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Surface Hardness Prediction of CrN Thin Film Coating on AL7075-T6 Alloy Using Fuzzy Logic System

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In recent years, CrN coating has been identified as one of the most promising protective layers on surfaces of tools and dies due to its excellent mechanical properties, corrosion resistance, and surface hardness. This study presents the predicting of chromium nitride (CrN) coating surface hardness on AL7075-T6 using fuzzy logic technique. First, Al7075-T6 was coated with CrN at different parameter conditions, after which the surfaces hardness of the CrN-coated specimens was measured using a micro hardness machine. Next, a fuzzy logic model was established to predict the surface hardness of CrN coating on AL7075-T6 with respect to changes in input process parameters, DC power, temperature, and nitrogen flow rate based on the trained data obtained from the micro hardness test. Three membership functions were allocated in connection with each model input. Finally, five new experimental tests were carried out to verify the predicted results achieved via the fuzzy logic model. The results indicate an agreement between the fuzzy model and experimental results with 94.664% accuracy.

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1. Introduction

It is greatly acknowledged that aluminum is currently the most widely used metallic material besides steel. The mechanical characteristics of aluminum offer an increasing application field, especially where lightweight constructions are required. The demand for improved characteristics such as higher strength and greater durability is achieved by development of new aluminum alloys. Continuous research efforts are being made to discover new possibilities for exploiting the advantages of aluminum in applications that have so far been reserved for harder and more wear-resistant materials.[1] Aluminum 7075-T6 alloy which is used in this research work has low specific weight, high strength-to-weight ratio, as well as high electrical and thermal conductivity. This alloy is popular in industry, particularly in aircraft structures,[2] and is perpetually subjected to different working conditions. Wear and fretting normally originate when the substrate comes in contact with other surfaces and rub each other under normal load, after which shear force acts leading to surface damage.[2,3] The PVD coating process is an alternative solution to depositing wear-resistant film that protects the aluminum surface.

Physical vapor deposition (PVD) has aroused great interest in recent years since it facilitates the deposition of denser and more compact coatings than chemical vapor deposition (CVD), and produces improved chemical and mechanical properties.[4] The technique may be utilized in an extensive range of hard nitride or carbide coatings widely used to manufacture tools and form moulds because of their high wear resistance and low chemical inertia.[5] CrN coatings comprise the new alternative in machining applications due to their thermal stability, low deposition temperature, high hardness, excellent abrasive and adhesive wear resistance, and fine corrosion resistance.[6] This combination of properties makes CrN coatings especially appealing in applications where parts are routinely exposed to high temperatures and aggressive atmospheres, e.g. the plastic injection industry, where such coatings could substantially prolong the service life of coated parts.[5,6]

Soft computing techniques are useful when exact mathematical information is not available. In contrast to traditional computing, these techniques suffer from approximation, partial truth, met heuristics, uncertainty, and inaccuracy. Fuzzy logic is one of the soft computing techniques that play an important role in input-output parameter relationship modeling.[7]

Artificial intelligence tools are significant to manufacturing and surface engineering processes. When compared to other artificial

intelligence (AI) approaches, fuzzy logic is relatively easier to develop and requires fewer hardware and software resources. Fuzzy logic controller developed by Zadeh in 1965 entails the successful application of the fuzzy set theory. It was introduced as an extension of the set theory by replacing a set's characteristic function with a membership function whose value ranges from 0 to 1. Fuzzy modeling is employed when subjective knowledge and expert suggestions are substantial in defining the objective function and decision variables.[8] Fuzzy logic is ideal in predicting coating characterization of surface topography based on input variables, due to the nonlinear condition in the coating process.[9] A considerable amount of investigations have been directed towards the prediction and investigation of surface coating, with countless researchers having used fuzzy logic to predict responses in manufacturing engineering. Balazinski and Jemielnaik presented a fuzzy decision support system that estimates the depth of cut and flank wear during the turning process.[10] With the fuzzy logic approach, Arghavani et al. could suitably select gaskets for sealing performance.[11] Yu ejiao et al. called on fuzzy adaptive networks in machining process modeling and employed fuzzy logic for surface roughness prediction in turning operations.[12] Moreover, Palanikumar et al. utilized fuzzy logic for optimizing multiple performance characteristics.[13] Chen and Savage developed a fuzzy net-based multilevel in-process surface recognition system for milling operations,[14,15] while Arup Kumar and Dilip Kumar designed a genetic-fuzzy system to predict surface finish and the power requirement in grinding.[16,17]

In this research work, Al7075-T6 substrate was coated with CrN at different coating parameter conditions, namely DC power, substrate temperature, and nitrogen flow rate. Fuzzy logic was proposed to predict the surface hardness of CrN-coated AL7075-T6 alloy.

2. Design of experiments

The most important step in experimental design consists of parameter selection and identifying the experimental array. In this investigation containing three parameters with four levels each, the fractional factors design used is a standard L_{16} experimental array. This particular array was chosen due to its ability to check the interactions occurring among parameters. The parameters and levels allocated are given in Table 1 while Table 2 portrays the sixteen experiments along with the details of experimental level combination for each of the parameters (A-C).

3. Test specimens and coating preparation

Aluminum alloy 7075-T6 was used in this study. All samples were polished with SiC papers grit 800-2000, after which their surfaces were polished to a mirror finish with diamond liquid. The substrates were ultrasonically cleaned in acetone for 14 minutes, thoroughly rinsed with distilled water and dried using nitrogen gas to avoid contamination. An SG Control Engineering Pte Ltd series magnetron sputtering system deposited thin films of metal. This system contains 600 W RF and 1200 W DC generators with 4 × 12” electrodes placed 15 cm away from the target. We designed the DC generators for straightforward metal sputtering. The substrate carrier is circular and can rotate at various speeds for the required co-sputtering deposition. The chamber was evacuated to less than 2×10^{-5} Torr before the argon gas for sputtering was introduced. Here, a constant sputtering pressure of 5.2×10^{-3} Torr was applied. The deposition time for the first, interfacial layer (Pure chromium) and the second, chromium nitride layer was adjusted to 1 and 2.5 hours, respectively. The substrate temperature, nitrogen flow rate and DC power coating parameters were arranged according to the experimental array shown in Table 2, with the aim of learning how to improve the adhesion of sputtered, thin CrN thin film. A pure (99.95%) chromium target was selected for exploring the sputtering conditions on Al 7075-T6 alloy. The layers were characterized using scanning electron microscopy (FE/SEM-FEG, Quanta FEG250), and layer hardness was determined by micro-hardness equipment (HMV micro hardness tester Shimadzu).

Table 1 Parameters and levels used in the experiment

Control factors		Experimental condition levels			
		1	2	3	4
A	DC Power (w)	200	300	400	500
B	Temperature (C)	150	200	250	300
C	Nitrogen low rate (%)	3	6	9	12

Table 2 Design of experimental array

Experiment	Parameter combinations		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

4. Experimental results

The surface hardness of the surface layers was measured using micro hardness equipment. Each measurement repeated three times, and the averages were calculated and summarized in Table 3. Figure 1 illustrates a typical example of CrN coating. SEM clearly shows that the coating structure is lamellar. Figure 1 also presents the diffusion rate of Cr and nitrogen, chemical composition of AL 7075-T6, as well as the interfacial layer of chromium, CrN and aluminum. The influence of film morphology on the electrochemical properties shall be illustrated on chromium nitride. Figures 2 (a) and (b) denote CrN coating on the surface of specimens at varying parameter conditions. Obviously, by increasing DC power and temperature, a denser coating surface is obtained.