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Research Article

STUDY OF WELDING PARAMETERS TO CONTROL THE WELD BEAD CHARACTERISTICS IN PLASMA TRANSFERRED ARC POWDER DEPOSITION SYSTEM USING COBALT BASED HARD FACING ALLOY

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ABSTRACT

The aim of this work is to compare the weld bead geometry values with experimental results at various input conditions and arrive at the optimum input parameters for desirable weld bead geometry. Plasma Transferred Arc (PTA) hard facing (weld overlay) process using powdered filler material, is increasingly used in applications where enhancement of wear and corrosion resistance of components is required. The shape of weld bead geometry obtained in the PTA welding process is an indication of the quality and health of a good weld. Plasma transferred arc hard facing has attracted increasing attention for its effective protection against corrosion, thermal shock, and abrasion. The quality of hard faced components depends on the weld bead geometry and dilution, which have to be properly controlled and optimized to ensure better desirable mechanical characteristics of the weld.

Good weld is achieved by selecting the right input parameters in this process and hence study of these input variables such as welding current, speed, etc. gives us a good analysis of how to achieve desirable weld bead characteristics using the known input variables. In this study, different weld beads would be deposited using PTA process with different parameters (welding current, travel speed, plasma gas flow and powder feed rate) using cobalt based powdered filler metal.

INTRODUCTION

The Plasma Transferred Arc welding method is used to weld several millimeter thick wear and corrosion resistant deposits. Traditionally, the dilution of the deposit has been the most studied parameter. It has been thought that it is the most important parameter of the weld bead, because low dilution means that the process is cost-effective and the properties of the deposit are automatically typical to the deposit alloy (Matthew, 2005). Welding parameters affecting most the dilution of the deposit are plasma arc current, temperature of the work piece, working distance, powder feed rate, process gas flow rates, and oscillation parameters like amplitude, frequency, and welding speed (Wilden, *et al*., 2006).

Some experimental tests and models are made during the years to determine the factors, which control the dilution and the abrasive wear resistance of the weld beads. The differences between the welding parameters may be small, but they have major effects on the microstructure and the abrasive wear resistance.

DESIGN OF EXPERIMENTS AND TAGUCHI

Design of experiments is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The traditional experimental design is difficult to be used especially when dealing with large number of experiments and when the number of machining parameter is

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increasing (Lakshminarayanan, *et al.*, 2008). The most important stage in the design of experiment lies in the selection of the control factors. Therefore, the Taguchi method, which is developed by Dr. Genichi Taguchi, is introduced as an experimental technique which provides the reduction of experimental number by using orthogonal arrays and minimizing the effects out of control factors (David, 1986). Taguchi is a method which includes a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analysis data in order to obtain the result.

Besides that, it is a set of methodologies that took into account of the inherent variability of materials and manufacturing process during the design stage. It is almost similar to the design of experiment (DOE) but the Taguchi design's balanced (orthogonal) experimental combination offers more effective technique than the fractional factorial design (Mujumdar, 2011). This technique has been applied in the manufacturing processes to solve the most confusing problems especially to observe the degree of influence of the control factors and in the determination of optimal set of conditions.

Taguchi used the signal-to-noise (S/N) ratio as the measurable value of the quality characteristics of the choice (Lee, *et al.*, 2000). This shows that the engineering systems can behave in a way such that the manipulated production factors can be divided into three categories:

- Control factors, (Factors that affect the process variability as measured by the S/N ratio)
- Signal factors (Factors that do not influence the S/N ratio or process mean)
- Factors (Factors that do not affect the S/N ratio or process mean)

The experimental observations are future transformed into signal-to-noise (S/N) ratios. Signal-to-noise (S/N) ratio was used by Taguchi as the quality characteristics of choice and here are several S/N ratios available depending on the type of performance characteristics. The S/N ratio can be characterized into three categories when the characteristics are continuous.

Nominal is the best characteristic

$$\frac{S}{N} = 10\log\frac{\overline{y}}{S_y^2}$$

Smaller the better characteristics

$$\frac{S}{N} = 10\log\frac{1}{n}(\Sigma y^2)$$

Larger the better characteristics

$$\frac{S}{N} = 10\log\frac{1}{n}(\Sigma\frac{1}{y^2})$$

where 'y' is the average observed data, 'S ' the variance of 'y', 'n' the number of observations, and 'y' the observed data. For each type of characteristics, higher or lower value of S/N ratio indicates the better result value

STEPS IN TAGUCHI

Identify the main function and its side effects

There are several variables which affect the quality of the weld. For better quality and strengthens certain variables are fixed and some are varied. From the available variables we have selected the three parameters Current (C), Powder feed (P), table speed (T) to analyze the weld bead quality.

Identifying the testing conditions and quality characteristics to be observed

Quality characteristics: Hardness, % of iron content

- **Work piece material:** Mild steel
- **Holding table:** Rotating table chuck type (Three jaw Chuck)
- **Operating machine:** Lathe machine
- **Testing equipment:** Portable surface tester
- **Work piece material:** Mild steel rod (Length=500 mm, Outer diameter= 88 mm, Inner diameter = 60 mm)

Identify the objective function to be optimized

For Hardness the objective function is Larger the better

$$\frac{S}{N} = 10\log\frac{1}{n}(\Sigma\frac{1}{y^2})$$

For Percentage of Iron content the objective function is Nominal the best

$$\frac{S}{N} = 10\log\frac{\overline{y}}{S_y^2}$$

Identifying the control factors and their levels

The factors and their levels were decided for conducting the experiment, based on a "brain storming session" that was held with a group of people. The factors and their levels are shown in Table 1.

Table 1. Factors and their levels for conducting experiment

S. No	Parameters	Unit	Level 1	Level 2	Level 3
1	Current	Ampere	141	130	150
2	Table Speed	mm/min	98.151	123.78	150.796
3	Powder feed rate	gms/min	36.85	29.35	42.75

Table 2. Conducting the matrix experiment different arrays of control factor combined with response factor and S/N ratio.

C1 T1 P1	C1 T2 P1	C1 T3 P1
C1 T1 P2	C1 T2 P2	C1 T3 P2
C1 T1 P3	C1 T2 P3	C1 T3 P3
C2 T1 P1	C2 T2 P1	C2 T3 P1
C2 T1 P2	C2 T2 P2	C2 T3 P2
C2 T1 P3	C2 T2 P3	C2 T3 P3
C3 T1 P1	C3 T2 P1	C3 T3 P1
C3 T1 P2	C3 T2 P2	C3 T3 P2
C3 T1 P3	C3 T2 P3	C3 T3 P3
Where C1=141A, C2=130A, C3=150A T1= 98.151 mmpm, T2=123.78 mmpm, T3= 150.796 mmpm, P1= 36.85 gms/min, P2= 29.35 gms/min, P3=42.75 gms/min		

The effect of an individual welding parameter on the PTA welding method has to be known for optimizing welding parameters and to learn interactions between different welding parameters. The welding parameters considered in this work are current, table speed and Powder Feed rate. The reason for selecting the above parameters is, these can be easily alterable by the welder and also a small change in these parameters can induce a major effect on weld beads, hence it is very essential to fix a range of values for the above parameters up to a certain limits.

Selection of orthogonal array

In the parameter design stage of Taguchi method, the first step is to setup and select a proper orthogonal array (OA). To accommodate three control factors into the experimental study, a standardized Taguchi-based experiment design, $L_{27}(3^2)$ was chosen to be used in this study. This basic design makes use of three control factors with three levels each and the design has capability to check the interaction between the factors. From the standard design there

Table 3. Values obtained during experimentation runs for different combined arrays.

S. No	Current (C)	Table Speed (T)	Powder Feed Rate (P)	(HRC)	Width (mm)	Height (mm)	Defects	(Fe)	
1	140	98.151	36.85	34.5	13	3.5	Scattered	14.84	Average
2	140	98.151	29.35	35.2	12.5	3.5	No Defect	12.67	Good
3	140	98.151	42.75	34.9	13	4	Crack	12.94	Good
4	140	123.78	36.85	36.4	11.5	4.5	Lack of fusion	12.47	Average
5	140	123.78	29.35	36.7	12	3.5	No Defect	15.52	Excellent
6	140	123.78	42.75	33.2	10	5.5	Lack of fusion	3.64	Poor
7	140	150.796	36.85	35	9	2.5	No Defect	5.28	Excellent
8	140	150.796	29.35	36.5	10.5	6.5	Crack, Under cut	3.53	Poor
9	140	150.796	42.75	35.6	9.5	3.5	No Defect	15.94	Good
10	130	98.151	36.85	24.3	11	4.5	No Defect	8.84	Average
11	130	98.151	29.35	28.3	12	4.5	Scattered, Pin hole, under cut	14.85	Poor
12	130	98.151	42.75	33.4	12.5	6	Scattered	13.41	Poor
13	130	123.78	36.85	36.5	11	4.5	Pin hole	10.93	Average
14	130	123.78	29.35	33.4	11.5	4	Crack	19.11	Good
15	130	123.78	42.75	33.4	12.5	5.5	Scattered	9.59	Average
16	130	150.796	36.85	35.7	11	3.5	Scattered	10.54	Poor
17	130	150.796	29.35	38	11	4.5	No Defect	6.64	Average
18	130	150.796	42.75	37.9	13	3	Pin holes	8.37	Excellent
19	150	150.796	42.75	27.7	13.5	4.5	No Defect	14.15	Good
20	150	98.151	36.85	27.7	16.5	5.5	No Defect	5.44	Poor
21	150	98.151	29.35	30.6	14	3	Pin holes	20.85	Average
22	150	123.78	42.75	30.6	15	5.5	Crack, Pin hole	12.18	Poor
23	150	123.78	29.35	25.7	11.5	3.5	No Defect	22.73	Excellent
24	150	123.78	36.85	31.1	12	4	No Defect	12.96	Good
25	150	150.796	36.85	32	11	4.5	Scattered	16.2	Average
26	150	150.796	29.35	32.5	12.5	3	Scattered	29.17	Poor
27	150	98.151	42.75	32	12.5	4.5	Scattered	14.26	Poor

are 27 experimental runs that need to be conducted with the combination of levels for each control factor (A–C). The selected parameters are current, table speed, powder feed rate. In this study, the control factors (current, table speed, powder feed rate) are the independent variables while the response factors (hardness and percentage of iron content) are the dependent variables. In table, a modified OA has been created by using basic Taguchi OA and the selected parameters. In this modified OA, the basic arrays of control factors are combined with the arrays of response factors along with the S/N ratio (g) values as shown in Table 2 and it brings to the total number of 27 experimental runs. Tables 3-5 shows values obtained during Experimentation runs for different combined arrays (Fig. 1-13).

Table 4. Examination of data for HRC hardness versus SN ratio.

Runs	A	B	C	Average Hrc	Sn Ratio1
1	1	1	1	34.8667	30.8482
2	1	2	2	35.4333	30.9882
3	1	3	3	35.7000	31.0534
4	2	1	2	28.6667	29.1475
5	2	2	3	34.4333	30.7396
6	2	3	1	37.2000	31.4109
7	3	1	3	28.6667	29.1475
8	3	2	1	29.1333	29.2878
9	3	3	2	32.1667	30.1481

Table 5. Examination of data for PMI average PMI versus SN ratio

Runs	A	B	C	Average Pmi	Sn Ratio
1	1	1	1	13.5	22.6067
2	1	2	2	10.5	20.4238
3	1	3	3	8.3	18.3816
4	2	1	2	12.4	21.8684
5	2	2	3	13.2	22.4115
6	2	3	1	8.5	18.5884
7	3	1	3	13.5	22.6067
8	3	2	1	16.0	24.0824
9	3	3	2	19.9	25.9771

Fig. 1 Work piece after mounting.

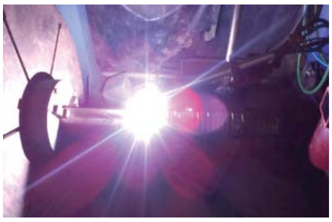

Fig. 2 PTAW process.

Fig. 3 Cross section test.

Fig. 4 LPT testing.

Fig. 5 LPT result.

Fig. 6 Portable hardness test.

Fig. 7 Cross section test result.

Fig. 8 Finished work piece.

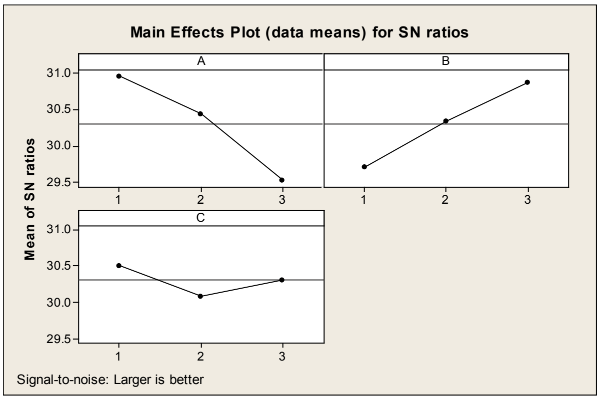

Fig. 9 Main effects plot (Data means) for SN ratios.

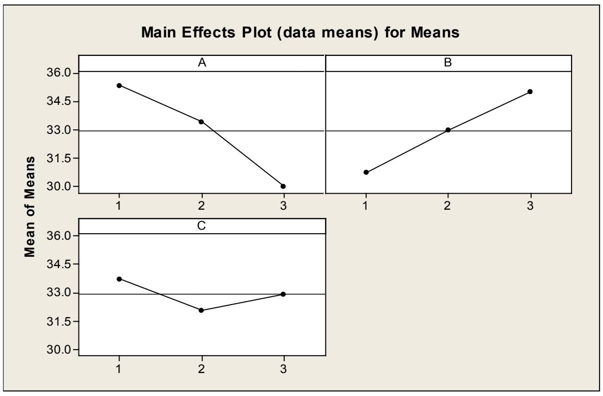

Fig. 10 Main effects plot (Data means) for means.

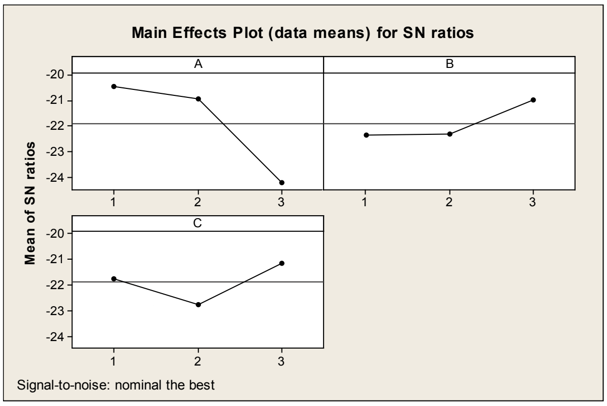

Fig. 11 Main effect plot (data means) for SN ratios.

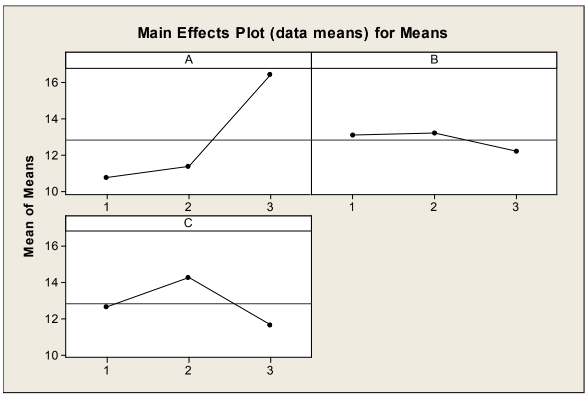

Fig. 12 Main effects plot (data means) for means.

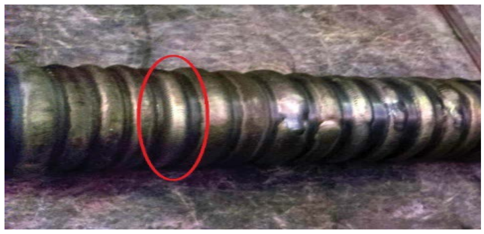

Fig. 13 View of a conclusion bead.

CONCLUSION

This paper introduces the application of Taguchi optimization methodology in optimizing the welding parameters of plasma transfer arc welding (PTAW) process for welding the work piece with cobalt based hard facing alloy. The machining parameters which are chosen to be evaluated in this study are the current (A), table speed (B) and powder feed rate (C). While, the response factors to be measured is the hardness and percentage of iron content of the weld bead. An orthogonal array of the Taguchi method was set-up and used to analyze the effect of the welding parameters on the hardness and percentage of iron content of the weld bead. The result from this study shows that the application of the Taguchi method can determine the best combination of welding parameters that can provide the optimal welding response conditions which are the highest hardness and lowest percentage of iron content value. For the best hardness, A1–B3–C1 (C=140V, T=150.796 mm/min, P=36.85 gms/min) is found to be the optimized combination of levels for all the three control factors from the analysis. Meanwhile, the optimized combination of levels for all the three control factors from the analysis which provides the lowest percentage of iron content was found to be A3–B2–C2 (C=150V, T=123.78 mm/min, P=29.35 gms/min).

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