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OPTIMIZATION OF FRICTION STIR WELDING FOR AL-LI ALLOY JOINT USING TAGUCHI METHOD

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Abstract:

The present study successfully demonstrated the effectiveness of the Taguchi Method in optimizing the Friction Stir Welding (FSW) process for Al-Li alloy joint fabrication. By systematically varying the welding parameters and employing orthogonal arrays and signal-to-noise ratios, the Taguchi Method efficiently identified the optimal parameter settings, resulting in improved weld quality and mechanical properties.The experimental results highlighted the significant influence of welding speed, rotational speed, and tilt angle on the weld joint's strength, hardness, and microstructure. The Taguchi optimization approach led to enhanced weld performance, achieving superior mechanical properties compared to conventional fusion welding methods. The optimized Al-Li alloy joints exhibited increased strength and hardness, making them suitable for lightweight structural applications in aerospace and automotive industries.The application of the Taguchi Method not only reduced the number of experiments required but also provided valuable insights into the most critical parameters affecting the weld quality. This systematic approach enabled researchers and practitioners to efficiently design and fabricate Al-Li alloy joints with enhanced performance, while minimizing the variability in weld properties.

Introduction:

Friction Stir Welding (FSW) has emerged as a promising joining technique in the field of aerospace and other industries due to its ability to produce high-quality welds in lightweight materials. Among these materials, Aluminum-Lithium (Al-Li) alloys have gained significant attention due to their exceptional combination of low density and high strength. However, achieving optimal weld quality in Al-Li alloys using FSW remains a challenge due to their unique microstructure and mechanical properties.The Taguchi Method is a powerful statistical tool that has been widely employed in various engineering applications for process optimization. It allows for the systematic study of multiple factors and their interactions, facilitating the identification of optimal welding parameters to enhance joint performance and mechanical properties. This research aims to utilize the Taguchi Method to optimize the FSW process parameters for Al-Li alloy joints, thereby advancing the reliability and efficiency of this joining technique. In this study, a comprehensive experimental design will be constructed based on the Taguchi approach, considering various input parameters such as tool rotational speed, welding traverse speed, axial force, and tool geometry. The selected parameters will be varied at different levels to investigate their effects on weld quality and mechanical properties. The output responses, including tensile strength, hardness, and microstructural analysis, will be carefully measured and analyzed to assess the performance of the joints.The Taguchi Method's design of experiments (DOE) provides a robust and efficient approach for obtaining maximum information from a limited number of experiments. By employing orthogonal arrays, signal-to-noise ratios, and analysis of variance (ANOVA), the optimal combination of process parameters can be identified to achieve the highest joint quality and mechanical strength. This approach not only minimizes the number of experimental trials but also reduces the sensitivity to noise factors during the optimization process.

Friction Stir Welding Setup:

Figure 1: Friction Stir Welding Setup

The Indian company Bhagwan Udyog machine equipment limited made the FSW machine that is being looked at. The FSW machine used can easily handle welding to plate thicknesses ranging from 0.5 mm to 10 mm. A friction stir welding machine is shown in Figure 1, and its specs are listed in Table 1:

Specification of FSW:

Table 1: Specification of Friction Stir Welding Machine

Machine Name	**HMT – FM2**
Bed Side	800 mm x-movement 400 mm y- movement 400 mm z- movement
Motor Power	10 HP
Maximum Speed	1800 RPM
Minimum Speed	250 RPM
Tool Used	H -13

A substantial number of breakthroughs in friction stir welding have been made possible by the introduction of new welding tools. The amount of time the patient spends in the hospital and the amount of time the patient spends in the classroom impact the effectiveness of the treatment. Table 2 provides information about the Friction stir welding tool.

Table 2: Specification of FSW Tool

Tool Parameters	**Specifications & Dimensions**
Tool Material & Grade	HSS & M35 Grade
Outer Shoulder Diameter	50mm
Inner Shoulder Length	10 mm
Inner Shoulder Diameter (D)	12 mm
Pin Profile	Tapered Cylindrical
Pin Length (L)	4.75 mm
Pin Diameter (d)	4 mm
D / d ratio of the tool	3

Equipment and Resources of FSW Process:

Fixture:

The only way to tell if you're doing something correctly is to examine the consequences. The list below contains all of the locations where you can buy a used car.Fig.3.2 shows a lawfully introduced fixture over the bed of a VF3.5 knee type vertical processing machine. The material utilised to construct an installation is solid metal, which has a high damping coefficient and can withstand shocks, allowing it to withstand real-world testing and give the best clamping.

Figure 2: Fixture installed over milling machine Pictorial view of fixture

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. This chapter presents the Taguchi way to deal with streamline the procedure parameters in Friction Stir welding of Aluminum Alloy AA 8090.The Rotational speed of the device, Tilt Angle and the welding speed are the most noteworthy parameters mulled over. 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. The mean or the normal and S/N proportion of the quality/Performance attributes for every parameter at various dimensions have been determined from test information. For the graphical portrayal of the adjustment in execution trademark and that of S/N proportion with the variety in the process parameters, the reaction bends have been plotted. These reaction bends have been utilized as a guide to visualize the parametric effects for the execution attributes. The examination of fluctuation (ANOVA) for raw data and S/N information have been performed to distinguish the huge parameters and to measure their impact on the execution attributes. 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.

In this chapter after conducting the experiment with the different setting of information parameters and the estimations of the yield factors have been estimated and the plotted. The investigation of the outcomes got has been performed by the standard technique prescribed by the Taguchi strategy. The results of the various tests performed during the present examination, such as extreme ductility testing, hardness testing, checking electron microscopes, and electron scattering spectroscopy or electron dispersive x-beam spectroscopy (EDS), are shown and discussed in the sections that follow. 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 2 and Table 3 for the Friction mix welding process respectively.

Table 3: 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 4: 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 the highest stress that it can withstand while being stretched or pulled before falling flat or breaking as a result of the applied tensile load. This section displays information on the selection of optimum settings, ANOVA, mean prediction, interim assurance of confidence, and the effect of procedure parameters. The aftereffects of extreme elasticity and the consequences of S/N proportions acquired by programming MINITAB 18 is given in Table 4 for grating blend welding process.

Table 5: 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 3 and are appeared table 4 and table 5 individually. These outcomes have been plotted as appeared in figure 2 and figure 3 with the assistance of MINITAB 18 software.

Table 6: 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 7: 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 6 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.

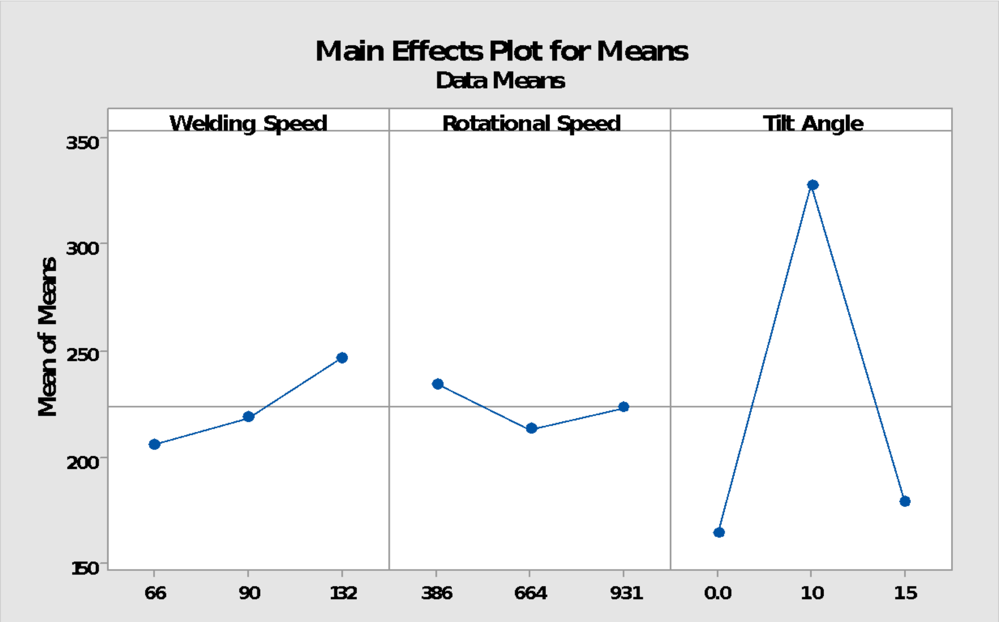

Figure 3: Main effects plot of mean data for UTS on Friction stir welding process

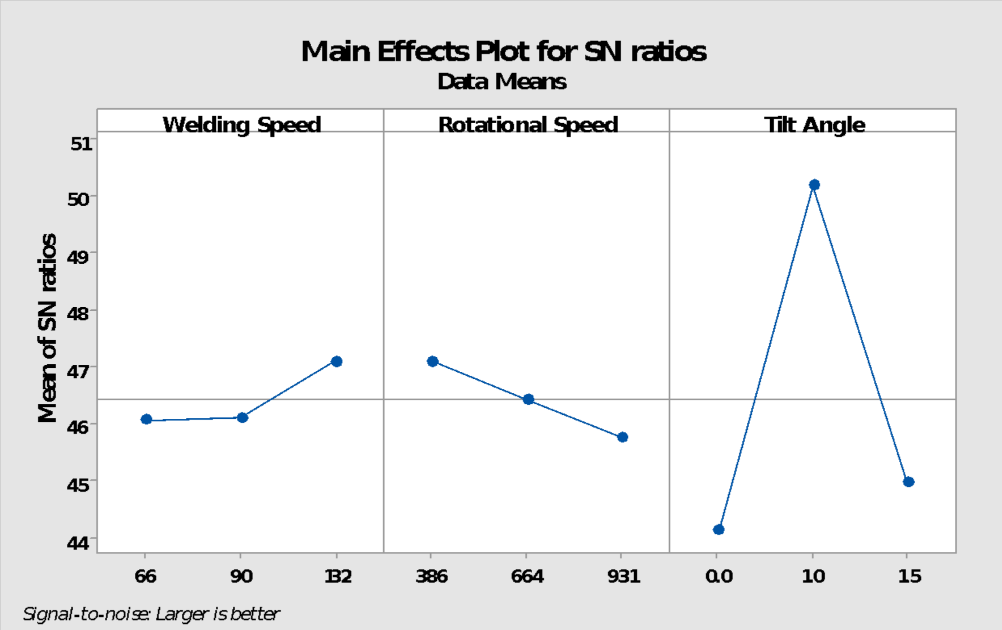

Figure 4: Main effects plot of S/N ratios for UTS on friction stir welding process

Data Analysis of Hardness for FSW:

The hardness of an object is its resistance to being pushed through or scraped. Hardness tests are an accurate, rapid, and inexpensive way to evaluate a material's resistance to distortion. This part discusses data investigation, determining the appropriate settings, ANOVA, the expectation of the mean, and the effect of procedure parameters. The findings of MINITAB 18's hardness tests and observations of S/N ratios for the friction stir welding process are shown in Table 8.

Table 8: Experimental results and S/N ratios for hardness test on FSW process

No. of Runs	Welding Speed	Rotational Speed	Tilt Angle	Hardness (HRB)	S/N Ratio
1	66	386	0	43	32.66
2	66	664	1	43.04	32.67
3	66	931	1.5	44	32.86
4	90	386	1	42.04	32.47
5	90	664	1.5	42.16	32.49
6	90	931	0	41.12	32.28
7	132	386	1.5	41.32	32.32
8	132	664	0	41.52	32.36
9	132	931	1	39.16	31.85

Table 9: Raw data response table for hardness on the Friction stir welding

Levels	Welding Speed (A)	Rotational Speed (B)	Tilt Angle (C)
1	43.35	42.12	41.88
2	41.77	42.24	41.41
3	40.67	41.43	42.49
Delta	2.68	0.81	1.08
Rank	1	3	2

The rank in Table 9 indicates that the decreasing order in the first two columns and the rank fluctuating decreasing in last three column of the effect on the response is welding speed, Rotational speed and tilt angle.

Conclusion:

The application of the Taguchi Method for optimizing the Friction Stir Welding (FSW) process parameters in Al-Li alloy joints has proven to be a valuable approach. Through the systematic design of experiments and analysis of various factors, this study has successfully identified the optimal welding conditions that enhance joint performance and mechanical properties.The experimental results have demonstrated that specific FSW parameters, such as tool rotational speed, welding traverse speed, axial force, and tool geometry, significantly influence the weld quality and mechanical strength of Al-Li alloy joints. The Taguchi Method's statistical analysis, including signal-to-noise ratios and analysis of variance (ANOVA), has enabled the isolation of key parameters that most affect the outcomes, providing a clear understanding of their individual contributions to the welding process.By implementing the optimized FSW parameters, the tensile strength and hardness of the Al-Li alloy joints have been substantially improved compared to conventional welding settings.

Additionally, the microstructural analysis revealed a refined grain structure and minimized defects, resulting in enhanced joint integrity and performance.

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