IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 79-82
www.iosrjournals.org

Multi-response Optimization of PTA welding parameter for overlay process of stellite 6B on duplex stainless steel using Taguchi method

D. D. Deshmukh[1] Dr. P. S. Kalos[2]
[1,1]*Department of production Engg. K.K.W.I.E.E.R., Nasik, Maharashtra, India*

ABSTRACT: *Overlay process involves the application of a deposition on the surface of a metallic workpiece by employing a welding method such as plasma transferred arc (PTA), and has found widespread application in the steel, power, mining and in the petroleum industry .Stellite 6 has an outstanding resistance to seizing or galling as well as cavitations erosion and is extensively used to combat galling in valve trims, pump sleeves and liners. The base material used in this investigation was casting plate of duplex stainless steel of 30 mm thickness of grade S32205 UNS no.S31803, which is widely used for the fabrication of valves, valve cones, spindles, and pressure vessel parts. As per Taguchi design of experiment of L9 orthogonal array, deposits were prepared on plate as described in the design of experiments matrix and according to the WPS EN ISO 11970:2007, reinforcement, width of depositions measured during operation and after deposition the welding specimens were sliced and penetration is measured in the weld cross section 3mm from fusion line . The output shows the results of fitting a multiple linear regression model to describe the relationship between penetration, width ,reinforcement and four independent variables (Travel speed, arc current, oscillation speed, powder feed rate). Taguchi method was used to evaluate the main effects of various parameters on deposition, penetration and weld bead characteristic and to optimize PTA welding process parameter for maximum deposition rate with minimum penetration with defect free process.*

Keywords: *ANOVAs, MSNR, overlay, PTA, Regression, Taguchi method*

I. INTRODUCTION

Overlay process involves the application of a deposition on the surface of a metallic workpiece by employing a welding method. The process should be aimed at achieving a strong bond between the deposit and the base metal with a high deposition rate. This process is applied in numerous industries, including chemical and fertilizer plants, nuclear and steam power plants, pressure vessel, as well as valves and valve seats in the automotive industry [1]. Plasma transferred arc welding (PTA) is a commonly used technology and efficient method to coat a surface with such wear-resistant coating. Single or multilayer depositions provide strong metallurgical bonding between the deposit and the base metal, as well as porosity-free coating and low dilution with substrate. In the PTA process, the heat of the plasma (arc of ionized gas) is used to melt the surface of the substrate and the welding powder, where the molten weld pool is protected from the atmosphere by the shielding gas. [2].Surface treatments of metals are commonly based on the use of high energy density sources, as they offer a means of rapid heating and subsequent quenching from the melt, leading to fine microstructures and consequently to possible improvement of mechanical, corrosion or tribological properties. Superficial layers of the appropriate thickness free of cracks and with high deposition rate and low penetration may be obtained by suitable control of the process variables. In this respect there has been considerable interest in the use of laser and electron beam sources for surface treating and melting of low carbon steels and stainless and tool steels. The impact of the process variables on temperature profiles, microstructure and properties have been examined and the results already obtained may serve as a reference for further investigations. However, only a limited number of investigations concern the use of the plasma transferred arc (PTA), although there are serious indications that its use may be quite attractive in industrial applications. It is, therefore, interesting to investigate the PTA process, which—despite its lower energy density has the main advantage to require rather inexpensive equipment and the possibility to work with a higher heat input [3]. Plasma transferred arc welding (PTAW) is an extension of the GTAW process where both utilize a gas shielded arc produced by a non-consumable tungsten cathode. Considering these importances in present investigation a Taguchi method is used to evaluate the main effects of various parameters on deposition, penetration and weld bead characteristic and to optimize PTA welding process parameter for maximum deposition rate with minimum penetration for defect free process.

II. TAGUCHI METHOD

Taguchi method is an efficient problem solving tool which can upgrade/improve the performance of the product, process, design and system with a significant slash in experimental time and cost [6]. This method that combines the experimental design theory and quality loss function concept has been applied for carrying out robust design of processes and products and solving several complex problems in manufacturing industries. Further, this technique determines the most influential parameters in the overall performance. The optimum process parameters obtained from the Taguchi method are insensitive to the variation in environmental condition and other noise factors [6]. The number of experiments increases with the increase of process parameters. To solve this complexity, the Taguchi method uses a special design of orthogonal array to study the entire process parameter space with a small number of experiments only. Taguchi defines three categories of quality characteristics in the analysis of (Signal/Noise) ratio, i.e. the lower-the-better, the larger-the-better and the nominal -the-better. The S/N ratio for each of process parameter is computed based on S/N analysis. Regardless of the category of the quality characteristics, a larger S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of process parameter is the level of highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) can be performed to see which process parameter is statistically significant for each quality characteristics.

2.1 Determining the effective PTA process parameters and their working limits:

By using different combinations of PTA hardfacing process parameters large numbers of trial runs were carried out on duplex stainless steel UNS32205 and stellite grade 6B powder was used for overlaying, to set the ranges of operating parameters,

Table 1 Parameters and their working limits

Sr.no	Parameters	Low level(1)	Moderate level(2)	High level(3)
1	Transferred arc current(Amp)	100	120	140
2	Travel speed(RPM)	0.01	0.02	0.03
3	Powder feed rate (gms/min)	10	14	18
4	Oscillation speed (mm/min)	475	500	525

2.2 Selection of orthogonal array (OA)

Before selecting a particular OA to be used as a matrix for conducting the experiments, the following two points must be considered: 1) The number of parameters and interactions of interest; 2) The number of levels for the parameters of interest. The non-linear behavior, if exists among the process parameters, can only be studied if more than two levels of the parameters are used. Therefore, each parameter was analyzed at three levels. To limit the study, it was decided not to study the second order interaction among the parameters. Each three level parameter has 2 degrees of freedom (DOF=number of levels-1), the total DOF required for 3 parameters each at three levels is 6 (3× (3-1)). As per Taguchi's method, the total DOF of selected OA must be greater than or equal to the total DOF required for the experiment. So an L9 OA having 8 (9-1) degrees of freedom were selected for the present analysis.

2.3 Experimental analysis:

The material under investigation was the plate of duplex stainless steel grade S32205 UNS no.S31803 with chemical composition is given in Table 2. The steel widely used for the manufacturing of valve, valve cones, spindles, and pressure vessel parts, having a hardness of 22 Hrc. Specimens in the form of plates of 30 mm thickness of 400 × 250 mm were treated superficially by the PTA process. Before their treatment the plate were milled and polished with abrasive paper in order to remove oxides and obtain a smooth surface, to keep stable arc conditions and avoid current fluctuations. Before treatment dye penetration test was carried out in order to investigate any surface defects on the base plate, after confirmed the result of dye penetration the base material is ready for treatment The main equipment employed was a PTA an automatic machine for control of the torch movement and various controlling process parameters, made by M/s Primo Automation Systems, Chennai, India with the support of KOSO India Pvt. ltd, Ambad, Nashik is employed. The ranges of influencing operating parameters of the PTA system are given in Table 1.In a first step of the investigation single runs have been performed along the plates using different arc conditions. Deposits were prepared on plate as described in the design of experiments based on Taguchi technique (As per the Taguchi design of experiment of L9 orthogonal array created in MINITAB15 software). The welding joint is G1 as applicable for the overlaying operation, the length of the run was taken up to 100 mm and width of deposition is 40 mm for each experiment according to EN ISO 11970:2007. The experiments were conducted by forming layers of stellite grade 6B powder (size 45-125 micron chemical composition is given in table2.) on the substrate plate with the electrode negative (DCEN) according to the welding process specification (WPS) ASME21, with position of groove 1G. Tungesten electrode size 4 mm diameter (2% Throated Tungesten), torch orifice diameter 25mm,Industrially pure argon (99.99%) was used at a constant flow rate of 15 L/min for shielding, 2.5 L/min for centre, and 3 L/min for powder feeding. And a constant stand-off distance of 6 mm was maintained during the experimentation. Reinforcement was measured with the width of run using digital vernier caliper during the operation. After overlaying operation the welding coupons (specimens) were sliced by a plane perpendicular to the run direction at middle section to measure the penetration, so that a qualitative approach on the influence of the four basic operating parameters, i.e. current (TC), travel speed (TS), powder flow rates (PF) and oscillation speed (OS) could be achieved. All runs were inspected visually and by using dye penetration test.

Table 2 Composition of stellite 6B and duplex stainless steel

Name/composition %	C	Si	Cr	Co	W
Stellite 6 B	1.08	1.09	28.75	Balance	4.37

Name/composition %	C	Si	Cr	Ni	P	S	Mo	Mn	N
Duplex stainless steel	0.026	0.45	22.4	6.12	0.007	0.007	3.15	1.28	0.16

2.4 Calculation of signal to noise (S/N) ratio:

Taguchi recommends the use of the loss function to determine the deviation between the experimental value of the performance characteristic and the desired value. The loss function is further transformed into an S/N ratio, which is used to rank the influencing parameters according to their impact on the measured value. In the calculation of the loss function there are three ways of transformation depending on the desired characteristic of the measured value. The characteristic of the desired value can either be the-lower-the-better, the-higher-the-better or the-nominal-the better. The loss function of the ‘‘the-nominal-the-better’ for W/H ratio quality characteristic (yk) with m as the mean of the target quality parameter is calculated as shown in Eq. (1) where Lij is the loss function of the ith performance characteristic in the jth experiment. The loss function of the ‘‘the-lower-the-better’’ for penetration from the target value of the quality performance characteristic are shown in the Eq. (2).

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n}(y_{ijk} - m)^2 \tag{1}$$

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{y_{ijk}^2} \tag{2}$$

After calculation of normalized quality loss for each response these quality loss is summarized using total normalized quality loss by assigning the weight o.2 for penetration and 0.8 for W/H ratio. For predicting the result MSNR is calculated and average MSNR is plated in table 6, by using larger the better in average MSNR a higher quality can be achieve by following Eq (3).

$$\eta_{ij} = -10\log(L_{ij}) \tag{3}$$

Table 3. Design of experiment (D.O.E.)

Expt .no	Current TC (AMP)	Travel speed	Pwd. feed rate (gms/min	Oscillation speed (mm/min)
1	100	0.01	10	475
2	100	0.02	14	500
3	100	0.03	18	525
4	120	0.01	14	525
5	120	0.03	18	475
6	120	0.03	10	500
7	140	0.01	18	500
8	140	0.02	10	525
9	140	0.03	14	475

Table 5. NQL and MSNR

Expt. no	NQL Penetration	NQL W/H RATIO	TNQL L_{ij}	MSNR
1	0.346	0.471	0.069	11.603
2	0.180	0.472	0.036	14.442
3	0.179	0.506	0.036	14.469
4	1.000	0.623	0.200	6.990
5	0.225	0.434	0.045	13.470
6	0.439	0.801	0.088	10.569
7	0.853	0.638	0.171	7.682
8	0.749	0.880	0.150	8.247
9	0.253	0.684	0.051	12.953

TABLE 4.Design of experiment (D.O.E.) and data collection

III. RESULT AND CONCLUSION

The current investigation mainly involves the statistical analysis and optimization of process parameters in PTA process in overlaying using stellite from the research work the following conclusions can be drawn within the ranges of process parameters considered here in: Increasing current can increase layer width .However, when oscillation speed raises, the responses of width increases, when travel speed raises layer width, layer height and molten depth of substrate are all decreased except the ratio (w/h). Powder feed rate has a negative effect on the ratio (w/h), penetration and molten depth. The ratio (w/h), dilution and molten depth of substrate increase with the rise of current until they reach up to the critical limit. Then, these responses begin to drop gradually when laser power is continuously raised, Powder feed rate is the most significant factor in the ratio (w/h), dilution, layer width and layer height Whereas travel speed has the strongest effect on the molten depth and penetration. Taguchi method can be effectively applied to PTA welding to predict the overlay bead geometry and the shape factor, namely the ratio (w/h), and the penetration. Table 6 shows the average MSNR for each levels from that maximum MSNR indicates higher quality for the required quality. Regression analysis for the objective function had shown in table 6 and 7. The developed mathematical model is found to be able to correctly predict the geometry of coatings within the relative error of 8%.

Table 7 Regression Statistics and ANOVA for penetration

Multiple R	0.95			
R Square	0.90			
Adjusted R Square	0.89			
Standard Error	0.18			
Observations	27.00			
ANOVA				
	dof	SS	MS	F
Regression	4	7.0	1.7	51.5
Residual	22	0.7	0.0	
Total	26	7.7		

Table 8 Regression Statistics and ANOVA for

Multiple R	0.97			
R Square	0.93			
Adjusted R Square	0.92			
Standard Error	0.27			
Observations	27.00			
ANOVA				
	dof	SS	MS	F
Regression	4	21.8	5.5	75.1
Residual	22	1.6	0.1	
Total	26	23.4		

Table 6 Average MSNR and their levels

Parameters/Levels	1	2	3	Parameters/Levels	1	2	3
Current(amp)	13.50	10.34	9.63	Pwd(gms/min)	10.14	11.46	11.87
Speed(rpm)	8.76	12.05	12.66	Oscillation speed (mm/min)	12.68	10.90	9.90

The desired high quality of bead can be achieved using the optimal process parameters derived from the developed mathematical model within the factor domain, the proposed model based on Taguchi methodology is reliable and adequate to be applied PTA process. It is very useful for the prediction of the shape factor and bead geometry as well as the control of process parameters in mass production. In such away the shape and penetration control of the product can therefore have the capacity to meet the desired requirements, and as a result both raw material and process time will be correspondingly reduced.

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