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OPTIMIZATION OF FRICTION STIR WELDING PARAMETERS FOR AL 6063 ALLOY USING THE TAGUCHI METHOD

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Abstract:

Through the Taguchi method, the key process parameters, such as rotational speed, welding speed, axial force, and tool geometry, were systematically varied and evaluated. The analysis of signal-to-noise ratios and analysis of variance allowed for the determination of optimal parameter levels to achieve desired weld characteristics. By optimizing these parameters, it was possible to minimize defects, such as voids and cracks, and enhance the mechanical properties of the weld. The Taguchi method not only facilitated the identification of optimal parameter settings but also provided a systematic approach to understand the relative importance of each parameter and its interactions. This knowledge can guide future process improvements and enable the establishment of robust process control strategies. the Taguchi method allowed for the quantification of the effects of process parameters on weld quality, providing valuable insights into the FSW process for Al 6063 alloy. This understanding can be utilized to develop guidelines and best practices for FSW operations, leading to consistent and high-quality welds.

Key Words: Systematic, Approach, Instruments, Operations and Strategies

Introduction:

Manufacturing, a branch of industry, is the appliance of instruments and processes for the transformation of uncooked substances into finished parts. The manufacturing industry is carefully related with engineering and industrial design. The term manufacturing process refers to a set or arrangement of operations and strategies used to make a required product or component. It entails the genuine apparatus's for composing the approaches and the arrangement of those methods. An extensive area of manufacturing approaches was developed with a purpose to develop the engineering add-ons limit from easy to difficult geometries with substances of exceptional physical, compound, mechanical and dimensional assets. There are 4 head assembling strategies i.e. Methods include molding, milling, welding, and casting. The difficulty of the element's geometry, the number of items to be made, the properties of the substances (physical, chemical, mechanical, and dimensional residences), and economics all play a role in the resolution of a suitable industrial technique for a formed /element. Depending on how they're employed to determine their ideal size and shape, unique manufacturing techniques will be classified as positive, negative, or zero(Yang *et al*. 2018):

- Casting: zero process
- Forming: zero process
- Machining: negative process
- Joining (welding): positive process

Casting and framing are considered zero-sum operations because they both need the most efficient transportation of steel from one site to another while retaining its precise dimensions and shape. Machining is expected as a negative strategy considering the way that undesired material from the stock is eliminated as little chips all through machining for the forming and estimating of an item thought process. Amid assembling, it is frequently required to join the basic structure accessories to get favored item. Considering simple shape additional items are presented on the whole through participating with an end goal to get favored type of usable item, consequently turning into an individual from is ordered as a constructive system

Classification of Manufacturing Processes:

The manufacturing strategies can be isolated as: Forming Methods, Molding Methods, Machining Methods, Assembly Methods, Finishing Methods. These are explained below:

- **Forming Processes:** Rolling typical forms out of metal, aluminum, and other materials is one of the most essential forming activities in the metal production business. Key fabricated forms obtained by these methods include bars, sheets, billets, I-beams, and so on. Those are a particular shape. These geometric forms can be put to further use in processing. Drop forging, stamping, extruding, press work, punching, drawing, etc. are all examples of forming processes.
- **Moulding Processes:** Sand casting, die casting, and other molding techniques are necessary for the production of certain goods. In a standard format that may or may not need further manipulation. Job

size, product diversity, accuracy, complexity, and cost will all play a role in determining the chosen process.

- **Machining Processes:** Steel is machined using the four fundamental machine tool processes: cylindrical surface release, flat surface release, complicated curve release, and hole release. The computer tools used to complete this task will change depending on the size, shape, desired quality of finish, and needed production rate of the phase being machined. Turning, shaping, drilling, boring, grinding, and a host of others are all examples of such techniques. Metals are removed from the work piece in the form of tiny chips during these machining processes, which are accomplished by the revolving, cutting motion of the tool. Both the rotation and the reciprocating motion of the tool across the section contribute to the complete cutting process.
- **Finishing Processes:** These operations are performed for the sake of aesthetics, precision, surface polish, or durability.
- **Assembly Processes:** Welding, riveting, soldering, brazing, mechanical fastening, adhesive joining, and the like are just some of the techniques used in these processes to assemble the various parts and materials.

Welding is likely a standout amongst the most utilized creation approaches for industrial engineering accessories for power, compost, petro-substance, automotive, sustenance handling, and loads of different divisions. Welding more often than not utilizes nearby heating for the length of normal combination welding forms (protected steel circular segment, submerged curve, gas metal bend welding, etc.) for eating away at the rust and filler steel. However, welding is very different from other assembly methods due to the limited and differential heating and cooling supplied by the steel during welding:

- Simple structure components to be consolidated are in sectionally dissolved.
- The temperature of the base metallic through welding in and adjacent the weld comes to as capacity of time (weld warm cycle).
- Chemical, metallurgical and mechanical places of the weld are more often than not anisotropic.
- Dependability of weld joint is typical.
- Small amount of steel is squandered inside the sort of splash, begin and stop.
- Strategy proficiencies of the welding in expressions of dimensional exactness, accuracy and completion are poor.
- Weld joints for basic capacities more often than not require present weld treatment comparable on heat treatment or mechanical attempting to get favored homes or reline lresidual stress

Working Principle of Friction Stir Welding:

The work piece is put on a reinforcement piece and fastened strictly through an apparatus to maintain a side distance from sidelong movement during FSW. A principally structured frustum framed instrument with a stick reaching out from the edge is pivoted with a rapidity of a couple of 100 rpm and gradually rushed into the combined streak. The pin no doubt has a width 33% of the shoulder and much of the time has a size moderate not up to the width of the work piece. The stick is compelled into the metal piece at the section aside from if the edge contacts the outside of the work piece. The weld typically evacuated the work piece metal by around 3-6 % of unique width. The part to be attached and the instrument are moved in respect to one another with the end goal that the apparatus paths with the weld edge. The spinning apparatus conveys the 'stir' activity, plasticizing steel inside a tight zone while conveying steel from the top essence of the stick to the irregular ends. As the instrument moves, the weld cools, along these lines gathering the two plates one another. On device expulsion an opening is left as the device is pulled back from the metal piece

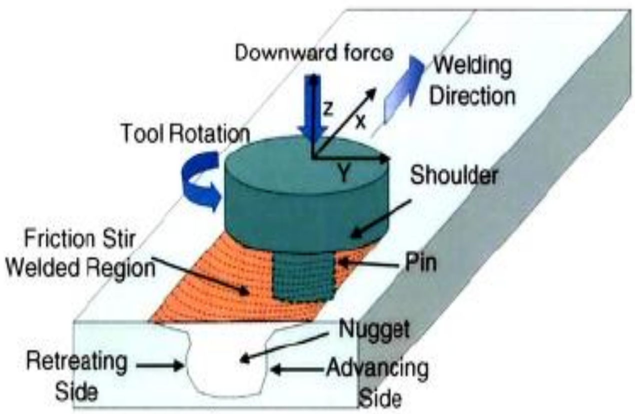

Figure 1: Schematic layout of friction stir weld Tool.

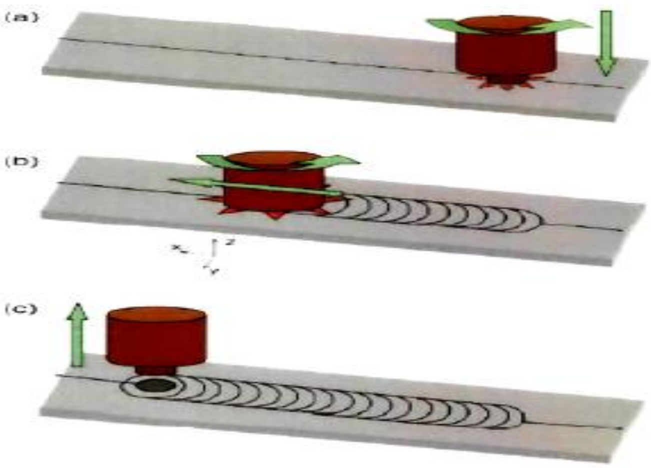

Figure 2: Stages of FSW

The approach was developed at first for aluminum alloys however when you consider that then FSW was determined suitable for becoming a member of tremendous quantity of resources like magnesium, copper, brass, titanium and steel (Adalarasan 2014 and Adams 2006). Aluminum and alloys soldering has dependably described a top-notch project for designers and technologists. Lot of challenges are related with this combination turning into an individual from the methodology, frequently concerning presence of a constant oxide layer, bigger warm conductivity, extreme coefficient of thermal development, cementing shrinkage and strikingly dissolvability of hydrogen and distinctive gases in liquid state. There might be central interest of plane businesses to search out substitution the conventional turning into an individual from advances with minimal effort and unnecessary productivity absolutely one of which is FSW. FSW innovation is anticipated to switch the fastener, bolted and bend welding turning into an individual from strategies for vast scale development capacities. FSW offers simplicity of managing, high phases of repeatability consequently making similar welds. Its appropriateness to aluminum composites, in definite specific compounds or those measured unweldable through traditional welding, types it an appealing strategy for the transference sectors (Ahmadnia 2015).

Scope of the Study:

This study focuses on the optimization of friction stir welding (FSW) for Al 6063 alloy, considering specific aspects within its scope:

Al 6063 Alloy: The study exclusively targets the aluminum alloy 6063, known for its widespread use in various industries due to its favorable combination of properties such as strength, corrosion resistance, and formability. The research aims to optimize the FSW process specifically for this alloy.

Process Parameters: The study considers the key process parameters that significantly influence FSW: rotational speed, traverse speed, axial force, and shoulder diameter. These parameters are selected based on their known impact on the weld quality and mechanical properties of Al 6063.

Optimization Criteria: The primary objective is to achieve the best possible weld quality and mechanical properties. The study aims to optimize the FSW process parameters to maximize tensile strength and hardness while minimizing weld defects, such as voids or cracks.

Taguchi Method: The Taguchi method, a statistical approach for design of experiments, is employed for parameter optimization. The study utilizes the L9 orthogonal array, allowing a limited number of experiments to efficiently explore the parameter space and identify the optimal parameter settings.

Experimental Analysis: The study conducts a series of experiments using different parameter combinations based on the Taguchi method. Tensile strength, hardness, and weld defect occurrence are the output responses analyzed to evaluate the impact of the process parameters on the FSW quality.

Industrial Application: The findings of this study can provide valuable insights for industrial applications of FSW in sectors that utilize Al 6063 alloy, including automotive, aerospace, and construction. The optimized parameter settings can aid in achieving high-quality welds with improved mechanical properties, leading to enhanced performance and cost-effective production.

It is important to note that the study's scope is limited to Al 6063 alloy and the specific FSW parameters considered. Other aspects such as tool design, post-weld heat treatment, or different aluminum alloys are beyond the scope of this study. Nonetheless, the research contributes to optimizing FSW for Al 6063, providing valuable guidance for industries seeking to enhance their welding processes for this specific alloy.

Material and Method:

- **Materials:** Aluminum is a lightweight and delicate metal. The components, such as manganese, magnesium, silicon, copper and lithium tend to alloy it. In the 1970s, manufacturers of aluminum / aluminum started making lithium-aluminum composites. Aluminum / aluminum 6063 alloy is a lithium-mixed designed composite. Expansion of lithium to aluminum diminishes thickness and increment firmness. At the point when legitimately alloyed, aluminum-lithium compounds can have incredible mixes of solidarity and durability. The accompanying data will give more insights concerning aluminum/aluminum 8090 combination.

- **Chemical Composition:** The table demonstrates the concoction creation of Aluminum/Al 6063 compound.

Table 1: Chemical configuration of Aluminum 6063

Element	Content (%)
Aluminum, Al	93 - 96.2
Lithium, Li	2.2 - 2.7
Copper, Cu	1- 1.6
Magnesium, Mg	0.60 - 1.3
Iron, Fe	≤ 0.30
Zinc, Zn	≤ 0.25
Silicon, Si	≤ 0.20
Titanium, Ti	≤ 0.10
Chromium, Cr	≤ 0.10
Manganese, Mn	≤ 0.10
Zirconium, Zr	0.040 - 0.16
Other (each)	≤ 0.050
Other (total)	≤ 0.15

Physical Properties:

The physical functions of AL 6063 compound are sketched out in the accompanying table.

Table 2: Physical properties of Al 6063 alloy

Properties	Metric	Imperial
Density	2.54 g/cm³	0.0918 lb/in³
Melting point	600 - 655°C	1110 - 1210°F

Mechanical Properties:

The mechanical functions of AL 6063 composite are organized below.

Table 3: mechanical functions of Al 6063

Properties	Metric
Tensile strength	450 MPa
Yield strength	370 MPa
Elongation at break	7%
Elastic modulus	77 GPa
Shear strength	270 MPa
Hardness, Brinell (@load 500 kg; thickness 10.0 mm)	121
Hardness, Knoop (converted from Brinell hardness value)	151
Hardness, Rockwell A (converted from Brinell hardness value)	47.2
Hardness, Rockwell B (converted from Brinell hardness value)	75
Hardness, Vickers (converted from Brinell hardness value)	137

Methods of Welding:

FSW includes intricate material development and plastic distortion. Welding limitations, for example, geometry, tool turning speed, welding speed, hub power and joint plan apply critical impact on the weld attributes. In this segment, a couple of central point influencing grinding blend welding process, for example, tool geometry, instrument rotating speed, welding speed and hub drive are measured for investigation. The starter setup was done as per the guidance gave in the guidance manual to Friction blend welding. The investigation was performed on a self-loader erosion mix welding machine of BMacT brand.

Procedure for Experimentation:

As the FSW process is considered welding between similar materials, Al 6063 alloy sheets were used. The dimensions of the sheets were 150 mm x 50 mm x 5 mm. In this technique, we used three separate parameters, each of which has two attributes. Welding velocity, rotational velocity, and angular deflection were some of the variables considered. Examples were welded and studied for tests like hardness, ultimate tensile, and rate Elongation when the heat treating process was performed according to certain criteria. After heat treatment, the for-microstructure test was also performed on the best of the eight samples. One of the characteristics was altered while the other two were held constant in order to guide the investigation. According to the size and number of informational components, The Taguchi Special Arrangement of Minitab Displays (MINITAB) is used to select the L9 Orthogonal Cluster.

Preliminary Setup:

The steps are used for all experimental procedure in all the setup as described under:

- In order to soldering AA, friction stirs were used for the preliminary analysis four parameters such as rotational speed, welding, axial power and tool geometries.
- Experimentations were executed according to the structure network.
- Single pass method was pursued to manufacture the links.
- W The joint was made using single-side welding by connecting two plate measures (150 * 50 * 5) mm.
- The pieces to be joined were safely clipped in the apparatus so the pieces remain set up and don't take off because of the welding forces.
- The rotating development of the pole was begun and the device was after reserved in interaction by the outside of the plated and the stick was entered to a prearranged depth in the metal plate outsides to be joined.
- The tool was specified most as it turns in interaction with the metal piece sides to relief the material because of the frictional warmth created and afterward the tool was given advancing movement which framed the joint. The tool was pulled back after the weld was finished; the procedure makes a hole toward the finish of the joint.

Taguchi Experimental Strategy for Design and Analysis:

Taguchi's logic depends on the three basic and basic ideas

- Quality should to be structured into the item and not review into it.
- Quality is the best achieved by reducing differences from the goal. The item or procedure should be planned to the fact that it is resistant to uncontrollable natural factors.
- The cost of value should be assessed as a component of deviation from the normal and the losses should be valued outline wide.

Symmetrical clusters using the Taguchi method (OA) to cheat on tests. Greek and Latin squares are used to total these OAs. Exam structure involves selecting the optimal OA and allocating the relevant parameters and participant shares to the appropriate subsets. Taguchi's recommended use of direct charts and triangle tables makes the task of parameters vital. The display directs all experimenters toward developing ambiguous tests.

In the Taguchi technique the results of the trials are performed to achieve at least one of the following goals.

- To evaluate the finest or the ideal state for an item or procedure.
- To appraise the commitment of separate constraints and collaborations.
- To assess the reaction below the perfect state.

Taking into account the underlying influences of all the parameters allows one to identify the ultimate state. The key factors demonstrate the overarching pattern of effect of each constraint. Knowledge of switch to be put up on a production process is mostly determined by the commitment information of individual parameters. In selecting the percent commitment of each parameter against an expressed dimension of confidence, the examination of change (ANOVA) is the measurable treatment most commonly associated to the findings of the tests. Examining the ANOVA table for a specific test helps determine which variables should be adjusted.

Taguchi suggests two separate methods for doing a comprehensive study (Roy, 1990). First, the conventional approach, wherein primary impact and ANOVA examination (Raw data investigation) are used to deal with the results of a single run or the norm of the repeating runs. Taguchi also recommends using signal-to-noise (S/N) ratio for similar steps in the inquiry, which is the second option. The signal-to-noise ratio (S/N) is a loss function-related simultaneous quality metric. The associated bad luck can be reduced by increasing the S/N ratio. When there is internal variation in the results, the S/N ratio is used to determine the optimal operating circumstances. The signal-to-noise ratio is viewed as a reaction parameter (raw datan transformation) in the study.

Results & Discussion:

Welding is one of the fundamental and broadly utilized manufacturing forms in any assembling businesses. The welding innovation has developed significantly in aviation and shipping enterprises with a shared objective of accomplishing higher quality and weld joint proficiency. Determination of ideal welding conditions is a key factor in accomplishing this condition. So as to acquire a great weld, the producer needs to set the info controllable elements at their ideal dimensions, with the base impact of wild or clamor factors on the levels and the variability of the responses. In order to streamline the procedure parameters in Friction Stir welding of Aluminum Alloy AA 8090, the Taguchi method is presented in this chapter.The most important factors to consider are the device's rotational speed, the tilt angle, and the welding speed. The ideal dimensions of the procedure parameters are resolved. The anticipated ideal estimation of elasticity is affirmed by leading the examination utilizing ideal parameters.

The experiments were directed utilizing L9 OA. The standard technique recommended by Taguchi has been utilized for analyzing the outcomes. Test data has been used to calculate the mean or normal and S/N proportion of quality/Performance attributes across all parameters and dimensions. The reaction curves have been generated to graphically represent the variation in execution hallmark and that of S/N ratio with the change in process parameters. The execution attributes' parametric impacts have been visualized with the help of these reaction curves. Raw data and S/N information were subjected to an analysis of variance (ANOVA) to separate out the major parameters and quantify their effect on the execution qualities. The pooled ANOVA and ANOVA (without pooling) are given additionally in this segment. The most great conditions or ideal dimensions of procedure parameters have been built up by investigating reaction bends of S/N proportion related with the Raw data.

The investigation of the outcomes got has been performed by the standard technique prescribed by the Taguchi strategy. The outcomes acquired from the different tests performed amid the present examination, for example, extreme ductile testing, hardness testing, checking electron magnifying lens and the electron scattering spectroscopy or the vitality dispersive x – beam spectroscopy (EDS) are exhibited and talked about in the consequent segments. An investigation based on the methods and S/N ratios examined in the ensuing segments. An examination based on the methods and S/N proportions are acquired utilizing the MINITAB-18 programming. This part contains investigation and exchange of the outcomes from the information acquired through friction stir welding.

Experimental Data for ANOVA of FSW:

An examination of change is a statistical method used to translate a trial information and make on the vital choice. The ANOVA is statically based choice apparatus for the identifying any distinction in the normal execution of gathering of the things tested. The ANOVA for the mean has been performed to distinguish the critical parameters to measure their impact on the execution attributes in the present examination for the erosion blend welding process. The exploratory information for the mean information and S/N proportion of extreme rigidity and hardness are given in Table 4for the Friction mix welding process respectively.

Table 4: Experimental data of UTS and S/N ratio for friction stir welding

No. of Exp.	Ultimate Tensile strength at weld zone			Ultimate Tensile Strength (Mean Value)	S/N Ratio
	Experiment No. 1	Experiment No. 2	Experiment No. 3		
1	209.7	197.4	205	204	46.19
2	258.8	257.4	271.2	262.4	48.38
3	135.7	179.1	139.2	151.3	43.59
4	336.8	323.6	310.9	323.7	50.20
5	209.8	212.3	207.9	210	46.44
6	129.6	128.6	105.8	121.3	41.67
7	174.8	179	170.9	174.9	44.85
8	170.2	171.5	159.4	166.9	44.45
9	610	585.33	502.2	565.8	55.05
Avg (µT)				242.25	46.75
Max.	610	585.33	502.2	565.8	55.05
Min.	129.6	128.6	105.8	121.3	41.67

Table 5: Experimental data of Hardness & S/N Ratio for FSW

No. of Exp.	Hardness at Weld Zone					Hardness (Mean Value)	S/N Ratio
	Experiment No. 1	Experiment No. 2	Experiment No. 3	Experiment No. 4	Experiment No. 5		
1	44	43.8	42	42.4	42.8	43	32.6694

2	43.2	41.2	43	43.4	44.4	43.04	32.6774
3	43	45.2	43.6	43.4	44.4	43.04	32.6774
4	42.8	42.6	41	42.2	41.6	42.04	32.4733
5	41	41.8	43.3	41.2	43	42.16	32.498
6	41.2	41	41.6	41.8	40	41.12	32.2811
7	41.8	41.6	39	42.2	42	41.32	32.3232
8	41	41.2	44	40.8	40.6	41.52	32.3651
9	39	39.6	39.8	39.2	38.2	39.16	31.8569
Avg (μT)						41.92	32.4459
Max.	44	45.2	44	43.4	44.8	44	32.8691
Min.	39	39.6	39	39.2	38.2	39.16	31.8569

Data Analysis of Ultimate Tensile Strength for Friction Stir Welding:

The ultimate tensile strength (UTS) of a material is defined as the maximum stress it can endure under tensile loading before yielding or breaking. The information examination choice of ideal settings, ANOVA, forecast of mean, assurance of certainty interim, the impact of procedure parameters is displayed in this area. The aftereffects of extreme elasticity and the consequences of S/N proportions acquired by programming MINITAB 18 is given in Table 6 for grating blend welding process.

Table 6: Experimental results and S/N ratios for UTS

No. of Runs	Welding Speed	Rotational Speed	Tilt Angle	Ultimate Tensile Strength (MPa)	S/N Ratio
1	66	386	0	204	46.19
2	66	664	1	262.4	48.38
3	66	931	1.5	151.3	43.59
4	90	386	1	323.7	50.20
5	90	664	1.5	210	46.44
6	90	931	0	121.3	41.67
7	132	386	1.5	174.9	44.85
8	132	664	0	166.9	44.45
9	132	931	1	565.8	55.05

The response table for the methods or the crude information and flag to commotion or S/N information at the three quantities of parameter levels are determined from Table 5 and are appeared table 6 and table 7 individually.

Table 7: Raw or mean data response for ultimate tensile strength

Levels	Welding Speed (A)	Rotational Speed (B)	Tilt Angle (C)
1	205.9	234.2	164.1
2	218.3	213.1	384.0
3	302.5	279.5	178.7
Delta	96.6	66.4	219.9
Rank	2	3	1

The rank in table 7 indicates that the increasing order in the first two columns and the rank also increasing order in the last three columns of the effect on the response is welding speed, Rotational speed and Tilt angle.

Table 8: S/N response Table for ultimate tensile strength on friction stir welding

Levels	Welding Speed (A)	Rotational Speed (B)	Tilt Angle (C)
1	46.06	47.08	44.11
2	46.11	46.42	51.21
3	48.12	46.78	44.97
Delta	1.04	1.33	6.08
Rank	2	3	1

The rank in table 8 indicates that the increasing order in the first two columns and the rank also increasing order in the last three columns of the effect on the response is welding speed, rotational speed, and tilt angle same as that calculated from above the raw data.

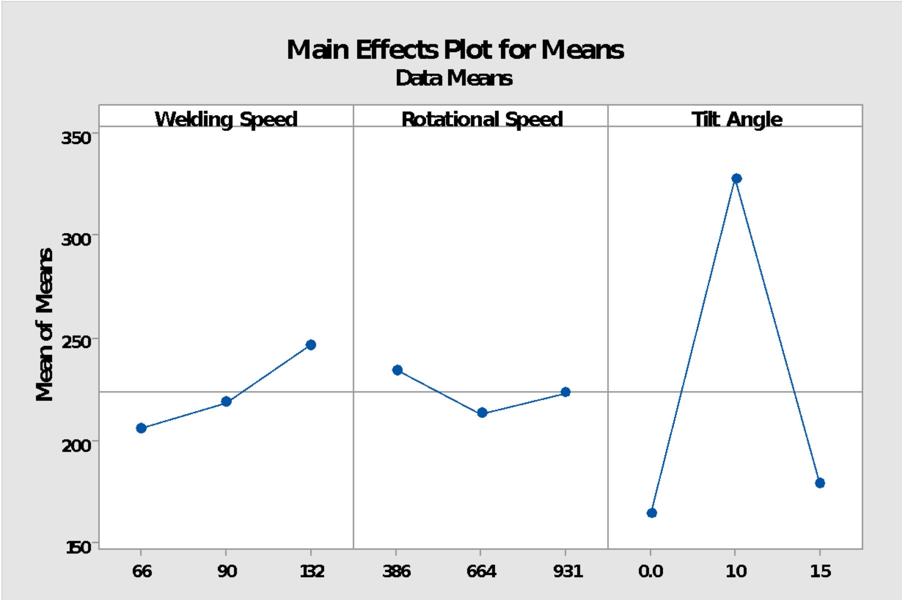

Figure 3: Main effects plot of mean data for UTS on Friction stir welding process

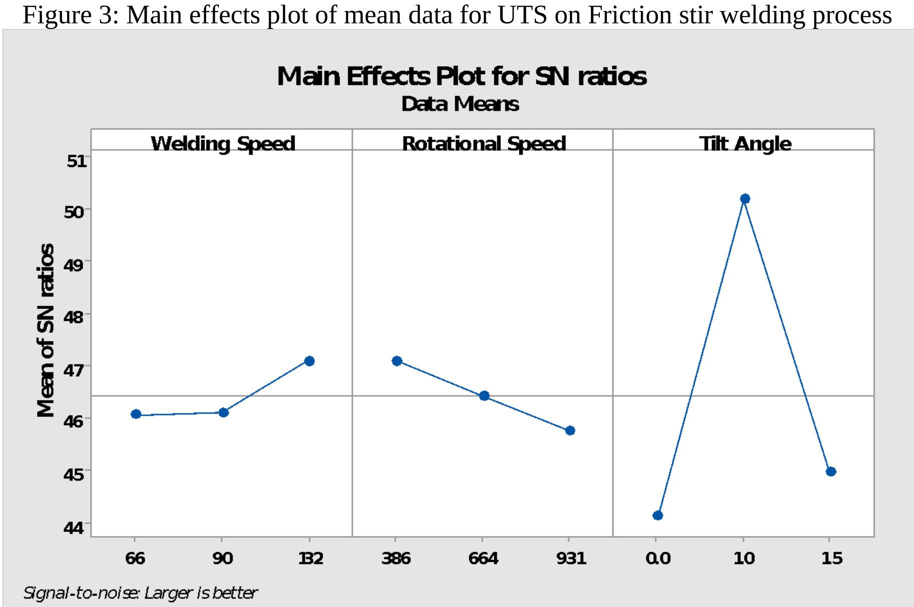

Figure 4: Main effects plot of S/N ratios for UTS on friction stir welding process

Conclusion:

In conclusion, the optimization of friction stir welding (FSW) for Al 6063 alloy has been a significant area of research and development. Through various experiments and investigations, several key findings and recommendations have emerged.it has been established that process parameters such as rotational speed, welding speed, and tool geometry greatly influence the quality and mechanical properties of the weld. By carefully selecting these parameters, it is possible to achieve improved joint strength and reduced defects such as voids and cracks. Additionally, the use of advanced tool materials, such as polycrystalline cubic boron nitride (PCBN), has shown promising results in enhancing the FSW process for Al 6063 alloy.pre-weld heat treatment techniques have been explored to mitigate the negative effects of precipitation and dissolution of alloying elements during welding. By carefully controlling the heat treatment conditions, the microstructure and mechanical properties of the weld can be optimized. post-weld heat treatment methods, such as artificial aging, have proven effective in enhancing the strength and hardness of the weld. This treatment promotes the formation of fine precipitates and reduces the residual stresses, resulting in improved mechanical performance.

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