Optimization of Process parameters of Friction Stir Welding for Similar HE-30 Aluminium Alloy

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Abstract - *Friction stir welding 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 is developed in Dec.1991 by The Welding Institute of UK using for Al, Mg, Cu, Ti, work pieces that could not welded by conventional types of welding and recently develop too much in different application because of economical and quality consideration. Modern types of tool developed recently for harder typed of materials work pieces like different type of steels. Also, different types of machines developed for this purpose. FSW can done by an ordinary CNC milling machine for small work pieces to professional single purpose robotic machine in orbital FSW in steel pipes welding in oil industries The process has been widely used in the aerospace, shipbuilding, automobile industries and in many applications of commercial importance. This is because of many of its advantages over the conventional welding techniques which include very low distortion, no fumes, no porosity or spatter, no consumables (no filler wire), no special surface treatment and no shielding gas requirements. FSW joints have improved mechanical properties and are free from porosity or blowholes compared to conventionally welded materials. In this project tapered cylindrical tool with three-sided re-entrant probe made of Tungstun Carbide (Wc) is used for the friction stir welding (FSW) of aluminium alloy HE30 – HE30 and test the mechanical properties of the welded joint by tensile test. Finally, we were compare mentioned mechanical properties and make conclusion. The result will help welding parameter optimization in friction stir welding process. Like rotational speed, depth of welding, travel speed, Tool Axial force, type of material, type of joint, work piece dimension, joint dimension, tool material and tool geometry. The detailed mathematical model is simulated by Minitab15. Experiments were conducted by varying rotational speed, transverse speed, and constant Axial force using L9 orthogonal array of Taguchi method. We analyzed the effect of these three parameters on tensile strength. In this investigation, an effective approach based on Taguchi method, has been developed to determine the optimum conditions leading to higher tensile strength. The present work aims at optimizing process parameters to achieve high tensile strength.*

Key Words: *Aluminium alloy HE30-HE30, Friction stir welding (FSW) Tool, Minitab15, Tensile test, Tapered Cylindrical Three sided re-entrant probe.*

1. INTRODUCTION

Friction stir welding is a welding process recently developed in 1991 using for Al, Mg, Cu, Ti, for work pieces that could not welded by conventional types of welding and recently develop too much in different application because of economical and quality consideration. Modern types of tool developed recently for harder typed of materials work pieces like different type of steels. Also different types of machines developed for this purpose. FSW can done by an ordinary CNC milling machine for small work pieces to professional single purpose robotic machine in orbital FSW in steel pipes welding in oil industries [1]. The schematic of friction stir process shown in Fig.I

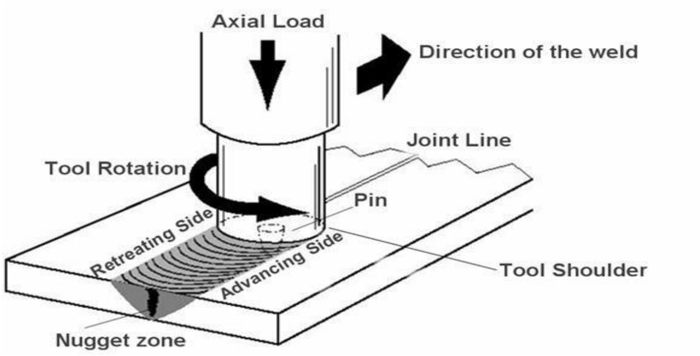

Fig-1: Schematic of Friction Stir Welding

Also the FSW process can be modeled as a metal working process in terms of five Conventional metal working zones: preheat, initial deformation, extrusion, forging and post heat/cool. Besides this preheating generally increase hardness and Tensile strength qualification therefore preheating recommended both when the friction stir welded joint under horizontal or vertical high loads [1]. Several process parameter optimization develop for friction stir welding in recent years. Base these modelling techniques the tool geometry have dominate effects in friction stir welding processes. The effect of bonding time and homogenization treatment on microstructure development and improvement is also considerable. Post bond heat treatment on mechanical Properties, micro hardness and shear strength of joints were also considered as important factors in any welding, joining or metal forming processes[1]. But as I mentioned before preheating preferred in friction stir welding processes and that's because of the nature of the process that base on heat generated by friction existence between tool and work pieces materials [1].

The process of Friction Stir Welding has been widely used in the aerospace, shipbuilding, automobile industries and in many applications of commercial importance. This is because of many of its advantages over the conventional welding techniques some of which include very low distortion, no fumes, porosity or spatter, no consumables (no filler wire), no special surface treatment and no shielding gas requirements. FSW joints have improved mechanical properties and are free from porosity or blowholes compared to conventionally welded materials. However along with these advantages there are a few disadvantages, which also need to be mentioned. At the end of the welding process an exit hole is left behind when the tool is withdrawn which is undesired in most of the applications. This has been overcome by providing an offset in the path for continuous trajectory, or by continuing into a dummy plate for non-continuous paths, or simply by machining off the undesired part with the hole. Large down forces and rigid clamping of the plates to be welded are a necessity for this process, which causes limitation in the applicability of this process to weld jobs with certain geometries [2].

In FSW, a cylindrical-shouldered tool, with a profiled threaded/unthreaded probe or pin is rotated at a constant speed and fed at a Constant traverse rate into the joint line between two pieces of sheet or plate material, which are butted together as shown in Figure 1. The parts have to be clamped rigidly onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. The length of the pin is slightly less than the weld depth required and the tool shoulder should be in intimate contact with the work piece surface. The pin is then moved against the work piece, or vice-versa. Frictional heat is generated between the wear resistant welding tool shoulder and pin, and the material of the work-pieces. This heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without reaching the melting point (hence cited a solid-state process). As the pin is moved in the direction of welding the leading face of the pin, assisted by a special pin profile, forces plasticized material to the back of the pin which applying a substantial forging force to consolidate the weld metal. The welding of the material is facilitated by severe plastic deformation in the solid state involving dynamic recrystallization of the base material. Friction Stir Welding is associated with various types of defects which result due to improper welding parameters. Insufficient weld temperatures, due to low rotation speeds or high traverse speed. [2]

Aluminium is the most prominent candidate to meet the challenges for future automotive regarding high strength/weight ratio, corrosion resistance, emissions, safety, and sustainability. A high thermal and electrical conductivity cause problems in fusion and resistance welding of aluminium alloys. Friction stir welding (FSW) is a solid state welding process and it considered the most significant development in metal joining techniques in the last decades, it was invented by The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys. However, the extended application of this welding process in industry still requires accurate knowledge of the joining mechanism, and the metallurgical and mechanical transformations it induces in the base materials. Actually the effectiveness of the obtained joint is strongly dependent on several operating parameters. First of all, the geometric parameters of the tool, such as the height and the shape of the pin and the shoulder surface of the head, have a great influence on both the metal flow and the heat generation due to friction forces. Secondly, both the rotating speed and the feed rate have to be selected in order to improve "nugget integrity" that results in a proper microstructure and eventually in good strength, fatigue resistance and ductility of the joint[2].

In FSW process heat generated by friction between the surface of the plates and the contact surface of a special tool, composed of two main parts: shoulder and pin. Shoulder is responsible for the generation of heat and for containing the plasticized material in the weld zone, while pin mixes the material of the components to be welded, thus creating a joint. This allows for producing defect-free welds characterized by good mechanical and corrosion properties. The advantages of FSW are due to the fact that the process is carried out with the material to be welded in the solid state. Avoiding melting prevents the production of defects, due, for instance, to the presence of oxygen in the melting bath, and limits the negative effects of material metallurgical transformations and changes strictly connected with changes of phase. Finally, the reduced thermal flux, with respect to traditional fusion welding operations, results in a reduction in residual stress state in the joints and, consequently, in distortions in the final products [4].

2. PROBLEM STATEMENT

Friction Stir Welding has been widely used in the aerospace, shipbuilding, automobile industries and in many applications because of many of its advantages over the conventional welding techniques some of which include very low distortion, no fumes, porosity or spatter, no consumables (no filler wire), no special surface treatment and no shielding gas requirements.

Aluminium is the most prominent candidate to meet the challenges for future automotive regarding high strength/weight ratio, corrosion resistance, emissions, safety, and sustainability. Aluminium HE30 has been widely used in the aerospace, shipbuilding, automobile industries and in many applications of commercial importance. So optimization of the Friction Stir Welding joint is find out for aluminium alloy HE30 by using Taguchi method which is used to analyze the effect of process parameters (i.e. RS, TS and Axial force) for optimizing tensile strength of FS welds of similar aluminium alloy HE30-HE30.

3. OBJECTIVES

I. To study the effect of different parameters like RS, TS and Axial force of Friction stir welded joint on Tensile strength.
II. To make a comparative study of contribution of process parameters.
III. Design of tool for FSW.
IV. Validation of experimental data by regression analysis and ANOVA.
V. To obtain the optimum process parameters i.e. RS, TS and Axial force for Tensile strength.

4. METHODOLOGY

1. Selection of Material Aluminium Alloy HE-30 & FSW on VMC/ CNC Milling Machine.
2. Design of Tool.
3. Making layout of Experimental Design according to L9 array.
4. Actual FSW operation by taking different combination values of RS, TS & Axial force.
5. Measurement of Mechanical Properties such as Tensile strength for the given combinations of RS, TS & Axial force of tool on UTM.
6. By using Taguchi analysis techniques experimentation was done.
7. Comparison of the results obtained through UTM and Taguchi analysis techniques with each other.
8. Result will reveal the suitability of selected combinations of RS, TS & Axial force for defect free FSW operation & optimum process parameters for high strength.

SCOPE OF WORK

The first step in the selection of process parameters is to conduct the brain storming session to select the process two process parameters were selected for study. When the RS was lower than 800 rpm, wormhole at the retreating side of weld nugget was observed and it may be due to insufficient heat generation and insufficient metal transportation; when the RS was higher than 1600 rpm, tunnel defect was observed and it might be due to excessive turbulence. Similarly, when the TS was lower than 0.16 mm/s, pin holes type of defect was observed due to excessive heat input per unit length of the weld and no vertical movement of the metal. When TS was higher than 1.5mm/s, tunnel at the bottom inretreating side was observed due to insufficient heat. Based on this the following range of process parameters is selected.

5. TAGUCHI METHOD

Incorrect business decisions can have very serious consequences for a company. The decisions that a company makes can be as simple as choosing on what side of a building to install bathrooms, or as complex as what should be the layout of a manufacturing plant, or as serious as whether it should invest millions of dollars in the acquisition of a failing company or not. In any event, when we are confronted with a decision we must choose between at least two alternatives. The choice we make depends on many factors but in quality driven operations, the most important factor is the satisfaction that the customers derive from using the products or services delivered to them. The quality of a product is the result of a combination of factors. If that combination is suboptimal, quality will suffer and the company will lose as a result of rework and repair. The best operations" decisions are the result of a strategic thinking that consists in conducting several experiments, combining relevant factors in different ways to determine which combination is the best. This process is known in statistics as Design of Experiment (DOE).

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process from data already in existence.

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way, while using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations.

A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, i.e. the lower-the-better, the larger-the-better, and the more-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design.

6. MATERIALS AND METHODOLOGY FOR FSW

A. Tungstun Carbide Tool:

Tool used in this study for Friction Stir Welding is made whose shank body is made with EN-31 & tapered three sided re-entrant Probe is made of Tungstun Carbide with following dimensions.

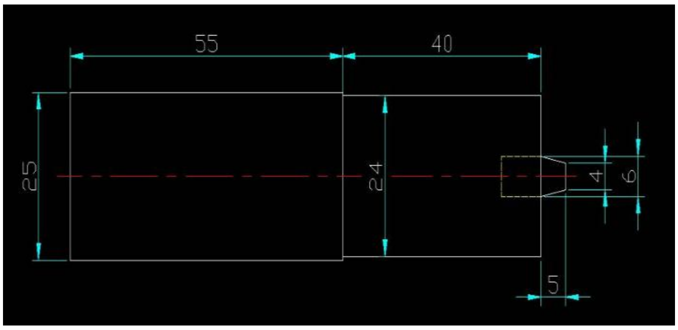

Fig-2: FSW Tool Design

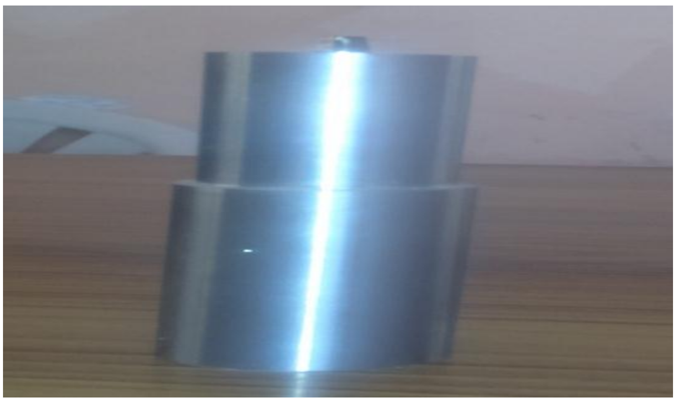

Photo-1: Actual FSW Tool before welding

B. Plate Material:

The base materials selected for this investigation were AA6082-T6 and AA6082-T6 aluminium alloys sheets of 6 mm thickness having chemical composition and mechanical properties shown in the Table I In the present study, sheets of size 100mm x 75mm of AA6082-T6 and AA6082-T6 were cut for welding by FSW.

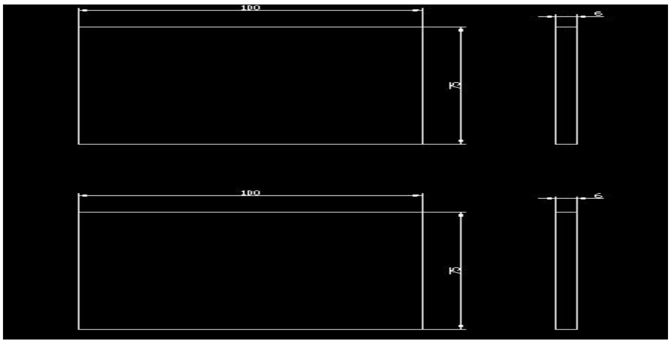

Fig-3: Work piece Dimension

Photo-2: Aluminium alloy HE30 work piece

Table-1: Chemical Composition of HE30

Element	Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn	Other	Other	Al
%	0.60-	0.70-	0.0-	0.0-	0.0-	0.0-	0.0-	0.40-	0.0-	0.0-	Balance

7. EXPERIMENTAL DATA

According to the L9 orthogonal array, three experiments in each set of process parameters have been performed on Al-6082 plates. The three factors used in this experiment are the rotating speed, axial force and travel speed. The experiments are performed on a vertical milling machine which serves to perform the FSW operation.

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Table-2: Experimental layout of L9 Orthogonal array

Experiment	Rotational Speed RPM	Travel speed mm/min	Axial Force N
1	1400	10	1000
2	1400	20	2000
3	1400	30	3000
4	1500	10	2000
5	1500	20	3000
6	1500	30	1000
7	1600	10	3000
8	1600	20	1000
9	1600	30	2000

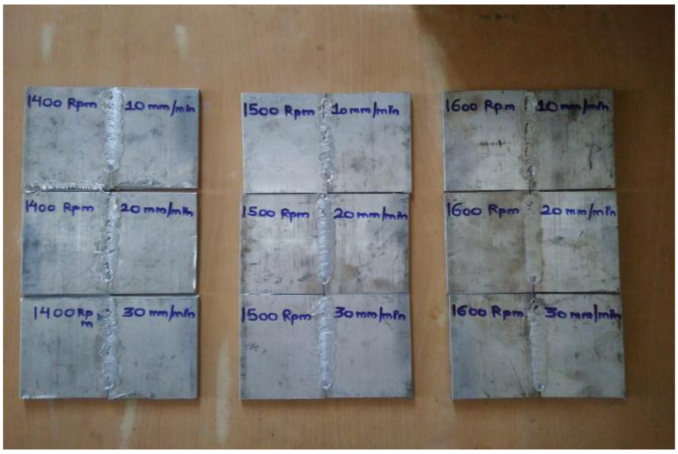

Photo-3: Aluminium Plates after FSW

Photo-4: FSW Tool after welding

Photo-5: Specimen after failure

Table-3: The input parameter of orthogonal array and the output characteristics

Experiment	Rotational Speed RPM	Travel speed mm/min	Axial Force N	Tensile strength (Mpa)
1	1400	10	1000	44.722
2	1400	20	2000	34.922
3	1400	30	3000	42.345
4	1500	10	2000	30.256
5	1500	20	3000	48.074
6	1500	30	1000	48.854
7	1600	10	3000	32.489
8	1600	20	1000	43.407
9	1600	30	2000	59.891

8. RESULT DISCUSSION

I.Results of Mechanical Properties of Friction Stir Welded Joint:

We weld the mention dimension aluminium alloy HE30-HE30 plates with the mentioned process parameter and VMC milling machine nine times with taper cylindrical three sided re-entrant probe tool & then perform tensile strength test to the welded joints compare the results and make conclusion.

i. S/N Ratio Analysis:

In the Taguchi Method, the term 'signal' represents the desirable value (mean) for the output characteristics and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), larger is better (LB). Larger is better S/N ratio used here. Larger the better quality characteristic was implemented and used in this study.

Larger the better characteristic:

S/N= -10 log10 (MSD)

MSD = $(1/Y1^2 + 1/Y2^2 + 1/Y3^2 + \ldots\ldots\ldots)/n$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and m is the target value of result. The level of a factor with the highest S/N ratio was the optimum level for responses measured.

Table-4: S/N ratio of tensile strength of FS Welds

Sr. No.	RS (RPM)	TS (mm/min.)	AF (N)	UTS (Mpa)	S/N Ratio
1	1400	10	1000	44.722	33.0104
2	1400	20	2000	34.922	30.8620
3	1400	30	3000	42.345	32.5360
4	1500	10	2000	30.256	29.6162
5	1500	20	3000	48.074	33.6382
6	1500	30	1000	48.854	33.7780
7	1600	10	3000	32.489	30.2347
8	1600	20	1000	43.407	32.7512
9	**1600**	**30**	**2000**	**59.891**	**35.5472**

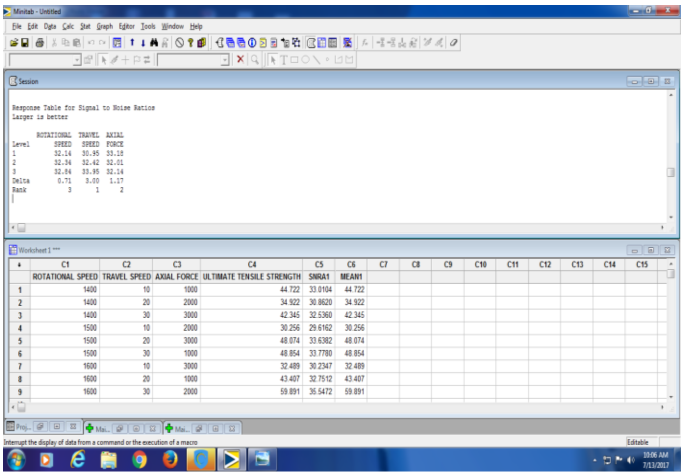

Photo-6: S/N ratio of tensile strength of FS Welds

Table-5: Response table for Signal to Noise Ratios

Level	RS	TS	AF
1	32.14	30.95	33.18
2	32.34	32.42	32.01
3	32.84	33.95	32.14
Delta	0.71	3.00	1.17
Rank	3	1	2

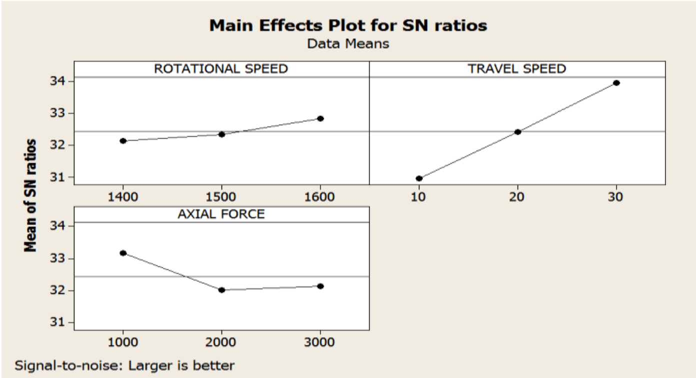

Chart-1: Main Effect Plot for SN Ratio

Table-6: Response table for Means

Level	RS	TS	AF
1	40.66	35.82	45.66
2	42.39	42.13	41.69
3	45.26	50.36	40.97
Delta	4.60	14.54	4.69
Rank	3	1	2

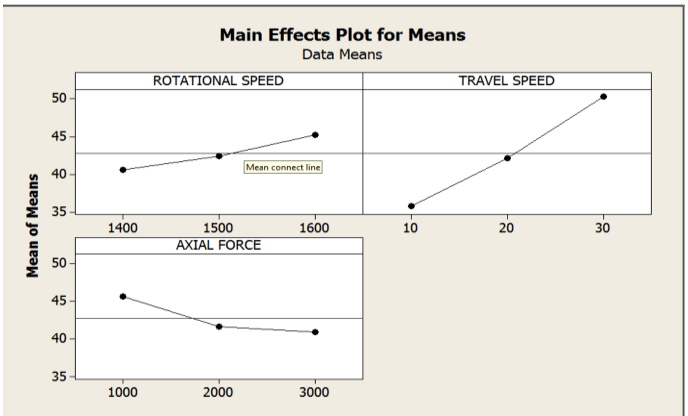

Chart-2: Main Effect Plot for Mean

ii. OVAT (One Variable at a Time) Analysis:

OVAT analysis is very much important tool utilized widely in engineering analysis. A control factors and there levels are selected for experimentation by using OVAT analysis. The main purpose of performing OVAT analysis is to clear that whether the selected process parameters having influence on quality characteristics. OVAT analysis perform by varying one process parameter from lower to higher value by keeping all other process parameters constants, and measure the effect on quality characteristics.

(A) OVAT analysis of Rotational Speed of Tool

The level of rotational speed of tool 1400rpm, 1500rpm, 1600rpm is selected. Rotational speed of tool is changing and remaining other parameter Travel speed, Axial force putting mean and result Ultimate tensile strength are taken and from table 7 it is clear that as rotational speed of tool increases the ultimate tensile strength increases. Hence the Rotational speed of tool is influencing factor on Ultimate tensile strength.

Table-7: OVAT analysis of Rotational speed of Tool

Rotational Speed (RS), RPM	Travel Speed (TS), mm/Min.	Axial Force (AF), N	Ultimate Tensile Strength (UTS), mpa
1400	20	2000	30
1500	20	2000	40
1600	20	2000	59

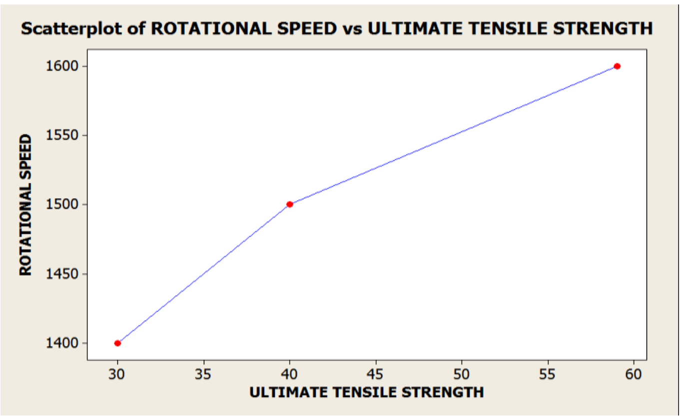

Chart-3: Rotational speed vs Ultimate Tensile Strength

Effect of Rotational speed of Tool on Ultimate Tensile Strength:

Chart-3 shows effect of Rotational speed of tool on Ultimate Tensile Strength. As Rotational speed of tool goes on increasing Ultimate Tensile Strength also increases.

(B) OVAT analysis of Travel Speed of Tool

The level of Travel speed of tool 10mm/min., 20mm/min., 30mm/min. is selected. Travel speed of tool is changing and remaining other parameter Rotational speed, Axial force putting mean and result Ultimate tensile strength are taken and from table 8 it is clear that as travel speed of tool increases the ultimate tensile strength increases. Hence the Travel speed of tool is influencing factor on Ultimate tensile strength.

Table-8: OVAT analysis of Travel speed of Tool

Travel Speed (TS), mm/Min.	Rotational Speed (RS), RPM	Axial Force (AF), N	Ultimate Tensile Strength (UTS), mpa
10	1500	2000	30
20	1500	2000	40
30	1500	2000	59

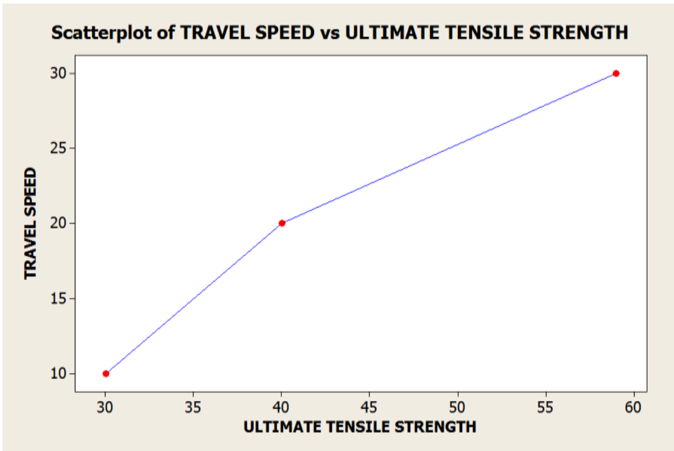

Chart-4: Travel speed vs Ultimate Tensile Strength

Effect of Travel speed of Tool on Ultimate Tensile Strength:

Chart-4 shows effect of Travel speed of tool on Ultimate Tensile Strength. As Travel speed of tool goes on increasing Ultimate Tensile Strength also increases.

(C) OVAT analysis of Axial Force

The level of Axial Force of tool 1000 N, 2000 N, 3000 N is selected. Axial Force of tool is changing and remaining other parameter Rotational speed, Travel Speed putting mean and result Ultimate tensile strength are taken and from table 9 it is clear that as Axial Force of tool increases the ultimate tensile strength increases. Hence the Axial Force of tool is influencing factor on Ultimate tensile strength.

Table-9: OVAT analysis of Axial Force

Axial Force (AF), N	Travel Speed (TS), mm/Min.	Rotational Speed (RS), RPM	Ultimate Tensile Strength (UTS), mpa
1000	20	1500	30
2000	20	1500	40
3000	20	1500	59

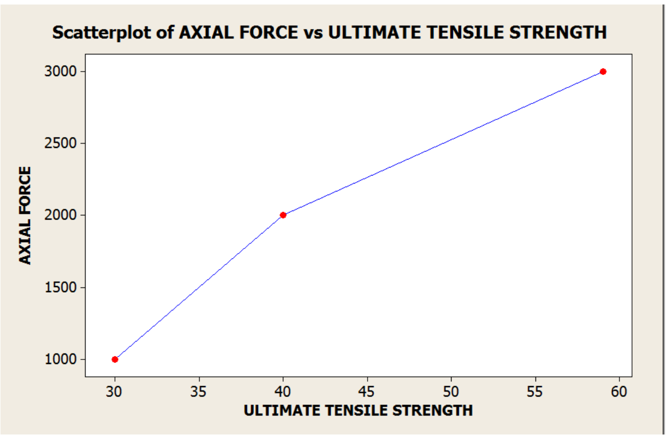

Chart-5: Axial Force vs Ultimate Tensile Strength

Effect of Axial Force of Tool on Ultimate Tensile Strength:

Chart-5 shows effect of Axial force of tool on Ultimate Tensile Strength. As Axial force of tool goes on increasing Ultimate Tensile Strength also increases.

9. CONCLUSIONS

The following conclusions have been derived by applying TAGUCHI METHOD on the experimental investigations of AA 6082-T6 and AA 6082-T6 alloys by FSW.

1. The cylindrical tool with a tapered three-sided re-entrant probe have efficient stirring of the metal and efficient filling of the material in the gap formed during the welding process. Friction stir welding can apply successfully for aluminum alloy HE30-HE30 by VMC machine.
2. FSW window was developed to decide the range of tool rotational speed, welding speed and axial force.
3. The tensile strength increases with increase in the rotational speed of tool and reaches maximum .The optimum value of process parameters such as rotational speed, traverse speed and axial force are found to be 1600rpm (level 3), 30 mm/min (level 3) and 2000 N (level 2) respectively.
4. The Ultimate Tensile strength increases with increase in the Tool Rotational speed and reaches maximum.
5. Also Ultimate Tensile strength increases with increase in the Tool Travel speed and reaches maximum.

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