

Erosion Wear Performance of Glass Micro-spheres Coatings using Artificial Neural Network

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Abstract: *This article proposes the application of artificial neural networks (ANN) to a Taguchi orthogonal experiment to develop a robust and efficient method of analyzing and predicting the solid particle erosion wear response of a new class of metal-glass coatings. An ANN model based on data obtained from experiments performs self-learning by updating weightings and repeated learning epochs. In this work, plasma-sprayed coatings of solid glass micro-spheres are deposited on aluminum substrates at various input power levels of the plasma torch. Erosion wear characteristics of these coatings are investigated following a plan of experiments based on the Taguchi technique, which is used to acquire the erosion test data in a controlled way. The study reveals that the impact velocity is the most significant among various factors influencing the wear rate of these coatings. An ANN approach is then implemented taking into account training and test procedure to predict the tribo-performance under different erosive wear conditions. This technique helps in saving time and resources for a large number of experimental trials and successfully predicts the wear rate of the coatings both within and beyond the experimental domain.*

Keywords: Plasma spraying; Glass micro-spheres; Erosion Wear; Taguchi Technique; ANN.

1. Introduction

Plasma spray coating is a typical thermal spraying process that combines particle melting, quenching and consolidation in a single operation. The advantages of plasma spraying include formation of ceramic microstructures with fine, equiaxed grains without columnar defects, deposition of graded coatings with a wide compositional variability, application of high deposition rates during formation of thick coatings with only modest investment in capital equipment [1-3]. But as high cost of spray grade powders limits the adoption of this technique, exploring newer and cheaper materials suitable for plasma spray coating has drawn a lot of attention. In thermal plasma, it is possible to spray all metallic and non-metallic materials, such as metal oxides, carbides, nitrides and silicides etc. [4-6]. The oxides of iron, aluminium and silicon are known to have high hardness, high wear resistance and good corrosion resistance, which are desirable properties for protective coatings. During recent years, although a large number of investigations have been carried-out on production of ceramic coatings using these metal oxides, little effort have been made with plasma processing of cheap and natural occurring materials/minerals. The plasma spray technology has been able to process various low-grade-ore minerals to value added products and also to deposit metals and ceramics, producing homogenous composite coatings (functionally graded) with desired properties [7, 8].

Wear is defined as the damage to a solid surface usually involving progressive loss of materials, owing to relative motion between the surface and a contacting substance or substances [9]. The effect of wear on the reliability of industrial components is recognized widely and the cost of wear has also been recognized to be very high. Although wear has been extensively studied scientifically, still wear problems persist in industrial applications. This actually reveals the complexity of the wear phenomenon [10]. Wear is a common occurrence on most plant and machinery and is often a slow and progressive process [11].

Erosion is one of the most important wear phenomena. It is caused by the impact of dispersed particles in a gas or liquid flow on the surface of materials. This in turn reduces the life of the mechanical components used in many industrial applications [12]. There are different types of erosion wear depending on the types of erodent and the methods of impact like slurry erosion, solid particle erosion, liquid impact erosion and cavitation erosion [12]. Solid particle erosion (SPE) is a wear process where particles strike against a surface and promote material loss. During flight, a particle carries momentum and kinetic energy, which can be dissipated during impact due to its interaction with a target surface [13]. In some cases SPE is a useful phenomenon, such as in sand-blasting and high-speed abrasive water jet cutting, but it is a serious problem in many engineering systems, including steam and jet turbines, pipelines and valves carrying particulate matter and fluidized bed combustion (FBC) systems [14]. Plasma sprayed coatings are being applied on engineering as well as structural components, where erosion occurs frequently. Due to severe dusty industrial environments, the study of solid particle erosive analysis of these coatings becomes highly relevant [15]. To reduce wear, all process parameters are needed to be understood, so as to undertake appropriate steps in the design of substrates and coating materials [16]. As the number of such process parameter is too large, statistical techniques could be employed for identification of significant process parameters for optimization. In recent years, the Taguchi experimental design technique has become an excellent tool for improving performance output and optimizing the total cost [17]. Hence, in this investigation, the Taguchi experimental design method has been adopted to find out the effects of impingement angle, impact velocity, erodent size erodent temperature and aluminum content of coating on the erosion wear rate.

2. Experimental Detail

2.1 Materials and Methods

The most important step in plasma spray coating technique is the preparation of the substrate surface in order to increase the mechanical anchoring between the substrate and the coating. The surface of the substrate subjected to grit blasting, where highly compressed air carrying alumina particles are embedded on the surface to make the surface rough of 6-8 μm .

The coating process was carried out at CSIR-IMMT, Bhubaneswar, India, using an 80 kW plasma spray system supplied by M/s Metallization, U.K. This is a typical atmospheric plasma spray system working in the non-transferred arc mode. This set-up mainly consists of a spray torch, six-axis robot, powder feeder, power supply, mass flow controller, a robot controller, control console, substrate holder, plasma gas supply, cooling water and spray booth. Argon and Helium are used as primary plasma gas and secondary gas respectively, taken from normal cylinders at an outlet pressure of 4kg/cm². A mild steel substrate of dimension 120×60×5 mm after surface preparation, was fixed on the substrate holder and the coating of glass micro-sphere was carried out at a constant powder feed rate of 20 gm/min.

2.2 Erosion Wear Test

Erosion wear tests are carried out in an Air Jet Erosion test rig as per ASTM G 76. The setup is mainly consists of an air compressor, an air-particle mixing chamber and accelerating chamber. This setup is capable of creating reproducible erosive situation for assessing erosion wear resistance of the prepared coated samples. In the present study, alumina of different particle sizes (i.e. 100, 200, 300 and 400 μm) is used as erodent. Before subjected to the test rig, the samples are cleaned and weighted. Then the samples are eroded in the test rig with different angle of impingement (varies from 30⁰ to 90⁰) for 20 min each. After that the sample are again weighted to determine the weight loss. The process is repeated till the erosion rate attains a constant value called *steady state erosion rate*. The erosion rate is defined as the

weight loss of the specimen due to erosion divided by the weight of the erodent causing the loss.

2.3 Experimental Design

Design-of-experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The erosion wear tests on the composites are carried out under different operating conditions considering four parameters, viz., impact velocity, impingement angle, erodent size and erodent temperature each at four levels as listed in Table 1 in accordance with Taguchi's L₁₆ (4⁴) orthogonal array. The impacts of these four parameters are studied using this L₁₆ array and the tests are conducted as per this experimental design. The experimental observations are further transformed into signal-to-noise (S/N) ratios. The S/N ratio for minimum wear rate can be expressed as "smaller is better" characteristic, calculated as logarithmic transformation of loss function as shown below [18].

$$S/N = -10 \log \frac{1}{n} (\sum y^2) \quad (1)$$

Here, 'n' is the number of observations and 'y' is the observed data. In conventional full factorial experimental design, it would require 4⁴ = 256 runs to study four factors each levels whereas, Taguchi's factorial experiment approach reduces it to only 16 runs offering a great advantage in terms of experimental time, cost and to estimate erosion rate (Er).

3. Results and Discussion

3.1 Wear Analysis Using Experimental Design

The erosion wear rates obtained for all the 16 test runs along with the corresponding S/N ratio are presented in Table 1. From this table, the overall mean for the S/N ratio of the wear rate is found to be -31.7239dB. This is done using the software MINITAB-14 specifically used for design of experiment applications. The S/N ratio response analysis presented in Table 2 shows that among all the factors, impact velocity is the most significant factor followed by impingement angle, while others has less significance on wear rate of the coated sample under this investigation.

Table 1: L16 Orthogonal array design with output and S/N ratio

Sl. No.	Impact Vel.	Imping. Angle	Erodent Size	Erodent Temp.	Erosion Rate	S/N Ratio
1	33	30	100	50	24.1935	-27.6740
2	33	45	200	75	21.2644	-26.5531
3	33	60	300	100	16.8067	-24.5096
4	33	90	400	125	8.6206	-18.7107
5	47	30	200	100	66.1157	-36.4061
6	47	45	100	125	48.3871	-33.6946
7	47	60	400	50	25.8620	-28.2532
8	47	90	300	75	21.2100	-26.5308
9	57	30	300	125	92.4369	-39.3169
10	57	45	400	100	34.4827	-30.7520
11	57	60	100	75	56.4516	-35.0335
12	57	90	200	50	49.5867	-33.9073
13	68	30	400	75	86.2068	-38.7108
14	68	45	300	50	53.6134	-34.5855
15	68	60	200	125	74.3801	-37.4291
16	68	90	100	100	59.6774	-35.5162

Table 2: Response table of S/N ratio

Level	A	B	C	D
1	-24.36	-35.53	-32.98	-31.10
2	-31.22	-31.40	-33.57	-31.71
3	-34.75	-31.31	-31.24	-31.80
4	-36.56	-28.67	-29.11	-32.29
Delta	12.20	6.86	4.47	1.18
Rank	1	2	3	4

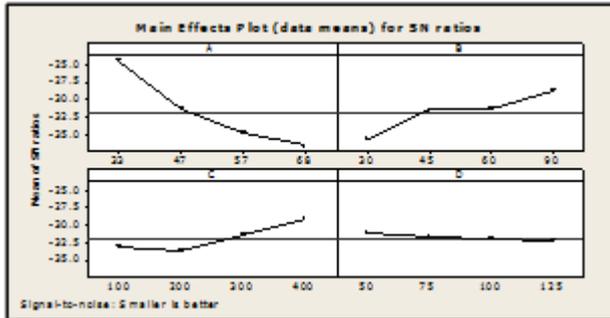


Figure 1. Main effects plot for S/N ratios

The effects of individual control factor are assessed by calculating the response and the results of response analysis lead to the conclusion that factor combination of A1, B3, C2, D4 and E4 gives the minimum wear rate.

3.2 Wear rate prediction using ANN

Wear process is considered as a non-linear problem with respect to its variables: either materials or operating conditions. To obtain minimum wear rate, appropriate combinations of operating parameters have to be planned. In this work, a statistical method, responding to the constraints, is implemented to correlate the operating parameters. This methodology is based on ANN, which is a technique that involves database training to predict input-output evolutions. In the present analysis, the impact velocity, impingement angle, erodent size and erodent temperature are taken as the four input parameters. Each of these parameters is characterized by one neuron and consequently the input layer in the ANN structure has four neurons. Different ANN structures with varying number of neurons in the hidden layer are tested at constant cycles, learning rate, error tolerance, momentum parameter, noise factor and slope parameter. Based on least error criterion, one structure is selected for training of the input-output data. A software package NEURALNET for neural computing using back propagation algorithm is used as the prediction tool for erosion rate of the composite samples under various test conditions. The three-layer neural network having an input layer (I) with four input nodes, a hidden layer (H) with ten neurons and an output layer (O) with one output node used in this work is shown in figure 2.

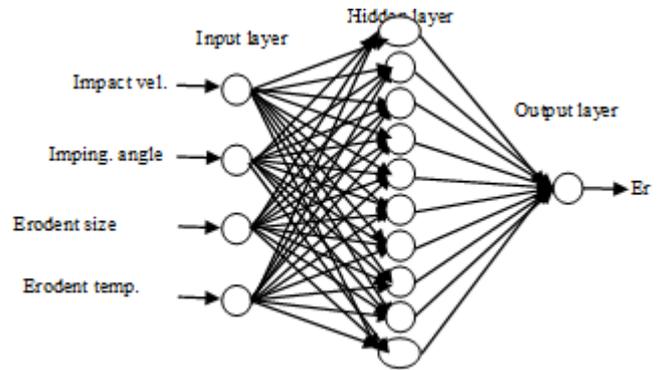


Figure 2: Three layer neural network

The simulated erosion rates indicating the effect of varying sliding velocity is presented in Fig. 3. It is interesting to note that the erosion rate increases with the increase in impact velocity.

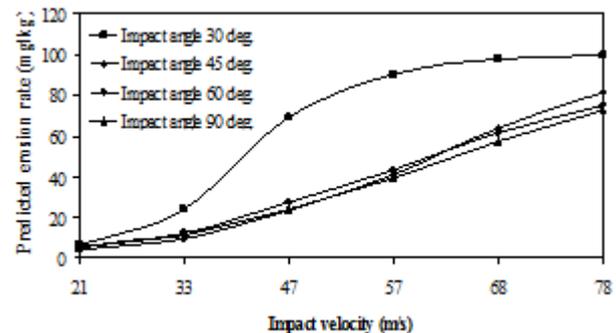
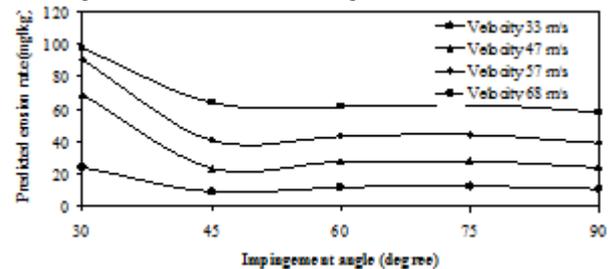


Figure 3: Effect of impingement angle on erosion rate of glass coating at different impact velocity

In Fig. 4 the simulated erosion rates indicating the effect of varying impingement angle are presented. It is interesting to note that the erosion rate is maximum at an angle of 30° showing ductile nature of coating.



4. Conclusions

Erosion wear characteristics of metal-glass coating can be experimented following a design-of-experiment approach. This study reveals that among all the factors, impact velocity is the most significant factor followed by impingement angle while others has less significance on wear rate of these coatings. ANN technique is successfully applied in this investigation and it is seen that the use of the neural network model to simulate experiments with parametric design strategy is quite effective for prediction of wear response of such coated materials within and beyond the experimental domain.

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