PARAMETRIC ANALYSIS OF ALUMINIUM ALLOY 6061 T6 BUTT JOINT BY LASER WELDING

G.Damodaran[1]

[1] *Assistant Professor, Department of Mechanical Engineering, Ganadipathy Tulsi's Jain Engineering College, Tamil Nadu, India*

Abstract - ***Laser beam welding (LBW) is a field of growing importance in industry with respect to traditional welding methodologies due to lower dimension and shape distortion of components and greater processing velocity. Because of its high weld strength to weld size ratio, reliability and minimal heat affected zone, laser welding has become important for varied industrial applications. With increased use of laser welding in continuous mode, there will be increased dependence on the use of equations to predict the dimensions of the weld bead. This paper presents the Pulse Frequency, Welding Speed and Pulse Energy on penetration depth to predict the geometry of weld bead in butt joint of aluminium alloy of 2 mm thickness are presented. A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of aluminium 6061 material & optimize the welding parameters. Finally the conformations tests have been carried out to compare the predicated values with the experimental values confirm its effectiveness in the analysis of penetration..***

Key Words:* *Laser welding, optimization, orthogonal array, S/N ratio.

1. INTRODUCTION

Laser beam welding (LBW) is a fusion joining process that uses the energy from a laser beam to melt and subsequently crystallize a metal, resulting in a bond between parts. Lasers generate light energy that can be absorbed into materials and converted to heat energy. Because of high power density of the laser beam, laser welding is characterized by very narrow fusion zone, narrow weld width and high penetration [1]. The energy input in laser welding is controlled by the combination of focused spot size, focused position, shielding gas, laser Pulse Frequency and welding speed. For the laser beam welding of butt joint, the parameters of joint fit-up and the laser beam to joint alignment [2] becomes important. In applying thermal energy to small areas, there are no other methods as efficient as lasers. Laser welding can be used successfully for welding low carbon, alloy steels, stainless steels, Titanium and its alloys and some Nickel alloys. Specific applications of laser welding include welding of pipeline, shipbuilding, and making micro-connections in electronic industries.

Aluminium 6061 have many advantages such as thermal conductivity, high resistance to corrosion and high stability at elevated temperatures and also it is a superior absorber of laser light. Due to these advantages, it is used in numerous industries, including electronics, medical instruments, home appliances, automotive and specialized tube industry. The rapid heating and cooling characteristic of laser welding alters the behavior of aluminium as compared to its reaction to welding processes with higher heat inputs [3]. A common problem with conventionally welded aluminium is sensitization. This needs a thorough understanding of the process characteristics affecting the technological and metallurgical characteristics of the weld. The effects of process parameters on bead geometry can be studied with the help of Taguchi technique, orthogonal array, signal to noise (S/N) ratio and analysis of variance.

Ugur Esme [4] an investigation of the effect and optimization of welding parameters on the tensile shear strength in the resistance spot welding (RSW) process. The experimental studies were conducted under varying electrode forces, welding currents, electrode diameters, and welding times. K. Kishore, P. V. Gopal Krishna, K. Veladri and Syed Qasim Ali[5] Research on welding of materials like steel is still critical and ongoing. K. Kishore, P. V. Gopal Krishna, K. Veladri and Syed Qasim Ali[5] Research on welding of materials like steel is still critical and ongoing. Sourav Datta, Ajay Biswas, Gautam Majumdar [6] Sensitivity Analysis has been carried out to check the case sensitiveness of relation importance of different bead geometry parameters imposing predominant effect on the optimal parametric combination. P K Palani, Dr N Murugan, (7) The DOE using Taguchi approach can significantly reduce time required for experimental investigations(8-10). In this investigation, in the first stage, Taguchi's orthogonal arrays were used to conduct the experiments to find the contributions of each factor and to optimize the parameter settings.

2. TAGUCHI'S DESIGN METHOD

Taguchi Technique is applied to plan the experiments. The Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly and at low cost. Dr.Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the mix of Design of Experiments with optimization of control parameters to obtain best results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

3. SIGNAL-TO-NOISE RATIO

There are 3 Signal-to-Noise ratios of common interest for optimization

(I) Smaller-The-Better:

n = -10 Log10 [mean of sum of squares of measured data]

(Ii) Larger-The-Better:

n = -10 Log10 [mean of sum squares of reciprocal of measured data]

(Iii) Nominal-The-Best:

$$n = 10 \text{ Log10} \frac{\text{square of mean}}{\text{variance}}$$

4. WORK MATERIAL

The work material used for present work is aluminium 6061 t6 plate, the dimensions of the work piece length 50 mm, width 100mm, thickness 2 mm.

Table 1: Welding Parameters And Their Levels

Symbol	Welding Parameters	Level 1	Level 2	Level 3
A	Pulse Frequency,Hz	3	4	5
B	Welding Speed,mm/min	30	35	40
C	Pulse Energy,J	28	30	32

L9 3 Level Taguchi Orthogonal Array:

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses). The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. Below Table No.2 shows L9 Orthogonal array from Table1.

Table 2 L9 orthogonal array

Expt. No.	Process Parameters		
	Pulse Frequency	Pulse Energy	Welding Speed
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	2
9	3	3	1

5. ANALYSIS OF S/N RATIO

In the Taguchi Method the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard Deviation) for the output characteristic. Therefore, the S/N ratio to the mean to the S. D. S/N ratio used to measure the quality characteristic deviating from the desired value. The S/N ratio S is defined as (11)

$$S = -10 \log (M.S.D.)$$

where, M.S.D. is the mean square deviation for the output characteristic.

To obtain optimal welding performance, higher-the better quality characteristic for penetration must be taken. The M.S.D. for higher-the –better quality characteristic can be expressed

$$M.S.D = \frac{1}{m} \sum \frac{1}{P_i^2}$$

Where, Pi is the value of penetration

Table3: Experimental result for penetration and S/N ratio:

Exp. No	Pulse Frequency	Pulse Energy	Welding Speed	Penetration	S/N Ratio
1	3	28	30	1.5	3.522
2	3	30	35	0.78	-2.158
3	3	32	40	1.73	4.761
4	4	28	35	1.43	3.107
5	4	30	40	1.82	5.201
6	4	32	30	1.70	4.609
7	5	28	40	1.42	3.046
8	5	30	30	1.04	0.341
9	5	32	35	1.48	3.405

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The S/N response table for penetration is shown in Table No.4.

Table 4: S/N response table for Penetration

Symbol	Parameter	Mean S/N Ratio		
		Level 1	Level 2	Level 3
A	Pulse Frequency	2.042	4.306	2.264
B	Pulse Energy	3.225	1.128	4.258
C	Welding Speed	2.824	1.451	4.336

6. ANOVA (ANALYSIS OF VARIENCE)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as,

$$SS_T = \sum (n_i - n_m)^2$$

The result of ANOVA is shown in table 5

Table 5: Result of analysis of variance for Penetration

Symbol	Welding Parameter	DOF	Sum of Sq.	Mean	F	(%)
A	Pulse Frequency	2	7.95	3.975	0.90	17.86
B	Pulse Energy	2	15.26	7.63	1.73	34.28
C	Welding Speed	2	12.49	6.245	1.42	28.06
Error		2	8.81	4.405		19.7
Total		8	44.51			100
Error		2	7.95	3.975	0.90	17.86

7. CONFORMATION TEST

Once the optimal level of design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio using the optimal level of the design parameters can be calculated as

$$\hat{\eta} = \eta_m + \sum_{i=1}^{n} (\bar{\eta}_i - \eta_m)$$

where,

η_m --total mean of S/N ratio,

$\bar{\eta}_i$ --the mean of S/N ratio at the optimal level, and n is the number of main welding parameters that significantly affect the performance.

The comparison of the predicted penetration with actual penetration using the optimal parameters, good agreement between the predicted and actual penetration being observed which is shown in the table 6.

Table -6: Result of the conformation experiment

	Initial Welding Parameters	Optimal Welding Parameters	
		Prediction	Expt.
Level	A2B2C2	A3B1C3	A3B1C3
Penetration	1.34 mm	2.22 mm	1.78 mm
S/N Ratio	2.573	7.16	5.01

8. CONCLUSIONS

Taguchi optimization method was applied to find the optimal process parameters for penetration. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

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