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Optimization of Plasma Spray Parameters for Wear-Resistant Coating on Metals

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ABSTRACT: This study focuses on the optimization of plasma spray parameter for the deposition of wear-resistant coatings on metallic substances. The plasma spray technique offers a versatile approach for enhancing the surface properties of metals, particularly in application where resistance to wear and abrasion is critical. The investigation aims to systematically explore and optimize key plasma spray parameters to achieve coating with superior wear resistance. A series of experiments conducted assess the influence of various process parameters, such as spray distance and powder feed rate on the microstructure and tribological performance of the resulting coatings. The study employs analytical techniques such as spectroscopy to characterize the coating and evaluate their wear-resistant properties. The optimization process involves a comprehensive analysis of coating adhesion, porosity, and microhardness, providing a holistic understanding of the interplay between plasma spray parameters and the resulting coating quality. The outcome of this study contributes valuable insights into the tailored design of wear-resistant coatings, enabling the optimization of plasma spray parameters for enhanced performance and durability. This work has practical implication across industries such as manufacturing, aerospace, and automotive, where the reliability and longevity of metallic components in advance surface engineering strategies for improved wear resistance in critical applications.

KEYWORDS: Coated Copper, TiO₂, Alloy, Plasma spray coating.

I. INTRODUCTION

The demand for durable and wear-resistant surfaces in industrial applications has prompted a surge in research focused on advanced coating technologies. Among these, plasma spray coatings have gained significant attention due to their versatility and applicability to a wide range of materials. This study delves into the optimization of plasma spray parameters with the primary aim of enhancing wear resistance in metallic substrates. As industries seek to extend the lifespan and performance of critical components subjected to abrasive environments, the development of wear-resistant coatings becomes imperative. Metallic components in industrial machinery and equipment are constantly exposed to harsh conditions, leading to wear and degradation over time. The consequences of wear can range from reduced efficiency and increased maintenance costs to catastrophic failures. To address these challenges, protective coatings have emerged as a pivotal solution, forming a robust line of defense against abrasive wear, erosion, and corrosion. Plasma spray technology, with its ability to deposit a variety of materials, presents an opportunity to engineer coatings with exceptional wear resistance tailored to specific applications. The economic and operational impact of wear on industrial components necessitates the development of coatings capable of withstanding severe mechanical and environmental stresses. Wear-resistant coatings not only extend the service life of components but also contribute to increased reliability, reduced downtime, and enhanced overall performance. By optimizing plasma spray parameters, it becomes possible to tailor coatings to the unique requirements of different industries, ensuring that critical components remain operational under challenging conditions.

II. RELATED WORK

Plasma spray is regarded as the most versatile of all the thermal spray processes e.g. flame spraying, arc spraying. The plasma spraying process involves the latent heat of ionised inert gas being used to create the heat source. The most common gas used to create the plasma is argon as the primary gas and hydrogen or helium as the secondary gas. However the gas usage depends on the type of material to be sprayed and coating application.

Plasma spray is able to use and melt any variety of ceramic materials. The plasma spray system consists of an electronically controlled power supply, a PLC-based operator control station, a gas mass flow system, a closed-loop water chilling system, a powder feeder and a plasma gun. A primary inert gas, such as argon is injected between two water-cooled electrodes (anode and cathode) in the gun, where it is ionised to form a plasma jet when ignited. Any powders is injected into the plasma flame will melt and subsequently deposited onto the component to form a coating.

Most of the ceramic materials used in plasma spray coatings are chromium oxide, TiO₂, zirconium oxide and aluminium oxide. The particle velocities of plasma spraying are higher than for those flame and arc spraying which produce denser coatings and finer surface roughness. Figure 2.7 shows a typical gun and plasma spray coating process.

The versatility of plasma spray has been widely recognised in many numbers of industries. The unique features that characterise plasma spray processing are listed below:

- It can be used to deposit a wide range of ceramics and metals and any combinations of the materials.
- It is able to develop homogeneous coating without composition change with coating thickness.
- High deposition rates are possible without extreme investments in capital equipment.
- Plasma spray can be applied at any environment conditions (air, vacuum and underwater).

Plasma system can be classified into RF plasma and DC Plasma. The processes are described as below:-

- RF plasma – The gas is passed through a radio frequency field so that electrical coupling occurs and energy is transferred to the gas.
- DC plasma – The gas is used as a medium in which a direct current arc is established between two or more electrodes.

In RF plasma, no electrode is necessary to produce the flame, no contamination of the working gas or materials injected into plasma occur during coating process.

Air plasma spray system used for the study is classified as DC plasma. The air plasma spray consist of several principle components to form a complete system in order to generate plasma flame, bring coating material to the plasma flame and produce a coating onto a substrate. In general, the air plasma system consists of:

- Plasma torch
- DC power supply
- Control and instrumentation system
- Cooling water system
- Gas supply system
- Material feeder system

The principle components of the plasma spray system are arranged and linked together in an optimum way in order to ensure maximum efficiency at minimum power, pressure and space. Figure 2.8 shows a flow diagram of plasma spray operation.

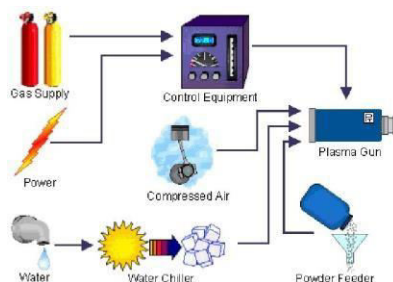


Figure 2.1: Basic system (gases, power, cooling, controller, feeder and plasma torch) of the plasma spray equipment.

III. METHODOLOGY

3.1 Optimization of Plasma Spray Parameters

Optimization of Plasma Spray Parameters was done based on Taguchi's orthogonal Arrays. Four factors which play vital role in producing quality coatings namely Critical Plasma Spray Parameter (CPSP), Standoff distance, Flow rate of hydrogen gas and Powder feed rate were chosen. Each factor was varied at three levels. The wear results presented are the average of three runs.

- CPSP: 700, 800, 900
- Standoff Distance: 10 cm, 15 cm, 20 cm
- Flow Rate of Hydrogen: 0.3 lpm, 0.6 lpm, 0.9 lpm
- Powder rate: 50 gm/min, 100 gm/min, 150 gm/min

Table 3.1 L9 Orthogonal Array for Optimising plasma spray parameters for slurry erosion

Sl. No.	CPSP	Standoff distance(cm)	H2 (lpm)	Powder rate(gm/min)
1	700	10	0.3	50
2	700	15	0.6	100
3	700	20	0.9	150
4	800	10	0.6	150
5	800	15	0.9	50
6	800	20	0.3	100
7	900	10	0.9	100
8	900	15	0.3	150
9	900	20	0.6	50

L9 Orthogonal Array for Optimizing plasma spray parameters for slurry erosion is shown in Table 3.1. Copper specimen was applied with TiO₂ coatings maintaining the above parameters for coating. Slurry erosive wear tests were conducted to obtain the wear values for 100µm thick coatings in order to choose that set of Plasma spray parameters which yields least wear. Wear is least for the best coating developed. Minitab was used to predict under which condition wear is minimum and a confirmation experiment was conducted by coating the substrates with the optimized parameters. The results of these experiments and also the Minitab results are presented in Chapter 4 in the form of tables and graphs.

3.2 Slurry Erosive Wear.

Slurry Pot test is a non-standardized laboratory test for slurry erosive wear measurements. It is used to simulate erosion caused by liquid-borne particles. Mass loss is taken as a measure of wear. Wet erosion is also called as Slurry erosion. Slurry erosion is caused by the interaction of solid particles suspended in a liquid and a surface which experiences loss of mass by the repeated impacts of particles mainly in marine environments and in turbine blades of hydroelectric plants. The line diagram and the photo of slurry pot tester are shown in Figure 3.1 and Figure 3.2 and the principle of operation is shown in Figure 3.3.

The slurry erosive wear sample is a coupon of size 2.5cmx2.5cmx8mm as shown in Figure 3.4. The rotational speed range selected was 1000 rpm, the particle sizes selected was 425 µm and the slurry concentration selected was 100 g/l. The silica sand mixed with water formed the slurry and 3.5 % NaCl was added to the slurry to simulate the corrosion erosion environment for sea water erosion. Wear was reported in the form of mass loss after erosion for a period of 5

hours.

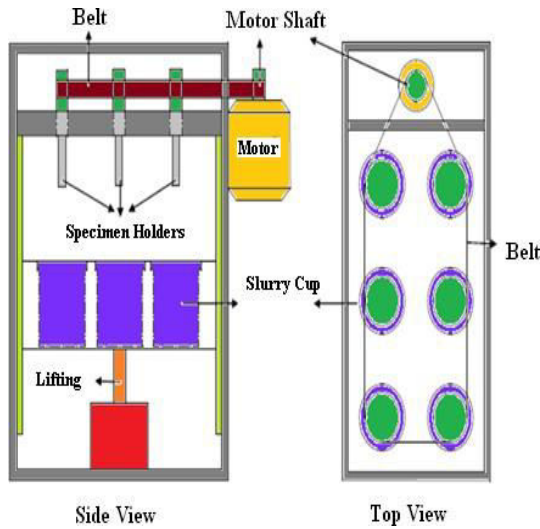


Fig: 3.1 Line diagram of Slurry erosive wear tester



Fig 3.2 Photo of slurry pot tester

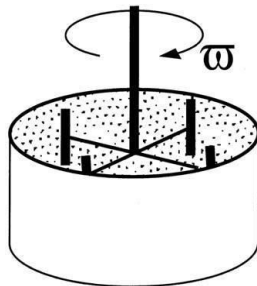


Fig: 3.3 The principle of slurry pot



Fig 3.4 Slurry erosive wear sample erosion test[81]

Table-3.2: Specifications of Slurry Erosive Wear Tester

Spindle speed	100-1500 rpm
Speed indicator	Digital rpm indicator
Timer	Digital timer 999.9 min
Slurry vessel	Doubled walled water cooled, diameter 120 mm lengths
Number of samples	6 nos
Max. Sample size	25.4mm*76.2mm*6.35 mm
Power	230 volts, 10amps

The specifications of the Slurry Erosive Wear Tester are presented in Table-3.2. The parameters that influence the slurry erosive wear behavior of plasma sprayed coatings are rotational speed, erodent size and erodent concentration.



IV. EXPERIMENTAL RESULT

Formula used:

The critical plasma spray parameter is calculated using the formula $CPSP = \frac{\text{Voltage} \times \text{Current}}{\text{Primary Gas flow rate (Argon)}}$

Voltage = 500 volts Current = 48 Amps

$760 = \frac{500 \times 48}{\text{Argon flow rate (lpm)}}$ Argon Flow Rate = 31.57 lpm

Argon flow rate of 32 lpm is selected

Table 4.1: Wear data for uncoated mild steel at 200 rpm

Sl. No.	CPSP	Standoff distance (cm)	H2 (lpm)	Powder rate (gm/min)	Mass Loss In grams
1	700	10	0.3	50	0.0908
2	700	15	0.6	100	0.006
3	700	20	0.9	150	0.02236
4	800	10	0.6	150	0.0027

5	800	15	0.9	50	0.03755
6	800	20	0.3	100	0.08987
7	900	10	0.9	100	0.06893
8	900	15	0.3	150	0.05461
9	900	20	0.6	50	0.07543

The main effects plots for Slurry Erosive Wear Test of Copper substrates coated with 100 thick TiO₂ coatings are presented in Figures 4.1

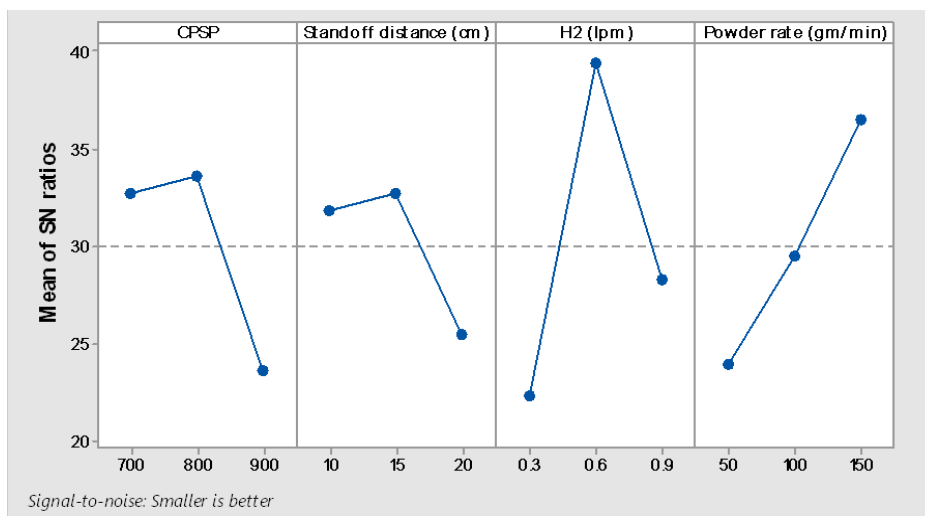


Fig 4.1 Main Effects plots

Table-4.2: Optimized values of factors for plasma spraying for slurry erosive wear

CPSP	Stand Off Distance in cm	H ₂ in liters/min	Powder rate in gram/min
800	15	0.6	150

From the results obtained after Taguchi analysis of the slurry erosive wear test results for minimum wear, the optimized values of factors for plasma spraying are presented in Table 4.2

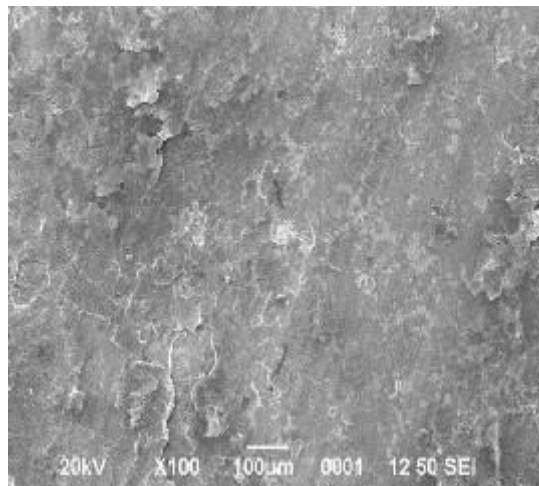


Fig 4.3 TiO₂ coated Copper

The surface of Copper coated with TiO₂ coatings after slurry test conducted at optimized values is shown in SEM micrographs Fig. 4.3. It can be seen that the coated sample showed removal of coating materials in the form of scale. This is well supported by the wear loss measured in grams.

V. CONCLUSION

From the present study following conclusions were drawn;

1. TiO₂ was successfully coated on Copper with varying plasma spray parameters as per Taguchi Orthogonal Array using plasma spray technique
2. The specimen were subjected to slurry erosive environment in accordance with the non-standardized test procedure for slurry pot test.
3. The Optimized plasma spray process parameters for slurry erosion of TiO₂ coatings were determined by using Minitab software.

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