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ANN Controlled Plasma Spray Process by using Industrial Waste

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Abstract
Plasma spray coating process has become a subject of intense research because it becomes an affordable solution for many industrial applications. The present work aims at developing and studying the industrial wastes (Flay-ash powder mixture) as the coating material, which is to be deposited on Mild Steel and Cupper substrates. To increase the coating deposition efficiency and to decrease the cost of coating process, one of the artificial intelligence (AI) method i.e. Artificial Neural Network (ANN) technique used. By this parameter optimization technique, it is sufficient to describe approximation complex inter-relations in atmospheric plasma spray process. ANN technique helps in saving time and resources for experimental trials. The aim of this work is to outline a procedure for selecting an appropriate input vector in ANN coating efficiency models, based on statistical pre-processing of the data set. This methodology can provide deep understanding of various co-relationships across multiple parameter set, which could be essential for improvement of product and process performance. The aim of this article is to find optimum parameter for deposition efficiency. ANN experimental results indicate that the projection network has good generalization capability to optimize the deposition efficiency.

Keywords: *ANN, Deposition Efficiency (DE), Plasma Spraying, Mild Steel, Cupper*

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INTRODUCTION
Plasma surfacing is an important established technology in high-performance coating applications [1–3]. Thermal spraying process implements a wide variety of materials and processes for improving surface properties [4]. The conventional plasma-spraying process is commonly referred to as air or atmospheric plasma spraying (APS). In this APS technology, the coating materials used with well-defined melting point ranging from metallic to ceramic material [5]. To generate the plasma, an inert gas typically argon or argon+ hydrogen mixture is superheated by a direct-current arc [6]. Plasma temperatures in the power heating region range from approximately 6000°C to 15000°C, which are significantly above the melting point of any known material [7]. The powder mixture of Fly-ash+quartz+illuminate (size from 40 µm to 100 µm) injected into a high-temperature plasma flame which is then rapidly heated and accelerated to a very high velocity by the plasma flame, impacts the surface of the substrate material in the form of molten or semi-molten state and very quickly cools to form a good adherent coating [6, 8, 9].

Parameter control by ANN for plasma spray technique generally considers the monitoring of the molten feedstock particle characteristics deposited at the substrate surface to increase the coating deposition efficiency (DE) [10]. DE can be defined as the ratio of the weight of coating deposited on the substrate to the weight of the expended feedback. DE represents the effectiveness of the deposition process as well as the coatability of the powder under study [11]. The coating DE directly or indirectly depends on many other parameters during spraying, in which each one is inter-related with each other. ANN study and design of systems capable of perceiving their environment and taking actions maximizing their chance of success, to increase deposition efficiency.

EXPERIMENTAL PROCEDURE

Coating material of Flay-ash, Quartz and illuminate mixture was taken with their weight percentage ratio of 60:20:20 and mechanically milled in Planetary ball mill for 3 hour to get a homogeneous mixture. This mixture used as feed stock for plasma spraying was first sieved and four different size i.e. 40 µm, 60 µm, 80 µm and 100 µm are separated out. The substrate materials are Mild Steel and Copper; having dimensions of 1 inch diameter and 3 mm thickness. The substrate were grit blasted at a pressure of 3 kg/cm^2 using alumina grit to make the surface roughness ~5.00 Ra. After grit blasting by acetone substrates surface were cleaned, then immediately plasma spraying was carried out. The coating process made by using a 40 kW plasma spray system at the Laser & Plasma Technology Division, BARC, Mumbai. The plasma input power level was varied from 11kW to 21 kW. This is a typically atmospheric plasma spray process, which is working in the non-transferred arc mode. A current regulated dc power supply was used. The injection of the powder was external from the torch nozzle and directed perpendicular to the plasma flow and parallel to the torch trajectory. The torch was operated using argon and hydrogen plasma mixture gas. The major subsystems of the set up include the power supply, plasma spraying torch, powder feeder, plasma gas supply, torch and substrate distance controller, control console, cooling water and spray booth. For cooling the system, a water cooling system used which is a four stage closed loop centrifugal pump, regulated at a pressure of 10kg/cm^2 supply. Operating parameters used for coating deposition are given in Table 1. Flow rate of plasma gas (argon) and Secondary gas (N_2) are kept constant. Powder feed rate, Powder Size and Torch to base distance (TBD) are varied with respect to increase in power level.

Table 1: *Operating Parameters during Deposition of Fly-ash+ Quartz+ Illmenite Coatings.*

Operating parameters	values
Plasma arc current	270, 300, 400& 420 Amp
Arc voltage	40,45 & 50 volt
Torch input power	11,15,18 & 21 kW
Plasma gas(argon) flow rate	28 IPM
Secondary gas(N_2) flow rate	3 IPM
Carrier gas(Ar) flow rate	12 IPM
Powder feed rate	12, 15 & 18 gm/min
Powder Size	40, 60, 80 & 100 µm
Torch to base distance(TBD)	100, 120, 140 mm

ARTIFICIAL NEURAL NETWORK

A neural network is a mathematical model processing system which is capable to relate input to output parameters and learning from data set through iteration, without requiring a prior knowledge on the relationships between the process variables [12]. This model can able to approximate various nonlinearities in the data series, among other models [13–15] and can give an appropriate optimized data output (Deposition efficiency), more quickly [16]. ANN of simple processing elements (neurons) typically organized in layers (input layers, hidden layers and output layers) shown in Figure 1. A software package NEURALNET for neural computing developed, by using back propagation algorithm as the prediction tool for output (coating deposition efficiency) [17,18].

There are no fixed rules for developing an ANN, but in general framework it can be followed based on previous successful applications in engineering. The aim of an ANN is to normalize a input-output relationship of the form of

$$\mathbf{y^m = \mathit{f}(x^n)}$$

where, x^n is an n-dimensional input vector represents variables $x_1, . . , x_i, . . , x_n$ and y^m is an m-dimensional output vector represents the resulting variables $y_1,.. , y_i,.. , y_m$. In plasma spray modeling, values of x may be Current, Voltage, Torch to base distance, powder federate and powder size.

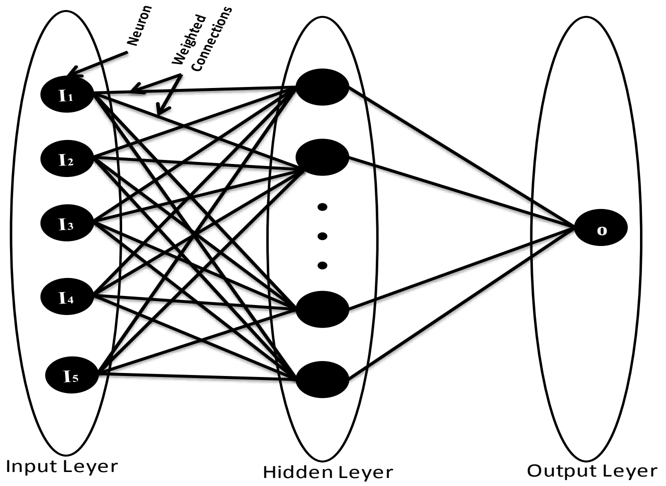


Fig 1: *Architecture of ANN.*

RESULTS AND DISCUSSION

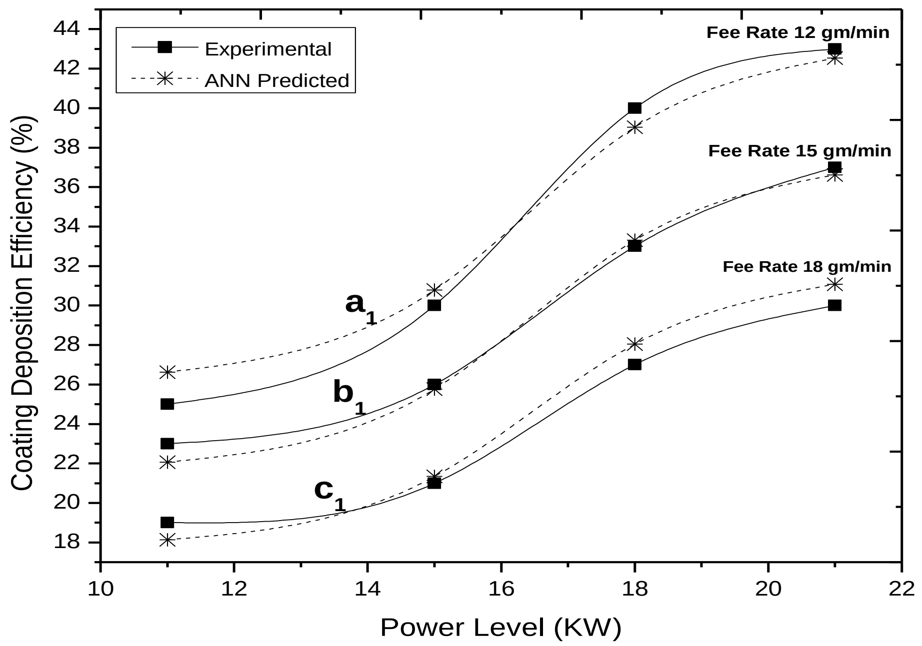
In NEURALNET Software, based on least error criterion as shown in Table 2, is selected for training of the input-output data in by taking 12 set of parameter. The network optimization process (training and testing) is conducted for 1,00,00,000 cycles for which stabilization of the error is obtained. Neuron numbers in the hidden layer is varied and in the optimized structure of the network, this number is 8 (for Copper) and 6 (for Mild Steel). The three layer network involved is shown in Figure 1.

Table 2: *Input parameters selected for training*

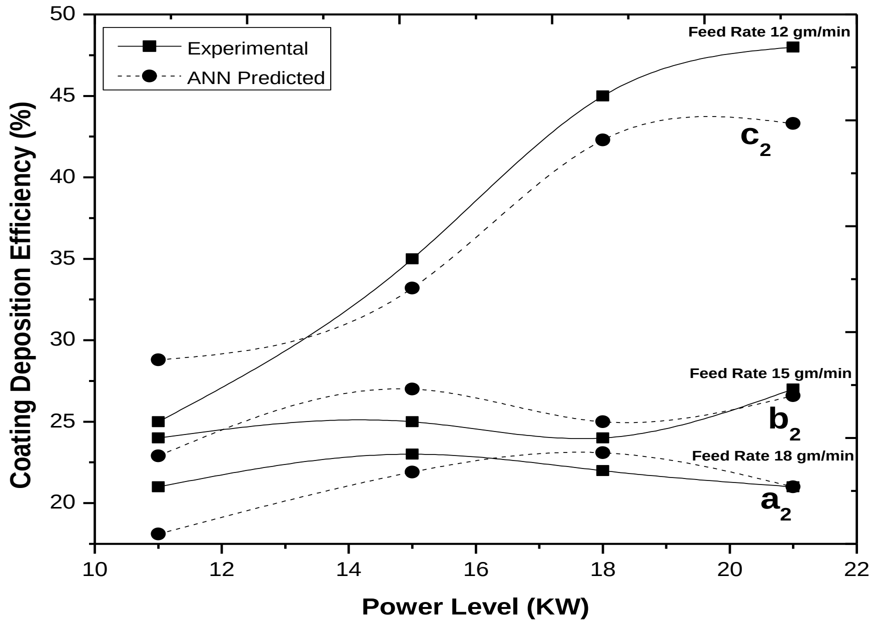
Input Parameters for Training	Values
Error tolerance	0.003
Learning parameter(ß)	0.002
Momentum parameter(α)	0.002
Noise factor (NF)	0.001
Maximum cycles for simulations	1,00,00,000
Slope parameter (£)	0.6
Number of hidden layer neuron	8
Number of input layer neuron (I)	5
Number of output layer neuron (O)	1

Predicted Deposition Efficiency Compare with Experimental Results based on Different Feed Rate

In Figure 2(a), there is a comparative study of ANN prediction value of coating deposition efficiency with that of experimental value for copper substrate. There are three comparison plot to confirm the error between ANN prediction and experimental. In plot (a_1), the fly-ash+quartz+illuminate powder mixture are deposited on copper substrate at 12 gm/min feed rate, 100mm torch to base distance with varying the power level. In plot (b_1), the powder mixture are deposited at 15 gm/min feed rate, 120mm torch to base distance and in plot (c_1), the powder mixture are deposited at 18 gm/min feed rate, 140 mm torch to base distance. Here there is same sigmoidal plot drawn as in increasing the powder feed rate. 42.54% efficiency obtained at 12 gm/min feed rate. As seen from the figure, the close agreement of the values of the coating deposition efficiency by the neural network and the experimental study clearly indicates that the model can be used for predicting the amount coating deposition efficiency. For Mild steel substrate the comparison plots are shown in Figure 2(b) by varying power level. In plot (b_2), the powder mixture 12 gm/min feed rate, 100mm torch to base distance, in which 43.3% coating deposition efficiency obtained. In plot (b_2), the powder mixture are deposited at 15 gm/min feed rate, 120 mm torch to base distance and in plot (c_2), the powder mixture are deposited at 18 gm/min feed rate, 140 mm torch to base distance. In case of Figure 3(curve b_2 & c_2), as increasing the feed rate from 12 gm/min, the slop of deposition efficiency curve is very low due to higher thermal gradient in between higher feed rate powder and mild steel substrate.



(a)



(b)

Fig 2: *Comparison Plot between ANN Prediction Deposition Efficiency and Experimental Value at Different Feed Rate **(a)** for Copper and (b) for Mild Steel (Fly-ash+Quartz+Illuminate Powder Mixture are Deposited Copper and Mild Steel Substrates).*

From the Figure 2(a, b), it is clear that the deposition efficiency of cupper is greater than that of iron substrate, when feed rate will more than 12 gm/min. This is due to differences in thermal conductivity from powder particle to substrate. The mode of heat transfer for the splat is thought to be rapid conduction cooling through the substrate or prior deposited splats. In effect, this process is similar to splat quenching by the Duwez gun technique [19].

Prediction Results based on Powder Size

The deposition efficiencies for 40μm, 60μm, 80μm, 100μm, 120μm, 140μm size powders were measured, which are shown in Figure 3(a) for cupper substrate and Figure 3(b) for Mild steel substrate. In case of cupper the deposition efficiency increases from 40 μm to 140 μm powder size which is reverse for mild steel substrate. So for copper substrate higher powder size than that of 140 μm can be utilize and for mild steel not go beyond 100 μm to economize the process at 12gm/min feed rate.

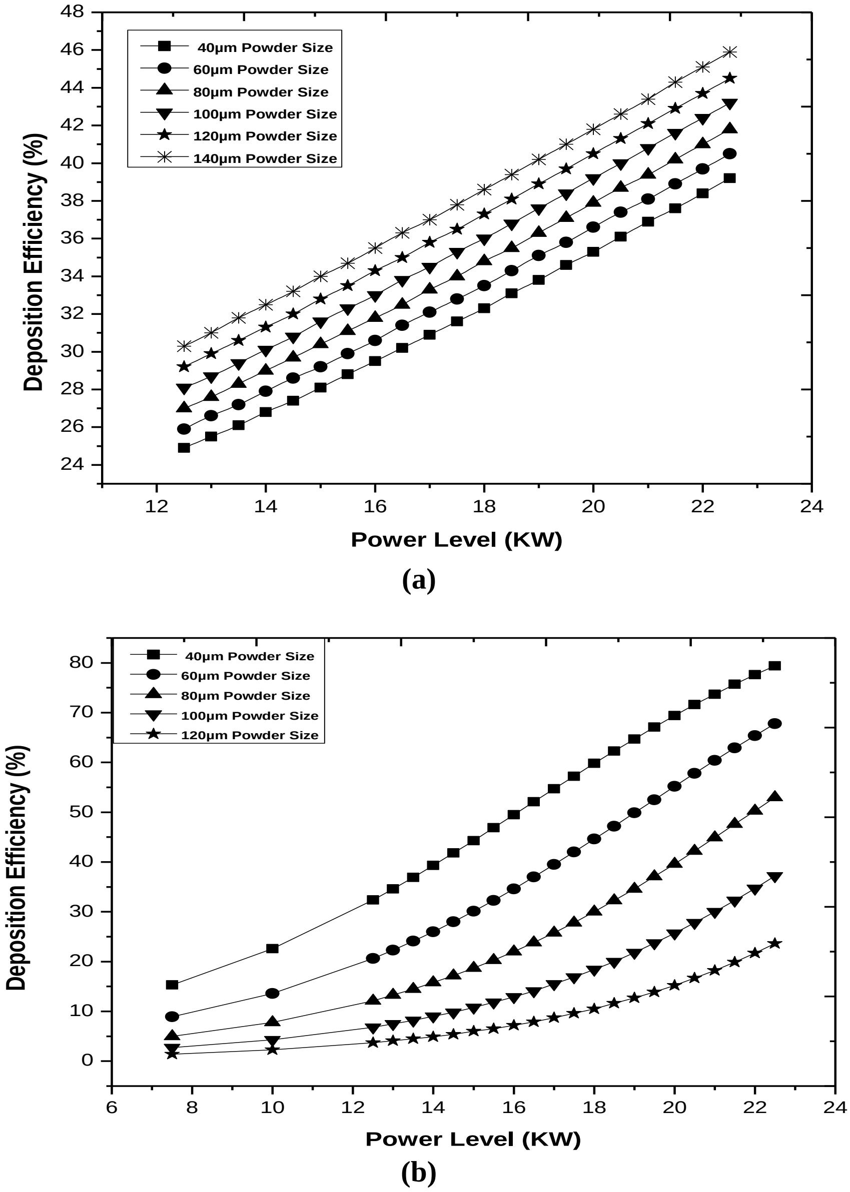


Fig 3: *ANN Prediction Deposition Efficiency for **(a)** Copper, **(b)** Mild Steel at 12 gm/min Feed Rate and 120 mm TBD.*

CONCLUSIONS

The deposition efficiency of the results indicates that neural networks can yield fairly accurate results and can be used as a practical tool in plasma deposition manufacturing process. Due to the parallel mechanism, once an ANN is trained, it can provide the ability to solve the mapping problems much faster than conventional methods. ANN has the capacity which roughly corresponds to their ability to model any given function and it is related to the amount of information that can be stored in the network and to the notion of complexity. ANN has a broad field of applications and that can do classifications, clustering, experimental design, modeling, mapping, etc.

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