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Optimization of laser welding of tri – metal joint via response surface methodology

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Abstract

Laser welding input parameters play a major role in determining the quality of a weld joint. In the nuclear power plants, hybrid structures of nickel and steel alloys offer an advantage in comparison to conventional materials, e.g. in heat exchanger tube areas. Due to demand in the nuclear industry for new material combinations based on commercially available and qualified materials, research into thermal joining of dissimilar materials has been initiated. The use of laser for joining mild steel / nickel with 316L austenitic stainless steel filler material and structures offers some advantages compared with usual thermal joining processes. The main aim is the control of phase formation, which occurs during thermal joining of mild steel to nickel. In this research work microstructure study and optimization of laser welding of mild steel / nickel sheets with wire feeding was done using Central Composite Design(CCD) and Response Surface Methodology (RSM) are used to build the mathematical model. By means of the laser power, welding speed and pulse width on the tensile strength model was developed and tested by analysis of variance method (ANOVA), the relationship between process parameters and output response and interaction among the process parameters are analyzed and discussed in detail.

Keywords: Laser welding; mild steel; Nickel; 316L stainless steel ; optimization; Ultimate tensile strength;.

1. Introduction

Nickel is a common material now rapidly gaining popularity in aerospace, nuclear power plants and food processing industries. Dissimilar metal joining of mild steel and nickel needs solution in assembling sections. The experimental investigations on Inconel 600 and Inconel 690 results that the base metals are not severely affected by the heat of welding and achieved satisfied tensile and shear strength. The characteristics of Neodymium-Doped Yttrium Aluminium Garnet (Nd:YAG) laser enable the welding of complicated structure in the nuclear power plant [1]. Pulsed Nd:YAG lasers are used in various aspects of nuclear power plant joints by laser brazing welding with zinc based filler wire. The strength of the joint superior when company with the conventional joining methods [2]. CO2 laser welding process was successfully applied on AISI316 stainless steel and AISI1009 low carbon steel plates. Welding speed and laser power has no stronger effect on the fusion area among the selected parameters [3]. Laser welding is so successful for welding of low carbon, alloy steels, stainless steel, titanium and alloys and some Nickel alloys [4]. AISI 304 stainless steel to join with AISI 420 stainless with pulsed Nd:YAG laser results good fillet geometry reduction in hardness forth the cross section of the weld zone was observed. The laser practice for dissimilar material is a suitable technique for dissimilar metal joints [5]. A laser - braze welding process for dissimilar Al-Cu connections have been developed and higher strength has been measured. Intermetallic beam width has shown, that was welding of the interface provides a better mechanical performance than underwelding [6]. AISI420 stainless steel to Kovar alloy dissimilar joint investigated using pulsed Nd:YAG laser. Sound welding can be brought out in joining of alloys when the heat input is low and hardness improved by solid solution strengthening and chromium carbide precipitation strengthen mechanism [7]. Nd:YAG laser is used to clad Inconel 600 wire on the same material sheet and hardness variations were analysed [8]. Pulsed Nd:YAG laser can be used to join Monel 400 thin foils results pulse energy effects on tensile properties and heat affected zone. Nickel based alloys normally good crack resistant so that no welding cracks were found. In this foil welding heat affected zone control is considerable importance for welder joint quality [9]. Laser welding investigations are carried out on dissimilar Titanium-stainless steel combinations. The experiments indicated here the embrittlement on the weld is leading the combination not feasible. The use of interlayer in the form of tantalum strip has gradually improved the joint strength. The joints were showing very less detects in welder [10]. Laser butt welding of medium carbon steel is investigated using co2 laser and optimized the process parameters, speed, focal position, power on heat input, bead geometry, weld zone width and heat affected zone based on Box-Behnken design. Welding speed has a unfavorable effect on all the responses and laser power has a positive effect. The focal position effects on Heat affected zone (HAZ) and weld zone width [11]. The experimental investigation on diode laser transmission welding of dissimilar thermo plastics between polymethyl methacrylate and Acrylonitrile butadiene styrene has been carried out and the effect of laser power, welding speed, stand- off distance and clamp pressure on weld strength and weld width investigated using response surface

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methodology (RSM). The above parameters control heat input to the weld zone and the quality of the weld [12]. A plasticing (TRIP700) steel sheets was done using response surface methodology (RSM) for laser power, welding speed, focus position on the heat input, weld bead geometry, ultimate tensile strength based on Box-Behnken design. Welding speed is the most significant parameter during the welding process [13]. Laser cladding of TC4 metal powder on the same base metal is investigated between clad geometry and laser power, travel speed and powder feed rate using central composite design (CCD) and response surface methodology (RSM) [14]. Nd:YAG laser welding of Nickel based alloy C-276 is investigated for the microstructure and mechanical properties. By varying the scan speed and other parameters kept constant for the experimentation and the weld join exhibited well matching tensile strength with that of base metal [15]. Full factorial design can be used to enhance the laser welding of AISI 416 and AISI 440 to obtain the most desirable weld bead geometry and shearing force for the optimal welding parameters, laser power, welding speed and fiber diameter. Laser power and welding speed are the most important factors affecting the responses [16]. Nickel based K 418 alloy can be welded by any Nd:YAG laser and investigated the microstructure and micro-hardness study in detail. The results show that the micro-hardness of the welded beam and HAZ are higher than the base metal due to the partial dissolution and alloy elements redistribution [17]. Austenitic stainless steel 304 butt joining by laser beam welding can be done and analyzed the beam power, welding speed and beam angle on bead dimensions using central composite design (CCD) and response surface methodology (RSM), welding speed plays a significant role in the responses [18].

However there is no information available in the open literature on prediction of optimum laser welding process parameters to attain maximum tensile strength in Nickel 200 / mild steel sheet dissimilar joints with 316L stainless steel filler wire. Hence in this investigation an attempt was made to develop an empirical relationship to predict tensile strength of laser beam welded dissimilar joints using statistical tools such as design of experiments, analysis of variance and regression analysis. This paper presents the mathematical models developed using response surface methodology for predicting the main and interaction effects of laser beam welding variables on tensile strength from the experimental data obtained for dissimilar welding of Nickel 200 and mild steel sheets of 1.5mm thickness using 316L austenitic stainless steel filler wire with 0.4mm diameter.

2. Experimental Procedure

The welding trials were carried out on 1.5mm thick sheet of Nickel 200 and mild steel sheets. Both the materials were joined by 316L stainless steel filler wire with 0.4mm diameter. The material composition of the metals is given in Table 1.

Table .1. Chemical composition of the materials (Wt%)

Material	C	Si	Mn	P	S	Cr	Ni	Mo	Zn	Fe	Co
AISI 1008	0.25	0.28	1.03	0.04	0.05	-	-	-	-	Bal	-
Ni 200	-	-	0.188	-	-	0.078	Bal	-	0.117	0.29	0.059
AISI 316L Filler wire	-	0.75	2	0.045	0.03	16-18	10-14	2-3	-	Bal	-

Pulsed Nd:YAG laser (Germany) with maximal average power 100W was used for welding of the dissimilar metal joint .Protective argon gas 10 l/min was supplied with the laser beam.

2.1 Plan of Investigation

To achieve the desired aim, the current investigation was planned in the following sequence:

- (i) Identifying the important process variables.
- (ii) Developing the design matrix.
- (iii) Finding the upper and lower limits of the process control variables.
- (iv) Conducting experiments as per design matrix.
- (v) Developing an empirical relationship using response surface methodology.
- (vi) Checking the adequacy of the models developed.
- (vii) Metallurgical study of the welded joints by SEM/EDS technology.

Table .2. Control parameters and levels

Parameter	Units	Notation	Factor levels		
			-1	0	1
Beam power	Watts	P	40	50	60
Welding speed	mm/s	S	0.7	1.4	2.1
Pulse energy	Joules	E	1.0	1.63	2.25

The response surface methodology (RSM) is used in the design matrix formation. Central composite (CCD) rotatable design face centered matrix class. The selected matrix consists of a full factorial 2^3 =8 plus 6 centre points and 6 star points [20].

The variants are known as natural variables if they were expressed in physical units of measurements. In the RSM, the natural variables are switched over to coded variables which more dimensionless. Trial was conducted by varying one of the parameters while keeping rest at constant values. The working range was decided by visually inspecting the bead strong and smooth appearance. The maximum capacity of the machine is to produce 100W of laser of maximum mean power and safer working range was identified as between 40W to 60W of power. The upper limit of the factor was coded as +1 and the lower limit as -1, the coded values for intermediate range being calculated from the relationship. The selected levels of the other process parameters with their units and notations are given in Table 2. A 100W pulsed Nd:YAG laser welding machine manufactured by OR laser Ltd., Germany, (model ECO 2600) was used to conduct the experiment. This machine is suitable for repairing of mechanical parts with complex alloys by deposition welding.

Alloy steel filler material was used to join the Nickel and low carbon steel sheets. Argon inert gas was supplied at the rate of 10 l/min to avoid contamination of the molten pool. Nickel and low carbon steel sheets of ASTM standard, 20 numbers of butt joints were welded with deposition method by varying the process variables as per the design matrix. The spot diameter is 0.8mm with the focal length of 180mm.The experiments were conducted according to the design matrix at random to avoid systematic errors creeping into the system. Typical welded sheet is shown in Fig.1 (a) & (b) along with the values of the process variables used in the respective trial as shown in Table 3.

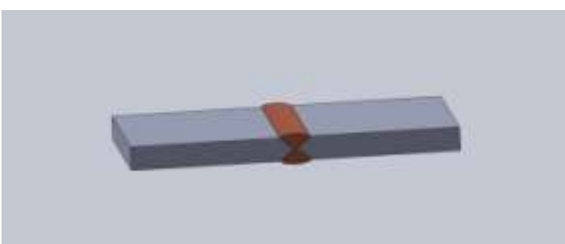

Fig. 1(a) . Schematic diagram of specimen

Fig. 1(b) . Photograph of a tensile specimen

Table .3. Design matrix and experimental results

Std	Run	Coded values			Real values			Tensile Strength of the joints TS (Mpa)
		P	S	E	Power P (watts)	Welding speed S (mm/s)	Pulse energy E (Joule)	
1	7	-1	-1	-1	40	0.70	1.00	374
2	19	1	-1	-1	60	0.70	1.00	364

3	20	-1	1	-1	40	2.10	1.00	388
4	10	1	1	-1	60	2.10	1.00	381
5	15	-1	-1	1	40	0.70	2.25	375
6	14	1	-1	1	60	0.70	2.25	369
7	9	-1	1	1	40	2.10	2.25	380
8	12	1	1	1	60	2.10	2.25	376
9	18	-1	0	0	40	1.40	1.63	401
10	6	1	0	0	60	1.40	1.63	393
11	8	0	-1	0	50	0.70	1.63	389
12	11	0	1	0	50	2.10	1.63	398
13	13	0	0	-1	50	1.40	1.00	378
14	2	0	0	1	50	1.40	2.25	377
15	3	0	0	0	50	1.40	1.63	396
16	4	0	0	0	50	1.40	1.63	396
17	5	0	0	0	50	1.40	1.63	396
18	1	0	0	0	50	1.40	1.63	397
19	17	0	0	0	50	1.40	1.63	398
20	16	0	0	0	50	1.40	1.63	396

Tensile tests were carried out for the welded samples based on ASTNE8M-04 standard. A universal testing machine under control of a micro-processor and with a maximum capacity of 400 kN is used for tensile test of welded specimens.

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problem in which a response of interest is influenced by several variables and the objective is to optimize this response.The response function the tensile strength (TS) of the joint, is a function of beam power (P), welding speed (S) and pulse energy (E) and it can be expressed as [20, 21],

$$TS = f(P, S, E) \quad (1)$$

The equation of second order polynomial (regression) used to represent the response surface 'Y'= is,

$$Y = b_0 + \sum b_i X_i + \sum b_{ii} X_i^2 + \sum b_{ij} X_i X_j \quad (2)$$

and the selected polynomial for three factors could be expressed as,

$$TS = b_0 + b_1 (P) + b_2 (S) + b_3 (E) + b_{11} (P^2) + b_{22} (S^2) + b_{33} (E^2) + b_{12} (PS) + b_{13} (PE) + b_{23} (SE) \quad (3)$$

where b_0 is the average of responses and $b_1, b_2, \ldots, b_{23}$ are the coefficients that depend on the respective main and interaction effects of the parameters.

In order to sizing up the regression coefficients, a number of experimental design techniques are available.In this, the central composite face centered design was employed, which fits the second order response surface very accurately. All coefficients were attained by applying central composite face centered design using the design expert statistical software package.After determining the important coefficients, the final relationship was developed using only those coefficients. The final experimental relationship to predict tensile strength of laser beam welded Nickel / low carbon steel joint is given below,

Tensile strength of the LBW joint,

= {396.37 – 3.50 P + 5.20 S – 0.80 E + 0.68 (PS) + 0.88 (PE) – 2.37(SE) +0.82(P2)-2.68(S2) – 18.68(E2)} Mpa

2.2 Checking Adequacy of the Developed Relationship

The adequacy of the developed relationship is tested using the analysis of variance (ANOVA) technique. As per this technique, if the calculated value of the Fratio (from F-table) value at a desired level of confidence (say 95%), then the model is said to be tolerable within the confidence limit. ANOVA test results are presented in Table 4 for the model .From the table, it is known that the developed relationship is found to be adequate at 95% confidence level.The model F-value of 448.15 implies that the relationship is significant.There is only a 0.01% chance that a 'Model E value'this large could appear due to noise. Values of "Prob>F "less than 0.05 indicate relationship terms are significant.In this case P, S, E, PS, PE, SE, S2, E2 are significant model terms values higher than 0.1000 reveal the relationship terms are not significant.The 'Lack of fit F-value' of 0.72 implies the lack of Fit is not convincing relative to the pure error.There is a 63.41% chance that a"Lack of Fit F-value"this large could occur due to noise.

The coefficient of determination,'r^{2}' , [19] is applied to determine how close the predicted and experimental values lie.The value ,'r^2 ' for the above developed relationship is also presented in Table 4,which indicates that a high correlation exist between experimental values and predicted values. The 'Pred R-squared' of 0.9898 is in reasonable agreement with the 'Adj R-squared' of 0.9953. It is exposed that the residuals for tensile strength are falling on the straight line by the normal probability plot of shown in Fig. 2,which means the errors are distributed normally.All the above consideration indicates the acceptability of the developed relationship. From the model in Fig. 3, the predicted value calculated is compared with each observed value.

Table .4. ANOVA test results

Source	Sum of squares	df	Mean square	F Value		P – Value Prob > F
Model	2433.77	9	270.42	448.15		<0.0001
P-P	122.50	1	122.50	203.01		<0.0001
S-S	270.40	1	270.40	448.12		<0.0001
E-E	6.40	1	6.40	10.61		0.0086
PS	3.13	1	8.13	5.18		0.0461
PE	6.13	1	6.13	10.15		0.0097
SE	45.12	1	45.12	74.78		<0.0001
P2	1.84	1	1.84	3.05		0.1113
S2	19.78	1	19.84	32.78		0.0002
E2	959.78	1	959.78	1590.59		<0.0001
Residual	6.03	10	0.60	-		-
Lack of fit	2.53	5	0.51	0.72		0.6341
Pure Error	3.50	5	0.70	-		-
Cor Total	2439.80	19	-	-	-	-
Standard deviation	0.78	-	R - squared		0.9975	-
Mean	386.10	-	Adj R-squared		0.9953	-
C.V %	0.20	-	Pred R-squared		0.9898	-
PRESS	24.93	-	Adeq Precision		66.703	-

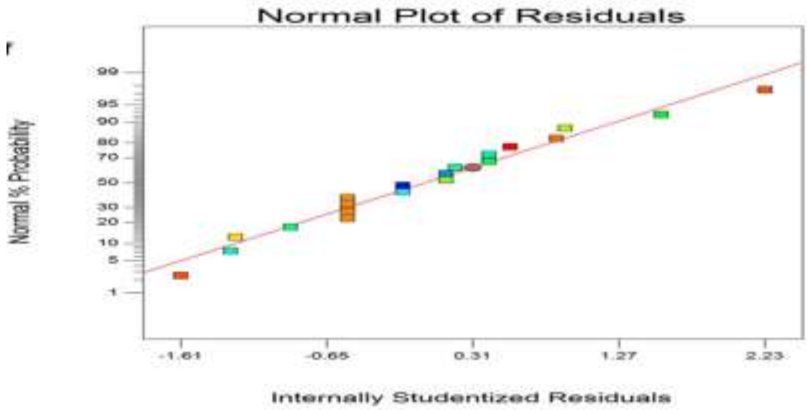

Fig.2. Normal Probability charts

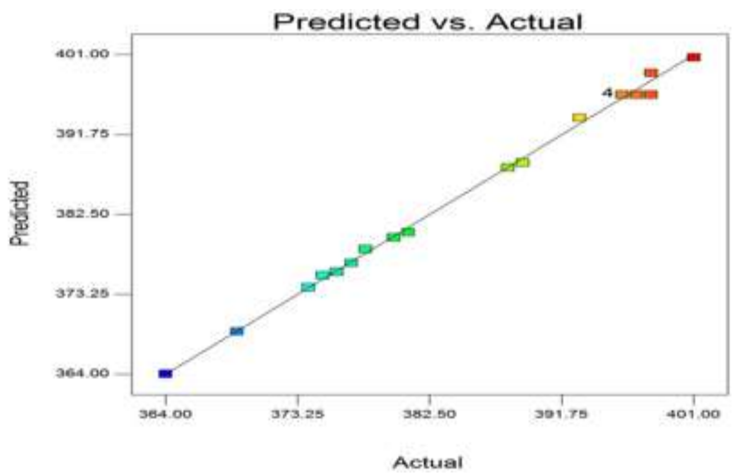

Fig.3. Normal Probability charts

2.3. Optimization of LBW parameters

The response surface methodology was again used as the optimization tool. The empirical relationship developed in the preceding section was framed using the coded values. The optimization was done on coded values and then converted to actual values. To optimize the process variables design expert statistical software package was used. The optimum values obtained are listed in Table 5.

Table .5. Optimized laser beam welding process parameters

S.No.	Parameters	Optimized parameters		Max. Tensile strength Mpa	
		Predicted by RSM	Experiment	Predicted value	Exp. value
1	Laser power(P)(Watts)	50	50	401	400.5
2	Welding speed(S)(mm/s)	1.40	1.40		
3	Pulse energy (E) J	1.63	1.60		

Response surface were developed for the relationship, taking two parameters in the 'X' and 'Y' axis and response in 'Z' axis .The response surface clearly indicate the optimal response point. The maximum tensile strength of laser beam welded Nickel / Low carbon steel joint is exhibited by the apex of the response surface (Fig. 4).From the contour plots shown in (Fig. 5), it was found that the optimum may be located with the reasonable accuracy by characterizing the shape of the surface. If the contours are circular, it leads to suggest the independence of factor effects while elliptical contours may indicate factor interactions.

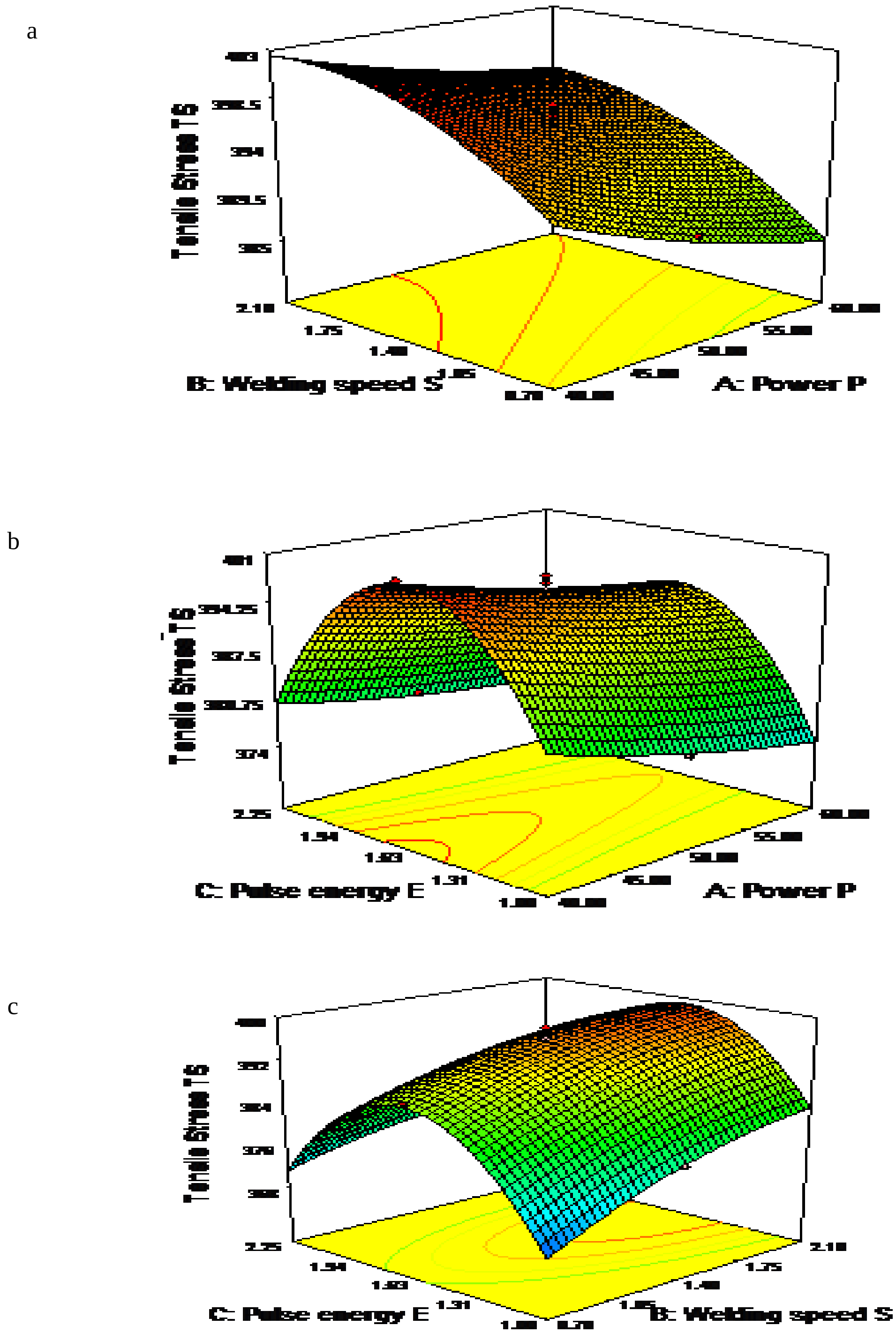

Fig.4. Response graphs.

a

b

c

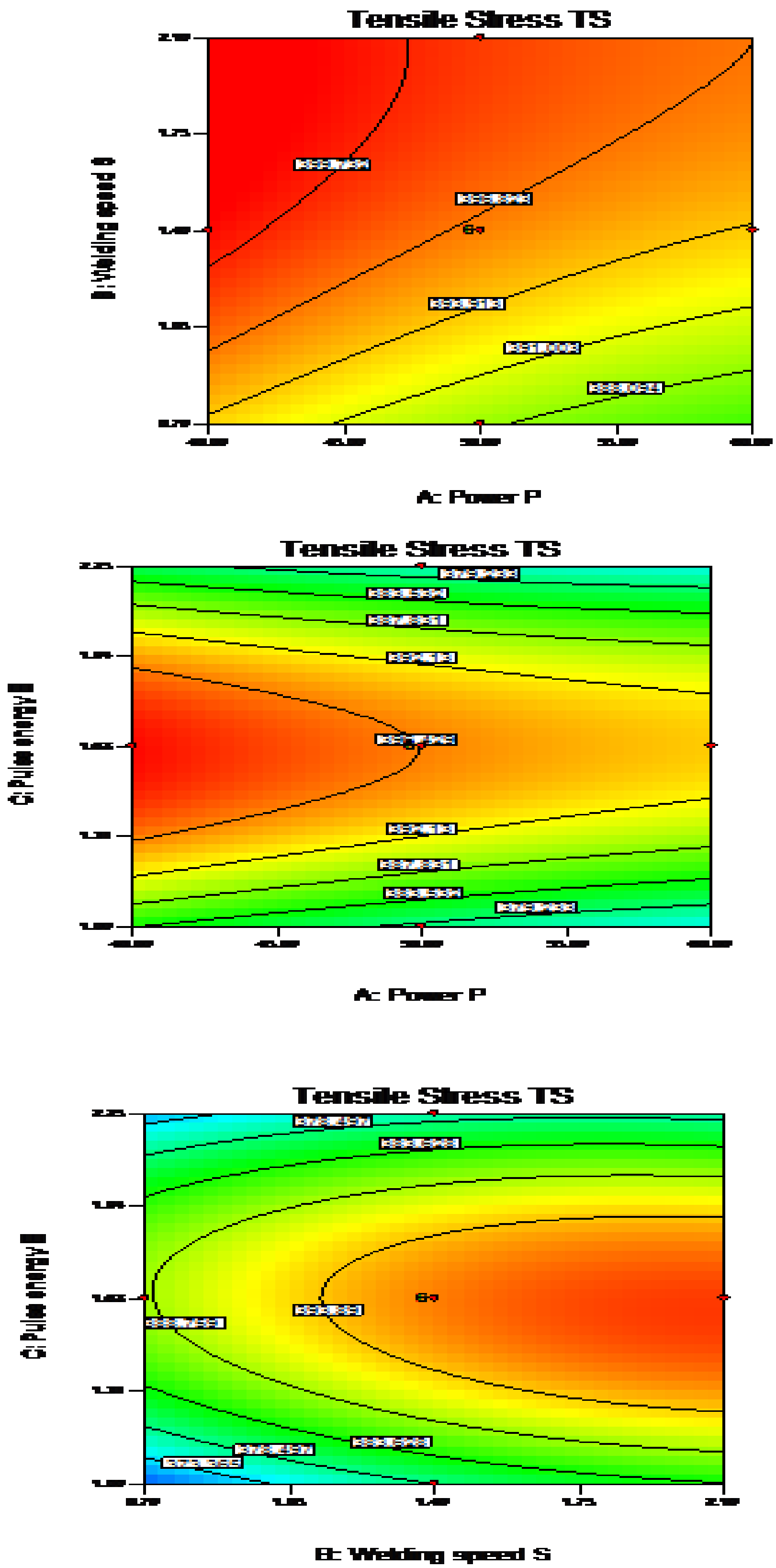

Fig.5. Contour plots.

2.4. Analysis of response graphs and contour plots

Fig. 4 (a) represents a three dimensional response surface plot for the response tensile strength obtained from the regression model assuming a laser power of 50W and a welding speed of 1.40 mm/s. The apex of the response surface is exhibits the optimum tensile strength. It is identified that the laser power 50W, the tensile strength of LBW joints is higher, from the response graph. The laser power is increased from 50W, the tensile strength decreases. This is the outcome of the increase in input heat coupled with the use of higher laser powers. Fig. 4(b) represents the three dimensional response surface plot for the response tensile strength obtained from the regression model, assuming a pulse energy of 1.63 J and laser power of 50W.The apex of the response exhibits surface optimum tensile strength by the from the response graph it is observed that the pulse energy is moved further down, then the tensile strength of the joint reduced. Using pulse energy results in an increase in the power. The variation indicated with the specimen, it creates liquid melt pool by absorbing variation is a result of high pulse energy and a high amount of material is molten and then propagates through the base material. When the pulse energy was 1.63 J the optimum weld was obtained. The optimum power might have reduced the grain size which resulted in an increase of tensile strength. The formation of finer precipitates in the fusion zone characterizes by the optimum power.

The response surface plot with three dimension for the response tensile strength obtained from the regression model is shown in Fig.4 (c), assuming a welding speed of 1.40 mm/s and energy of 1.63J. The apex of the response surface exhibits the optimum tensile strength. From the response graph if the inferred that at lower welding speed, the tensile strength of the joint is lower. When the welding speed is increased, the tensile strength also increased. The welding speed usually has an inversely proportion relationship with heat input lower welding speed resulted in higher pulse energy and slow cooling rate leading to grain coarsening. This may be another reason for higher tensile strength of these joints. From the contour plot Fig. 5(a), for optimum tensile strength of laser beam welded Nickel and steel sheets is more sensitive to changes in welding speed, the laser power. From the contour plots Fig. 5(b) it can be seen that the tensile strength is more sensitive to changes in laser power than it is to changes in pulse energy. From Fig. 5(c) it can be seen that the tensile strength values is more sensitive to changes in welding speed than in pulse energy. The SEM micrographs of the base metal and fusion zone of joint made with a laser power of 50W,welding speed 1.40 mm/s and pulse energy of 1.63 J are shown in Fig.6.The main reason for higher tensile strength is the formation of grains in weld region and moderate precipitators of the above joint.

The grains in the fusion zone rough with rising heat input. This incident can also be explained by the change of cooling rate. It is well-known that a raise in heat input will conclude in slow cooling rate. Moreover, the slower the cooling rate during solidification, the greater the time available for grain coarsening. This may be the reason for the decrease in tensile strength. In contrast, a reduction in laser power gives rise to a decrease in the heat input. This leads to a faster cooling rate and accordingly finer grain size in the fusion zone, concludes in an increase of tensile strength. During the tensile tests, two types of breaking failure were observed. (a) Shear failure from weld interface, and (b) crack of base material starting from fusion zone.

3. Conclusion

An experiential relationship was developed to shape out tensile strength of laser beam welded Nickel / mild steel sheets by employing response surface methodology. The developed relationship can be adequately used to figure out the tensile strength of the laser beam welded joints at 95% assurance level. A maximum tensile strength of 401 Mpa is obtained under the welding conditions in which the laser power is 50W, welding speed 1.40 mm/sec and pulse energy of 1.60J. Welding speed is the factor which has the greater influence on tensile strength, succeed by laser power and pulse energy. Finally from the view of the whole joint in the present report , the welding of mild steel with nickel by using stainless steel wire altered the bonding mode from the mechanical bonding to semi-metallugical bonding, it can also be seen that such tramsformation that asvanced the joint strength in the present fusion welding process. Though, it is apparent that the corrosion problems may control the properties of the joint. Hence in future studies should be needed to lower the tendency to cause corrosion.

4. References

[1] Jae-Do Kim, Cheol-Jung KIM, Chin-Man Chung (2001), Repair welding of etched tubular components of nuclear power plant by Nd:YAG laser. Material Processing Technology 114, 51-56.

[2] Alexandre Mathieu , Rajashekar Shabadi, Alexis Deschamps, Michel Suery, Simone Mayei, Dominique , Grevey, Eugen Cicala (2007), Dissimilar material joining using laser (aluminum to steel using zinc-based filler wire). Optics & Laser Technology, 39, 652-661.

[3] E.M. Anawa, A.G. Olabi (2008), Control of welding residual stress for dissimilar laser welded material. Material Processing Technology, 204, 22-33.

[4] Dawes C (1992) Laser welding, Abington, Newyork.

[5] Jose Roberto Berretta, Wagner de Rossi, Mauricio David Martins das Neves, Ivan Alves de Almeida, Nilson Dias Vieira Junior. (2007), Pulsed Nd:YAG laser welding of AISI 304 TO AISI 420 stainless steels. Optics & Laser Technology,45, 960-966.

[6] Tobias Solchenbach, Peter Plapper (2013), Mechanical characteristics of laser braze-welded aluminium-copper connections. Optics & Laser Technology, 54, 249-256.

[7] S.H.Baghjari, S.A.A.Akbari Mousavi (2014), Experimental investigation on dissimilar pulsed Nd:YAG laser welding of AISI 420 stainless steel to kovar alloy. Materials and Design, 57, 128-134.

[8] Jae-Do Kim, Yun Peng (2000), Plunging method for Nd:YAG laser cladding with wire feeing. Optics & Laser Technology, 33, 299-309.

[9] Vicente Afonso Ventrella, Jose Roberto Berretta, Wanger de Rossi (2011), Micro welding of Ni-based Alloy Monel 400 thin foil by pulsed Nd:YAG laser. Physics Procedia, 12, 347-354.

[10] B.Shanmugarajan, G.Padmanabham (2012), Fusion welding using laser on Ti-SS dissimilar combination. Optics & Laser Technology, 50, 1621-1627.

[11] K.Y.Benyounis, A.G.Olabi, M.S.J.Hashmi (2005), Efect of laser welding parameters on the heat input and weld-bead profile. Materials Processing Technology, 164-165, 978-985.

[12] Bappa Acherjee, Arunanshu S. Kuar, Souren Mitra, Dipten Misra, Sanjib Acharyya (2012), Experimental investigation on laser transmission welding of PMMA to ABS via response surface modeling. Optics & Laser Technology, 44, 1372-1383.

[13] U.Reisgen, M.Schleser, O.Mokrov, E.Ahmed (2012), Statistical modeling of laser welding of DP / TRIP steel sheets. Optics & Laser Technology, 44, 92-101.

[14] Yuwen Sun, Mingzhong Hao (2012), Statistical analysis and optimization of process parameters in Ti6Al4V laser cladding using Nd:YAG laser. Optics & Laser Technology, 50, 985-995.

[15] Manikandan M, Hari P R , Vishnu G, Arivarasu M, Devendranath Ramkumar K, Arivazhagan N, Nageswara Rao M, Reddy G M (2014), Investigation of Microstructure and Mechanical Properties of Super Alloy C-276 by Continuous Nd:YAG laser welding. Procedia Materials Science, 5, 2233-2241.

[16] M.M.A.Khan, L.Romoli, M.Fiaschi, G.Dini, F.Sarri (2011), Experimental design approach to the process parameter optimization for laser welding of martensitic stainless steels in s constrained overlap configuration. Optics & Laser Technology, 43, 158-172.

[17] Ming Pang, Gang Yu, Heng-Hai Wang, Cai-Yun Zheng (2008), Microstructure study of laser welding cast nickel-based superalloy K418. Material Processing Technology, 207, 271-275.

[18] K.Manonmani, N.Murugan, G.Buvanasekaran (2007), Effects of process parameters on the bead geometry of laser beam welded stainless steel sheets. Advanced Manufacturing Technology, 32, 1125-1133.

[19] Miller I, Freund JE, Johnson (1999). Probability and statistics for engineers. New Delhi: Prentice of Hall of India.

[20] C Velmurugan, R Subramanian, S Thirugnanam, T Kannan, B Anandavel (2011) Experimental study on the effect of SiC and graphite particles on weight loss of Al6061 hybrid composite materials. Nova science Publishers, 2, 49-68.

[21] T Kannan, N Murugan (2006), Prediction of Ferrite Number of Duplex Stainless Steel Clad Metals Using RSM. Welding Journal. May, 91s-100s.

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