15853
7	16	2000	100°	234.02	48.12907
8	16	2000	150°	274.32	48.76485
9	16	2000	200°	223.31	46.99108
10	20	1000	100°	207.23	46.33292
11	20	1000	150°	213.65	46.97762
12	20	1000	200°	224.65	47.15601
13	20	1400	100°	223.34	47.80541
14	20	1400	150°	245.60	48.45085
15	20	1400	200°	228.00	46.97762
16	20	2000	100°	224.56	47.38310
17	20	2000	150°	255.01	48.16890
18	20	2000	200°	213.66	46.36100
19	25	1000	100°	204.33	46.27643
20	25	1000	150°	208.02	46.58302
21	25	1000	200°	215.33	46.36461
22	25	1400	100°	208.03	47.14601
23	25	1400	150°	235.02	47.81541
24	25	1400	200°	224.63	47.02868
25	25	2000	100°	223.31	47.40804
26	25	2000	150°	253.35	48.12807
27	25	2000	200°	207.34	46.32291

TABLE III. SHOWS THE DIFFERENT EXPERIMENTS CONDUCTED BASED ON TAGUCHI'S L27 ORTHOGONAL ARRAY AND TEST RESULTS.

IV. EXPERIMENTAL PROCEDURE

Following are the processes carried out during Friction Stir Welding:

A. Cutting

The required base metals Aluminum alloy 6082-T6 and Mild-Steel materials are cut as per the dimensions 100 mm x 50 mm x 4 mm.

B. Preparation of Job

The edges of the faces were cleaned by using different grain size emery paper to remove oxide layers or any surface contamination and washed with acetone just before each experiment started. Then the plates are secured in a position firmly using mechanical clamps.

C. Welding

All the experiments are carried out at almost same room temperature and other parameters selected are kept constant for all the experiments (such as machine operator, dwell time, plunge depth, tool offset, tool profile etc…).

The direction of welding is normal to the rolling direction. Single pass welding procedures are used to fabricate the joints. Non-Consumable cylindrical tapered tool is made up of tungsten carbide is used to fabricate the joints. A non-consumable rotating tool is specially designed by pin and shoulder to insert into the abutting edges of sheets or plates (offset towards steel to get better joint strength) which have to be joined. The primary functions of the tools are: Heating the work piece and Movement of material to form joints

In the present work, additional source for heating the base material is introduced with conventional Friction Stir Welding (FSW) process which is used to preheat steel plate to different temperature levels. Preheat source located in front of the tool in the welding direction provides adequate metal flow around the tool and simultaneously prevents formation of a large amount of brittle aluminum – steel intermetallic compounds. The mechanical properties of the welded joints are analyzed for selected process parameters

Due to the friction produced between the rotating tool and the work piece plastic deformation of the work piece is achieved. Preheating and the high heat which is produced softens material around the pin and shoulder. The combined effect of tool rotation and translation leads to movement of materials from front to the back of the pin (visa-versa).

The formation of rings are observed on the line of joining, thus a solid joint is formed. During FSW process the material undergoes a plastic deformation at high temperature which results in generation of fine and equaled re-crystallized grains. It is expected that preheating of material not only reduces the forces acting during welding by softening the base metal but also minimizes the chances of tool wear. Also helps better mixing of the materials and provides better welding results interms of improved welding efficiency and weld joint quality.

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Fig. 1 shows Friction Stir Welding appearance to join Dissimilar Materials, the process is started with edge preparation of the plates of A6082-T6 and Mild-Steel alloys to make sure both the edges meet each other then they are clamped firmly by using suitably designed clamping setup which is fixed on the table of the machine, with the help of preheating torch which is a preheating heat source is positioned at an angle of sixty degree w.r.t. base metal at standard distance. It was made sure that less arc effect on the tool and softer material.

Then the process is followed by rotating a specially designed FSW tool at predefined speed (rpm) before it is inserted into wild line of the plates to be joined. A vertical force (z-axis load) is applied perpendicularly to the joint line, driving the rotating pin into the work piece (01 mm offset towards advancing side). Frictional heat is generated at two points: one at the top surface of the workpiece under the FSW tool shoulder and second is in the base material at the interface with the pin.

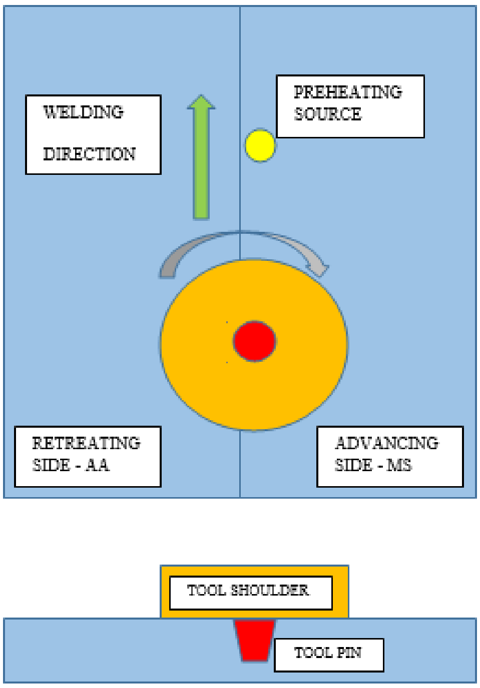

Fig. 1:- Friction Stir Welding appearance to join Dissimilar Materials

A lateral force (x-axis load) is applied in the direction of travel, after sufficient dwell time (to allow for homogeneous heating and softening of the material). Both z- and x-axis loads act on the rotating welding tool as it traverses along the joint line, sweeping the softened material along the periphery of the pin and depositing it in the tool's wake.

This "stirring" action, along with the pressure and restraining forces induced by both the tool and fixturing, creates a heavily deformed region of material which upon cooling defines a strong metallurgical joint which will be having fine-grained with no entrapped oxides or gas porosity.

Fig. 2a shows the new tool profile before welding and Fig. 2 (b&c) shows the status of the tool after welding, it can be observed that aluminum material deposited on the tool shoulder and change in pin profile or pin completely broken.

Fig. 2:- Tool Profile (a) New Tool (b&c) Pin broken and Deformed Metal sticks the tool shoulder

V. RESULTS AND DISCUSSION

A. Tensile strength

Tensile strength or ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. The value of the test specimen does not depend on the size of the work piece but it depends on factors like surface finish, temperature of the test environment etc. Tensile testing of material was carried out at ASTM E8M-04.Thus we need larger tensile strength to make the material withstand when stretched or pulled. Thus we use Larger the better to calculate S/N ratio.

B. Analysis of Variance

Sl. No.	Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
1	X1	2	1.545	1.5458	0.7729	55.21	0.000
2	X2	2	3.497	3.4971	1.7486	124.87	0.000
3	X3	2	3.322	3.3212	1.6605	118.59	0.000
4	X1*X2	4	0.298	0.2979	0.0744	5.31	0.021
5	X1*X3	4	0.065	0.0657	0.0164	1.16	0.390
6	X2*X3	4	3.544	3.5446	0.8861	63.30	0.000
7	Residual Error	8	0.112	0.1120	0.0140		
8	Total	26	12.384				

TABLE IV. ANALYSIS OF VARIANCE FOR SN RATIOS

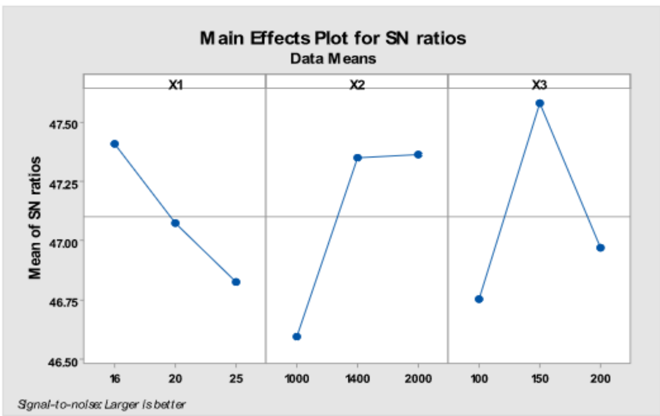

Fig. 3:- Main Effect Plot For SN Ratio

C. Interaction Plot

Whether interactions between factors exist or not can be shown by plotting a matrix of interaction plot. However, the interaction plot doesn't tell if the interaction is statistically significant.

To visualize interactions during DOE, interaction plots are used most often. Matrix of interaction plot for means and signal to noise ratios are shown in Fig. 4.

Sl. No.	Level	X1	X2	X3
1	1	47.411	46.591	46.751
2	2	47.017	47.335	47.580
3	3	46.812	47.346	46.970
4	Delta	0.581	0.770	0.830
5	Rank	2	3	1

TABLE V. RESPONSE TABLE FOR SN RATIOS

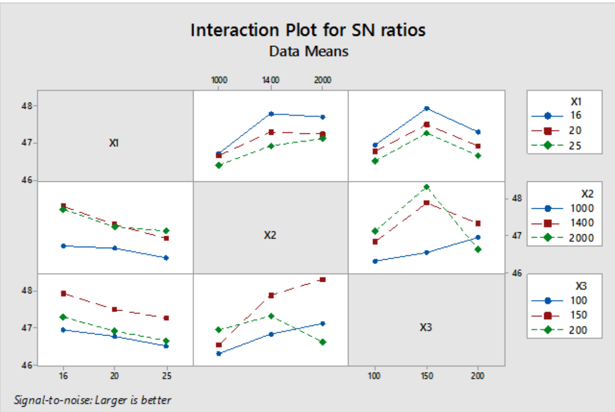

Fig. 4:- Interaction Plot for Signal to Noise (SN) Ratios

D. Interpretation of Interaction Plots

The interaction plots show that the interaction between Preheat temperature and Rotational Speed is major important factor. The other two-factor interpretations do not appear to be important though they are significant.

E. SEM Microstructural Investigation

To understand material in clear way Scanning Electronic Microscope (SEM) method is used. The atomic number of aluminium is 13 and atomic number of steel is 26. If atomic number is more then brightness of the material is more, if atomic number is less then brightness of material is less in microstructural view which can be seen by the help of SEM images obtained.

From Fig. 5, it is observed that steel composition is found in the aluminium side near the welded zone. The images taken in this trial are of magnification of 200X, 500X, 2000X and 5000X. When the magnification is about 200X on the interface zone, it is been observed that most of the steel composition as white dots found in the black aluminium side. Same at 500X magnification the transferred composition of steel over aluminium is observed. In 2000X it is clearly seen that there is much traces of aluminium particles over the steel, very near to the interface.

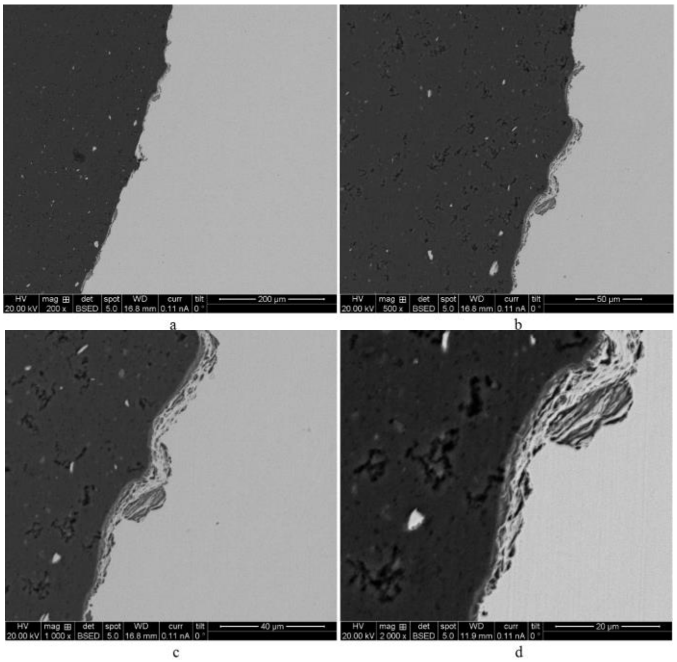

Fig. 5:- SEM Images at various Magnification (a) 200X (b) 500X
(c) 1000X (d) 2000X

VI. CONCLUSION

In the present work, Taguchi method was used to obtain optimal condition for Friction Stir Welding of A6082-T6 and Mild Steel, then the experimental results were evaluated using ANOVA.

The results can be draw as follows:

To get good weld strength, Tool Pin offseted 1 mm towards steel (at joint interface).

It is observed that Preheating Temperature was the major factor affecting the Tensile strength.

The maximum Tensile Strength was exhibited by the Friction Stir Welded joints with the optimized parameters of Preheating Temperature 150°C, Traverse Speed 16 mm/min, and Rotational Speed 2000 rpm.

It's better to withdraw the FSW-Tool from joint line (when it reaches other end of the joint) while still it is in rotation, else pin may break.

REFERENCES

[1] A. Kelkar - Automobile bodies: can aluminum be an economical alternative to steel? , JOM (2001) 53 (8).

[2] New trends in welding in the aeronautic industry, 2nd Conference of New Manufacturing Trends, Bilboa (2002) 19-20 by P. F. Mendez.

[3] U.R. Kattner, binary alloy phase diagrams. ASM International, Materials Park, OH, USA (1990).

[4] L. Agudo - Intermetallic Fex Aly-phases in a steel/Al-alloy fusion weld, Journal of Materials Science 42 (2007).

[5] M. J. Rathod and M. Kutsuna, aluminum alloy 5052 and low-carbon steel by laser roll welding, Welding Journal 83 (1) (2004).

[6] M. Naka, H. Date and S. Kobayakawa, Microstructure and bonding strength of impact-welded aluminum-stainless steel joints, J M P T 85 (1999).

[7] S. Surendran, R. N. Shubhavardhan, Friction welding to join stainless steel and aluminum materials, IJMMSE 2 (3) (2012).

[8] J. Tsujino, Ultrasonic butt welding of aluminum, aluminum alloy and stainless steel , Ultrasonic 40 (2002).

[9] J.H. Zhang, P. He and X. Yue, Hot pressing diffusion bonding of a titanium alloy into SS with an aluminum alloy interlayer, Materials Science and Engineering A 486 (2008).

[10] M. Acarer, B. Demir, An investigation of mechanical and metallurgical properties of explosive welded aluminum-dual phase steel, Materials Letters 62 (2008).

[11] S.A.A. Akbari Mousavi, M. Dehghani and A. Amadeh, - Effects of FSW parameters on intermetallic and defect formation in joining aluminum to mild steel, Materials and Design 49 (2013).

[12] A. Mathieua et. al. Laser brazing of a steel/aluminum assembly with hot filler wire Materials Science and Engineering A 435-436 (2006).

[13] P. Peyre, G. Sierra, F. Deschaux - Beaumec, G. Fras, D. Stuart, Steel - aluminum key-hole laser welding, Materials Science and Engineering (2007).

[14] M. Kashani, T. Aizawa and K. Okagawa, Application of magnetic pulse welding for aluminum and SPCC steel joints, Welding Journal, 86 (2007).

[15] Dissimilar welding of carbon steel to 5754 Aluminum by ND: YAG pulsed laser, Materials and Design 31 (2010) by S. Tahamtan, M. J. Torkamany and J. Sabbaghzadeh -

[16] E. Schubert, Light-weight structures produced by laser beam joining, Journal of Materials Processing Technology 115 (2001).

[17] FSW of Aluminum Alloy to Steel Aluminum alloy, Welding Journal 277 –S, October 2004.

[18] Laser assisted Friction Stir Welding of steel-aluminium by M. Merklein and A. Giera. IJMF, April 2008, Vol. 1, Issue 1 Supplement.

[19] Friction Stir welding of Steel-Aluminium dissimilar joints, (LNLS) and (ABTLuS). Ministério da Ciência, Tecnologia e Inovação (Brasil). Campinas, SP, Brazil. December - 2008 - February - 2012.

[20] Taguchi Optimization of Process Parameters in Friction Welding of 6061 Aluminum and 304 steel - A Review, IJETAE, Volume 3, Issue 4, April 2013).

[21] Multi objective Optimization of FSW Process Parameters on AA 5083 Using Taguchi-Based Grey Relation Analysis, S. R. K Rao. Materials and Manufacturing Processes, Volume 25, Issue 11, 2010.

[22] Research on Friction Stir Welding and TIG assisted Friction Stir Welding of Copper, Recent Advances in Manufacturing Engineering, ISBN: 978-1-61804-031-2

[23] Effect of Preheating on AL 6061 T-6 using FSW by RSM Method. INDIAN JOURNAL OF APPLIED RESEARCH, Volume – 1.