PARAMETER OPTIMIZATION IN PLASMA SPRAYING OF RED MUD USING FRACTIONAL FACTORIAL TECHNIQUE

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ABSRACT

Coating deposition by plasma spraying involves a number of process variables, which contribute in a large way to the quality of the coating. During spraying, various operating parameters are determined mostly based on past experience. It therefore does not provide the optimal set of parameters for a particular objective. In order to obtain the best result with regard to any specific coating quality characteristic, accurate identification of significant control parameters is essential. Deposition efficiency of any coating is a characteristic which not only rates the effectiveness of the spraying method but also is a measure of the coatability of the material under study. This paper analyzes the experimental results on the deposition efficiency of red mud coatings made at different operational conditions. For this purpose, a statistical technique fractional factorial testing is employed, with the help of which parameters are identified according to their influence on the coating deposition. The most significant parameter is found.

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INTRODUCTION

In industries, mechanical components have to operate under severe conditions such as high load, speed or temperature and hostile chemical environment. Thus their surface modification is necessary in order to protect them from various types of degradation. Ceramic coatings produced by thermal spray techniques are widely used for a range of industrial applications to confer wear and erosion resistance, corrosion protection and thermal insulation [1, 2, 3, 4]. Thermal spraying belongs to a class of semi-molten state coating technique. Plasma spraying is one such route that involves projection of selected powder particles into the area of high thermal density, where they are melted, accelerated and directed on to the substrate surface [4]. Coatings are formed by the immediate solidification of the molten droplets on the substrate surface of lower temperature where they form splats. Oxide ceramics such as Alumina, Zirconia, Titinia, Chromia, Silica, Yittria have been used widely as surface coating materials to improve wear, erosion, cavitations, fretting and corrosion resistance [5, 6]. Despite all the advantages plasma spraying has not been that much attractive, mostly because of the high cost of spray grade powders required for coating. This problem can be addressed to by exploring the use of some cheaper coating materials. Literatures are available on coatability of red mud, fly ash and redmud-flyash mixture [7, 8, 9], but nothing so far has been reported on the tribological behaviour of these coatings.

In the present work, *redmud* and *flyash*, two abundantly available industrial wastes were taken as the materials to be coated on metal substrates via Atmospheric Plasma Spraying (APS) technique and the influence of the torch operating power on the sliding characteristics of these coatings was examined. Plasma sprayed coatings are often used to restore dimensions of worn or damaged components. Hence a more detailed understanding of the effect of this deposition parameter on wear properties of plasma sprayed coatings is desirable.

EXPERIMENTAL

Plasma sprayed coatings of redmud-flyash mixture in various ratios (by weight) on aluminium substrates were prepared using a 40kW atmospheric plasma spray system at the Laser & Plasma Tech. Division, BARC, Mumbai. Red mud is the waste produced during alumina production following Bayer's Process. Similarly fly ash is the waste produced in large quantity in all coal based thermal power plants. These powders were collected from National Aluminium Co. (NALCO) sites at Damanjori and Angul in Orissa state. The chemical analysis of both red mud and fly ash show Fe_2O_3, Al_2O_3, TiO_2 and SiO_2 as their major constituents. The set up used for coating deposition works in the non-transferred arc mode. A current regulated DC supply was used. A four stage centrifugal pump at a pressure of 10kg/cm^2 supplied cooling water for the system. Argon and Nitrogen taken from normal cylinders at an outlet pressure of 4kg/cm^2, were used as plasma gas and carrier gas respectively. Prior to coating, the substrates were vapour greased, grit blasted to get the required surface roughness and subsequently cleaned with acetone. Plasma sprayed coatings of thickness varying between 250-350 micrometer were deposited on these grit blasted aluminium and copper strips of size 50mm x 25mm x 5mm at different operating power levels in the range of 6 to 16 kW.

The operating parameters used in the experiment are presented in Table 1.

Parameter	Range
Operating Power (kW)	6-16
Current (Amps)	150-400
Voltage (V)	30-40
Primary Plasma gas (Argon) flow rate (lpm)	20
Secondary gas (Nitrogen) flow rate (lpm)	2
Torch to base distance (mm)	100
Powder feed rate (g/min)	10
Powder carrier gas (Argon) flow rate (lpm)	6

Table 1: Operating parameters for plasma spraying of red mud-fly ash mixture

FRACTIONAL FACTORIAL TESTING

In the plasma spray field there are at least three situations that frequently arises where optimum spray parameters must be experimentally determined: first, when presented with new powders which have no published spraying parameters; secondly, when two or more standard powders are combined as a blend for spraying ; and third, when certain undesirable coating features develop and a relatively standard set of parameters needs to be evolved. The first two situations are encountered in the present work during the deposition of red mud and of different mixtures of red mud and fly ash powders on metallic substrates. These materials are new in the field of plasma spray coating. The fractional factorial testing is chosen as the technique for analysis primarily for its ability to identify the most significant among the variables.

A full factorial test plan includes all possible combinations of the factors being tested, while a fractional factorial test plan is simply a desired fraction of the full factorial plan. In this method of testing, all the factors affecting the process are first selected. In plasma spraying, parameters viz. plasma arc current, arc voltage, electrical power level, surface roughness etc. are the main factors which affect the coating qualities. The values of any factor in an experiment are known as ‘ levels ’. Factorial testing is carried out in a manner, which will help in evaluation of all the factors independently. In a full factorial testing, each and every combination of parameters with different levels is considered. For a test involving seven parameters with each parameter being tested at two levels, the number of tests to be performed will be 2^7, i.e. 128. In case of a fractional factorial test, only a small fraction of the full factorial testing is done. This test, though sacrifices the completeness, includes the effect of simultaneous parameter changes. The advantage of this test is that by performing just ‘ n ’ tests, ‘ n -1 ’ number of factors can be included [10].

Test Grids

The limit of fractionating a factorial plan is called fully saturated factorial test plan. A number of fully saturated test grids are available for testing, e.g. 3 factor 4 test grid, 7 factor 8 test grid etc. These grids are at two levels for each parameter. The two test levels are marked as ‘ + ’ and ‘ – ’.

For the present investigation, a 7 factor 8 test grid is selected to optimize the control parameters in just eight tests. The factors and levels chosen are based on experience and equipment capabilities. The evaluation of the coatings is done on the basis of deposition efficiency.

The parameters and the test levels selected for the test coatings are given in table 5.1. The complete test grid showing test layout with results is presented in table 5.2.

Parameter	**Code**	**'+' Level**	**' – ' Level**
Arc current intensity(amp)	A	400	200
Arc voltage (volt)	B	40	30
Fly ash content (wt%)	C	50	0
Surface roughness(micron Ra)	D	6.8	4
Torch to base distance(mm)	E	125	100
Powder feed rate (gm/min)	F	15	10
Carrier gas flow rate (lpm)	G	10	7

Table 2 Control parameters and selected test level

Test No.	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Deposition efficiency (%)**	
								Al	**Cu**
1	+	+	+	+	+	+	+	31.23	27.83
2	+	+	-	+	-	-	-	23.59	24.00
3	+	-	+	-	+	-	-	26.50	25.20
4	+	-	-	-	-	+	+	20.68	21.95
5	-	+	+	-	-	+	-	16.02	17.19
6	-	+	-	-	+	-	+	13.00	13.40
7	-	-	+	+	-	-	+	09.30	10.35
8	-	-	-	+	+	+	-	07.20	07.00

Table 3 Complete test grid with test outputs

Test Results

The outputs (experimental values of deposition efficiency on aluminium and copper substrates) are summed up for each level of a given factor to produce a comparison of levels for that factor. A favour ratio (FR) is calculated from the total of output values of the specimens with "+" levels and "-" levels of any factor. The level, which shows a better "total", is considered as the favorable level over the other. The optimized set of parameters for a particular coating quality characteristic on any substrate will have the favoured levels of all the factors.

Code	Parameter	Favoured Level	Favour Ratio	
			Aluminium Substrate	Copper Substrate
A	Arc current intensity(amp)	400	2.24	2.232
B	Arc voltage (volt)	40	1.316	1.404
C	Fly ash content (wt %)	50	1.288	1.279
D	Surface-roughness (micron)	6.8	1.205	1.202
E	Torch to base distance(mm)	100	1.013	1.020
F	Powder feed rate(gm/min)	10	1.267	1.259
G	Carrier gas flow rate (lpm)	7	1.019	1.032

Table 4 Fractional factorial test results for deposition efficiency

The favoured levels and their ratios are given in table 5.3. Factorial testing experience in plasma spraying suggests that a ratio above 1.20 is necessary to display significant benefit [11]. Therefore, factor G i.e. the carrier gas flow rate and factor E i.e. the torch to base distance at favour ratios 1.019, 1.032 (for aluminium) and at 1.013, 1.020 (for copper) respectively do not greatly affect the coating at the levels chosen. The factorial test results then suggest the levels favoured as significantly better than their counterpart. It gives the optimized set of process within the test range so as to get the maximum deposition efficiency. It further suggests that factors A (plasma arc current intensity), B (arc voltage), C (fly ash content in the feed stock), F (powder feed rate) and D (substrate surface roughness), in that order, influence the deposition efficiency.

Plasma arc current emerges as the most significant control parameter followed by arc voltage, fly ash content and powder feed rate.

CONCLUSIONS

Functional coatings have to fulfill various requirements. The deposition efficiency is one the main requirements of the coatings developed by plasma spraying. It represents the effectiveness of the deposition process as well as the coatability of the powders under study. In order to achieve certain values of deposition efficiency accurately and repeatedly, the influence parameters of the process have to be identified and controlled accordingly. Since the number of such parameters in plasma spraying is too large and the parameter-property correlations are not always known, statistical methods can be employed for precise identification of significant control parameters for optimization. The present investigation attempts to analyze of the results using fractional factorial plan and identifies the plasma arc current as the most significant control parameter followed by arc voltage, fly ash content and powder feed rate.

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