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Original Research Article

Investigations on effect of process parameters of electrodeposited Ni-Al_2O_3 composite coating using orthogonal array approach and mathematical modeling

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ABSTRACT

This research article aims at preparation of nickel-aluminum oxide (Ni-Al_2O_3) metal matrix composite coatings that were prepared from conventional electro-deposition process. Micron sized alumina particles were deposited in nickel matrix by electro-co-deposition technique. The primary electroplating parameters of current density, pH value of electrolyte, temperature of bath, amount of ceramic particles (Al_2O_3) in bath, and agitation speed were considered for experimental studies. Experimental design and run orders were framed by orthogonal array of Taguchi's approach. L_{27} orthogonal array was chosen for experimental design based on five plating parameters and three levels. The experiments were conducted by adjusting the plating parameters and the samples were prepared from electrolytic bath. Volume fraction of Al_2O_3 and micro-hardness of deposits were recorded for each coated sample systematically. The mean effect studies of electroplating parameters were investigated using Taguchi's approach. The S/N ratio values for the response of micro-hardness were calculated and analyzed for significances of independent input parameters. It was found that current density, pH, temperature and agitation speed were the most significant factors. A second order quadratic equation was developed as prediction model for micro-hardness. The predicted micro-hardness values were found to be in good agreement with the experimental results.

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1. Introduction

In recent years, the electro-deposition method has been acknowledged to be a technically feasible and greater cost-effective technique for the preparation of metal matrix composites (MMCs), due to the advantages of precisely controlled operation, low cost equipment setups, carried out at a normal pressure, unvarying deposition rate, handling of intricate geometries and simple equipment setup scale-up with ease of maintenance [1]. The properties of composite coatings principally depend on the matrix phases and also the amount and distribution of co-deposited particles within the matrix. Adequate level of strengthened particles within the metal matrix directs enhancement of properties like micro -hardness, wear resistance, tribological behaviors and corrosion resistance of the coatings [2]. Steinbach and Ferkel [3] had prepared the Ni-Al_2O_3 composite coating by DC and pulsed DC electroplating, and concluded that pulsed DC technique had produced efficient smaller particle deposition. The addition of ultrafine SiC or Al_2O_3 powder into Ni matrix by co-deposition carried out by Wang and Wei [4] had reduced the Ni matrix crystallite size and pinned the grain growth during heat treatment; 20% improvement of micro-hardness in Ni matrix layer was also observed. Aruna et al. [5] had investigated the deposition behavior of in situ impregnated alumina particles in Ni matrix; they suggested that utilization of porous particles provided better direction to improve the adhesion property of particles and micro-hardness in the development of electro-deposited metal matrix composites. Feng et al. [6] prepared Ni-nano Al_2O_3 composite coating by sediment co-deposition (SCD) and conventional electroplating (CED) techniques; they found that the incorporation of nano-Al_2O_3 particles over Ni matrix had changed the surface morphology; wear resistance of composite obtained by SCD was superior. Saha and Khan [7] had reported that the increase in Al_2O_3 particles over Ni matrix in the coatings had increased the mechanical properties due to grain refining and dispersion strengthening mechanisms. García et al. [8] had conducted a comparative study on the effects of mechanical and ultrasound agitation, and observed that ultrasound agitation method absolutely affected the characteristics of electrodeposited Ni-Al_2O_3 composite coatings when compared to composite coatings obtained from mechanical agitation. Narasimman et al. [9] investigated that electro-co-deposition process principally was influenced by the parameters like current density, amount of ceramic particles within the plating bath, pH scale of the solution, temperature of bath and stirring speed.

The experimental studies carried out by earlier work experience randomized selection of process parameters and levels, method schemers, and trial and error technique, and are enormously tedious and time consuming. No deliberated experimental design approaches were followed to identify the mean effects of process parameters on outcomes of experiments. Based on the literature studies, in electro-deposition domains, very few works have been accomplished to investigate the influences of process parameters using scientific approaches. Aruna et al. [10] had explored the significances of process parameters on Ni-YSZ (yttria stabilized zirconia) composite coatings using L9 orthogonal Taguchi approach and analysis of variance (ANOVA). Suman and Sahoo [11] had investigated the effects of process parameters on the electroless Ni-B composite coating by orthogonal array studies; they revealed that annealing temperature and concentration of reducing agent had more momentous influences on hardness characteristics. The Taguchi methodology for electro-deposition has been employed in few cases by considering less number of process parameters. Thus, it is a necessity to develop a technique to analyze the influences of process parameters by robust experimental design approaches with wide range of parameter sets and effect studies that would obtain specified level of properties in final deposits. Thus, the above reasons are the motivations for this research study to investigate the influences and significances of principal electroplating process parameters on micro-hardness of Ni-Al_2O_3 composites by scientific approaches. In this study, Taguchi method of design of experiments has been implemented to investigate the direct effects of parameters on micro-hardness.

The design of experiment (DOE) approach is an efficient tool in modeling and analyzing the effect of process parameters and outputs [10]. DOE permits minimizing experimental effort. Experimental outcomes are estimated based on statistical techniques and the influences of process parameters on experimental results can be measured. Many DOE methods (Taguchi's orthogonal array, central composite design, response surface approach, etc.,) have been developed for experimental design [12]. Robust design method endorses the accuracy of experimental work with two tools called orthogonal array and signal-to-noise ratio (S/N ratio). It is a successful methodology and widely employed in numerous experimental studies [13]. Mathematical modeling can be implemented for identification of similarities among prediction values and experimental output [14].

In this work, experimental works were conducted in nickel electrolytic bath contained with Al_2O_3 particles. Five most important electro-deposition parameters with three levels were considered for experimental work and L_{27} orthogonal array was chosen. Trials were performed based on the run order of the L_{27} orthogonal arrays template. Influences of plating parameters were investigated by mean effect studies and S/N ratio techniques and the parameters were ranked by order. Both effect studies established the similar rank orders. A mathematical model was developed by regression analysis for prediction of micro-hardness. The experimental data sets were employed for development of mathematical model.

2. Experimental materials and methods

2.1. Plating solution

A watts-type nickel solution [9,15] was used for preparation of composite plating. The plating solutions were prepared from laboratory graded substances and sanitized by traditional method. Plating solution of 1000 ml was taken for experimental work. pH value of electrolytic bath was measured by pH meter and it was adjusted to 5. Level of plating solution was monitored adequately and maintained with the addition of distilled water.