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INFLUENCE OF PROCESS PARAMETERS ON WELD BEAD WIDTH IN LASER BEAM WELDING USING DOE TECHNIQUE

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ABSTRACT

The ability to create new advanced mathematical techniques with improved and unique properties has contributed to the progress of many areas of science. Especially in the past few decades, the applications in welding have relied heavily and in some critically on design of experiments. Accurately complied statistics help to achieve process efficiency in manufacturing activities, which in turn results in modernized production methods. The laser welding which is one of the modern manufacturing tools has the output variables which are characterized with parameters like depth of penetration and bead width in addition to the qualitative metallurgical factors. Laser input parameters like beam power, beam angle and welding speed are observed to have an influence on the output parameter weld bead width. A solid state Nd: YAG laser system with 2 kW capacity at WRI is used for conducting the experimental study. The effect of input process parameters on the weld bead width have been investigated using full factorial design of experiments, employing orthogonal array technique. The individual and interactive effect of input parameters on the depth of penetration is studied in detail for AISI 304 grade stainless steel. Using Analysis of Variance (ANNOVA), the significance of input parameters is evaluated. The effect of input parameters on the weld bead width is arrived at in the form of second degree polynomial equation using orthogonal contrast coefficients.

Key words: ANNOVA, Nd:Yag laser, Weld bead width, Beam power, Welding speed, Beam Angle.

1. INTRODUCTUTION

Technology has led to the increased use of Nd:Yag laser beam welding as replacement to other welding methods in various applications. This paper deals about the mathematical modeling of laser beam welding process [7] which helps to understand the effect of laser input parameters on the resultant output the weld bead width. Beam Power, Beam Angle and Welding Speed are identified as input variables[1,2] and the beam focal length, spot diameter, shielding gas are considered as fixed parameters, maintained at pre determined levels. Weld trials are conducted on stainless steel plate of AISI 304 grade, with 4 mm thickness. Experiments are conducted using full factorial design of experimental technique and the orthogonal array is selected for this technique [3,4]. Experiments are conducted after proper randomization of the experimental sequence [5,6]. The laser beads are prepared by metallographic methods and etched to record the bead geometry profile with the help of profile projector. Using the available input data, the main effects and the interaction effects of the parameters on the weld bead width are calculated through factorial design. Orthogonal contrast coefficient is used for arriving at the polynomial equation [6].

2. OBJECTIVE

The objective of the present work is to study the effect of process parameters (Beam Power, Beam Angle and Welding Speed) on Weld bead width in 4mm thick AISI 304 grade steel plates by using 3k factorial design of experiments. Obtained results are analyzed for determining the effect of process parameters and a polynomial equation is arrived using orthogonal contrast coefficient to determine the Weld bead width

3. DESIGN OF EXPERIMENTS

Factorial design of experimental approach is selected for the investigation varying three controllable parameters at three levels, since 3k factorial design is efficient to study the effects of two or more factors. Factors and interactions are denoted by capital letters. Without loss of generality three levels of factor are referred as Low, Intermediate and High. These levels are designated by the digits 0 (Low), 1(intermediate),

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2 (High). Each treatment combination in the 3k design is denoted by k digits where the first digit indicates a level of factorial, A (Welding Speed), B (Beam Angle), indicates the level of factorial second and C (Beam Power) indicates the level of three. The three factors and each factor at three levels are arranged using factorial experiment. This results in 27 treatment combinations with 26 D.O.F. Each main effect has 2 degrees of freedom; each 2 factor interaction has 4 degrees of freedom and 3 factor interactions have 8 degrees of freedom if there are n replicates. The sum of squares is calculated using the standard methods of factorial design. In addition, for the factors which are quantitative and equally spaced the main effects is partitioned into linear and quadratic components each with single degree of freedom. The two factor interaction is decomposed into linear * linear, linear * quadratic, quadratic * linear, quadratic * quadratic. The three factor interaction is portioned into eight single degree of freedom corresponding to linear * linear * linear, linear * linear * quadratic, linear * quadratic * linear and so on. Using all the interaction effects a polynomial equation is created using orthogonal contrast co efficient.

4. EXPERIMENTAL PROCEDURE.

The study was conducted to optimize the parameters for laser beam welding. The following input parameters were identified for ND: YAG laser welding process under three variations. The first variation, material properties are selected based on the applications and the second variation; machine parameters are specified based on equipment capacity, type of materials and application. The third variation, controllable parameters are the one that are taken up for the study.

4.1 Material Parameters

1. Type of material: SS (304).
2. Thickness of the material: 3.15mm.

4.2 Machine Parameters – Fixed

1. Type of beam mode: Continuous wave.
2. Focal Length: 80mm
3. Shielding gas: Argon shielding gas at a floe rate of 20 lit/min.

4. 3 Machine Parameters

1. Beam Power: 0 to 2000 watts.
2. Beam Angle: 5 to 15 deg.
3. Welding Speed : 0.8 to 2 m/min

5. EXPERIMENTAL TRIALS

The input parameters Beam Power, Beam Angle and Welding Speed are varied using the following sequence after randomization process to obtain more homogeneous effect distribution through out the investigative field. Two sets of trials are conducted to make the data more consistent. For each set of trials 27 experiments are conducted and as total 54 experiments are carried out. The Table 1 and 2 give the details of the experiments and the output responses.

Table 1: First set of experimental trials

	Input parameters			Output parameter
Ex.No	BP	BA	WS	BW
1	600	10	0.8	1.05
2	600	15	0.8	1.09
3	600	5	2	0.83
4	600	5	0.8	1.01
5	1000	15	2	1.00
6	600	15	2	0.83
7	1000	5	0.8	1.05
8	1400	15	0.8	1.30
9	1400	5	0.8	1.15
10	600	10	1.4	1.08
11	1400	10	1.4	1.15
12	1000	10	2	0.95
13	1000	15	0.8	1.18
14	600	10	2	0.88
15	1000	5	1.4	1.05
16	1400	5	1.4	1.13
17	1400	10	2	1.15
18	600	15	1.4	1.15
19	1000	15	1.4	1.30
20	1400	15	2	1.20
21	600	5	1.4	1.00
22	1000	10	0.8	1.15
23	1400	5	2	1.10
24	1000	10	1.4	1.20
25	1400	15	1.4	1.18
26	1000	5	2	0.90
27	1400	10	0.8	1.25

BP : Beam power (watts)
BA : Beam Angle (Deg)
WS : Welding Speed (m/min)
BW : Bead Width (mm)

Table 2: Second set of experimental trials

	Input parameters			Output parameter
Ex.No	BP	BA	WS	BW
28	600	10	0.8	1.03
29	600	15	0.8	1.10
30	600	5	2	0.91
31	600	5	0.8	0.99

32	1000	15	2	1.01
33	600	15	2	0.81
34	1000	5	0.8	1.05
35	1400	15	0.8	1.31
36	1400	5	0.8	1.14
37	600	10	1.4	1.09
38	1400	10	1.4	1.16
39	1000	10	2	0.94
40	1000	15	0.8	1.20
41	600	10	2	0.85
42	1000	5	1.4	1.11
43	1400	5	1.4	1.11
44	1400	10	2	1.16
45	600	15	1.4	1.13
46	1000	15	1.4	1.31
47	1400	15	2	1.22
48	600	5	1.4	1.01
49	1000	10	0.8	1.16
50	1400	5	2	1.10
51	1000	10	1.4	1.22
52	1400	15	1.4	1.16
53	1000	5	2	0.92
54	1400	10	0.8	1.23

BP : Beam power (watts)
BA : Beam Angle (Deg)
WS : Welding Speed (m/min)
BW : Bead Width (mm)

6. EXPERIMENTAL DESIGN AND MAIN EFFECTS OF VARIATIONS ON RESPONSE.

The main effects of the input parameters on the output response are shown in table 3. The response which can be measured is quantitative response and depth of penetration is selected as quantitative output in this investigation. The response which can be assessed but not quantifiable is qualitative response and the defects are all part of this qualitative response. The interactive effects of variances are shown in the tables 4, 5 and 6.

Table 4: Interactive effects of variances A*B (welding speed * beam angle) on the response Y (Weld Bead Width)

Yij	0.8	1.4	2
5	6.39	6.46	5.76
10	6.87	6.9	5.93
15	7.18	7.23	6.07

Table 5: Interactive effects of variances A*C (welding speed * beam power) on the response Y (Weld Bead Width)

Yik	0.8	1.4	2
600	6.27	6.46	5.11
1000	6.79	7.24	5.72
1400	7.38	6.89	6.93

Table 6: Interactive effects of variances B*C (beam angle * beam power) on the response Y (Weld Bead Width)

Yjk	5	10	15
600	5.75	5.98	6.11
1000	6.13	6.62	7
1400	6.73	7.1	7.37

The values shown in table 4, 5 and 6 show the interactive effects of the input parameters on the output response weld bead width, The analysis of variance of main effects is shown in table 7.

Table:3 Experimental Design And Main Effects Of Variations On Response.

BP	WS									
	0.8 m/ min			1.4 m/min			2 m/min			
	5 deg	10 deg	15 deg	5 deg	10 deg	15 deg	5 deg	10 deg	15 deg	
600 watts	1.01 0.99	1.05 1.03	1.09 1.10	1.00 1.01	1.08 1.09	1.15 1.13	0.83 0.91	0.88 0.85	0.83 0.81	Yk
	2.00	2.08	2.19	2.01	2.17	2.28	1.74	1.73	1.64	17.84
1000 watts	1.05 1.05	1.15 1.16	1.18 1.20	1.10 1.11	1.20 1.22	1.30 1.31	0.90 0.92	0.95 0.94	1.00 1.01	
	2.10	2.31	2.38	2.21	2.42	2.61	1.82	1.89	2.01	19.75
1400 watts	1.15 1.14	1.25 1.23	1.30 1.31	1.13 1.11	1.15 1.16	1.18 1.16	1.10 1.10	1.15 1.16	1.20 1.22	
	2.29	2.48	2.61	2.24	2.31	2.34	2.20	2.31	2.42	21.2
Yi	20.44			20.59			17.76			
Yj	18.61			19.7			20.48			58.79

Table 7: Analysis of variance of main effects

Sources of variation	Sum Squares	Degrees of Freedom	Mse = M Streat/dof	Fo= Mstreat/ Mse	F test
A	0.281737	2	0.1408685	589.6820	5.49[a]
B	0..98026	2	0.049013	205.1706	5.49[a]
C	0.31556	2	0.15778	660.4744	5.49[a]
AB	0.01235636	4	0.0031409	13.14795	5.49[a]
AC	0.124163	4	0.03104075	129.9380	5.49[a]
BC	0.010874	4	0.0027185	11.379767	5.49[a]
ABC	0.0202364	8	0.00252955	10.58881	NS
Error	0.00645	27	0.00023888		
Total	0.86961	53			

a = 1 % significant.

The interactive effects is split into linear* linear, linear* quadratic, quadratic* linear, quadratic*quadratic components. The analysis of variance of interactive components is shown in table 8.

Table 8: Analysis of variance of interactive effects

Sources of variation	Sum Squares	Degrees of Freedom	Mse = M Streat/dof	Fo= Mstreat/ Mse	F test
A	0.281737	2			
A_L		1	0.1995111	835.1938	7.68[a]
A_Q		1	0.0822259	344.21424	7.68[a]
B	0.098026	2			
B_L		1	0.09713611	406.63140	7.68[a]
B_Q		1	0.0008898	3.72488	
C	0.31556	2			
C_L		1	0.3136	1312.7930	7.68[a]
C_Q		1	0.0019592	8.201607	7.68[a]
AB	0.0125636	4			
AB_{LL}		1	0.0096	40.18754	7.68[a]
AB_{LQ}		1	0.00268888	11.256195	7.68[a]
AB_{QL}		1	0.000272222	1.1395763	LS
AB_{QQ}		1	0.000001851	<1	
AC	0.124163	4			
AC_{LL}		1	0.021004166	87.92768	7.68[a]
AC_{LQ}		1	0.0595125	249.131363	7.68[a]
AC_{QL}		1	0.003901388	16.3319993	7.68[a]
AC_{QQ}		1	0.0397449	166.3801	7.68[a]
BC	0.010874	4			
BC_{LL}		1	0.0032667	13.675066	7.68[a]
BC_{LQ}		1	0	<1	
BC_{QL}		1	0.0076056	31.83858	7.68[a]
BC_{QQ}		1	0.000001851	<1	
Error	0.00645	53	0.00154		

a= 1 percent significant, LS – Less Significant

7. RESULTS AND DISCUSSIONS.

Beam power exhibited significant influence on depth of penetration. Welding speed also found too significantly effect the weld bead width. Beam angle is observed to have very low effect on the weld bead width. Among the interactive effects of input parameters the interaction between beam power and welding speed show significant effect on depth of penetration. A second order polynomial equation is derived to calculate the weld bead width (Y) as function of input parameters Welding speed (X_1), Beam angle (X_2), and Beam power (X_3).

$$Y=1.477693781X_1^2 + 0.004449757X_2^2 + 0.000002308X_3^2 - 3.61719687X_1 - 0.0695353 X_2 - 0.004606317X_3 - 0.008706998X_1X_2 + 0.009764966X_1X_3 + 0.000067499X_2X_3 - 0.001222244X_1X_2^2 - 0.000005035X_1X_3^2 + 0.003238704X_2X_1^2 - 0.000003038X_3X_2^2 - 0.000002118X_1^2X_3^2 + 2.780235348$$

8. VALIDATION TRIALS & RESULTS

The second order polynomial equation thus obtained is validated by conducting validation trials and the bead width obtained by solving the equation is compared with the actual experimental data. On comparison the value of bead width got by solving the equation is found very close to the experimental bead width value. The comparison results are shown in Table 9.

Table 9: Comparison of calculated value and measured value

Ex.No	Input parameters			Measured	Calculated
	BP	BA	WS	BW	BW
1	900	10	0.9	1.14	1.17
2	1600	5	1.5	1.07	1.05
3	1300	5	1	1.15	1.14
4	600	10	1.7	1.00	0.97
5	750	15	1.9	0.98	0.96
6	1000	15	1.4	1.23	1.25
7	1500	10	0.7	1.21	1.20
8	1200	5	1.2	1.17	1.17
9	800	10	1.6	1.08	1.08
10	500	5	1.8	0.94	0.92

BP : Beam power (watts)
BA : Beam Angle (Deg)
WS : Welding Speed (m/min)
BW : Bead Width (mm

9. CONCLUDING REMARK

A detailed study of the most important three parameters (Beam power, Welding speed, Beam angle) that affect the weld bead width in ND: YAG laser beam welding was performed in this investigation. Using the ANNOVA analysis technique we were able to identify, the factors that are most significant in affecting the depth of penetration. The analysis results also suggest the best setting of these control factors. It is noted that the second order polynomial equation derived form the present investigation can be readily applied to calculate the weld bead width and the corresponding best setting of the various control parameters can be obtained accordingly.

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