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Prediction of TiN Coating Adhesion Strength on Aerospace AL7075-T6 Alloy Using Fuzzy Rule Based System

Erfan Zalnezhad[1,2], Ahmed Aly Diaa Mohammed Sarhan[1,3,#], and Mohd Hamdi[1]

1 Center of Advanced Manufacturing and Material Processing, Department of Engineering Design and Manufacture, Faculty of Engineering, University of Malaya, Kuala Lumpur, 50603, Malaysia
2 Faculty of Engineering, Islamic Azad University, Chalous Branch, 46619/61367, Iran
3 Department of Mechanical Engineering, Faculty of Engineering, Assiut University, Assiut, 71516, Egypt
Corresponding Author / E-mail: ah_sarhan@yahoo.com, TEL: +60-7967-4593, FAX: +60-7967-5330

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In this research work, predicting of titanium nitride (TiN) coating adhesion on AL7075-T6 is presented. First TiN was coated on Al7075-T6 in different conditions and the surfaces adhesion of TiN coated specimens were measured using micro scratch force machine. Second a fuzzy logic model was established to predict the of TiN coating adhesion on AL7075-T6 with respect to changes in input process parameters, DC power, DC bias voltage, and nitrogen flow rate based on the tried data obtained from the scratch force test. Four membership functions are allocated to be connected with each input of the model. Third, new five experimental tests were carried out to verify the predicted results achieved via fuzzy logic model. The result indicated settlement between the fuzzy model and experimental results with the 95.534% accuracy.

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1. Introduction

Aerospace applications and energy saving strategies in general raised the interest and study in the field of lightweight materials, especially on aluminum alloys. Aluminum alloy itself does not have suitable wear resistance. Therefore, improvements of surface properties are required in practical applications.[1] Aluminum 7075-T6 alloy which is used in this research work has low specific weight and high strength to weight ratio and also high electrical and thermal conductance. This alloy is widely used in industry and in particular in aircraft structure and pressure vessels,[2] however, it is always subject to different working conditions. Wear and fretting normally begin when the substrate is in contacting with other surfaces and rubbing each other under normal load, causing share force to act on the surface.[2,3] With the advent of new technologies, such as vacuum processing, high power laser and advances in materials, such as ceramics and composites, the surface modification techniques based on new technologies have attracted more attention with respect to the traditional surface modifications ranging from glazing and painting to gas carburizing and electroplating over past decade.[2]

Physical Vapor Deposition (PVD) is one of the vacuum coating processes in which the film material is usually deposited atom by atom on a substrate by condensation from the vapor phase to the solid phase. This technology improved durability, higher surface hardness and increased service temperatures can be achieved from less expensive.[3] TiN coating using PVD method is a method used to improve the surface properties of Al7075-T6 for less wear and longer fretting fatigue service life. The creation of a titanium nitride coating on the surface of the substrate material is one of the most effective methods of enhancing the wear resistance of materials.[4] However the most important parameter in practical application of coated elements is adhesion between a coating and a substrate. Regardless of its importance, there is no widely accepted characterization technique for quantitative measurement of adhesion strength of thin coatings. Adhesion is usually evaluated by generally accepted scratch test technique. During the scratch test a diamond tip is dragged over the surface with the normal force increasing linearly with the traveled distance.[5] The critical load, the load at which the coated film is removed from the substrate, is influenced by many different coating parameters that can be setup in advance, such as; DC power, temperature, nitrogen flow rate, and substrate DC bias voltage. Hence, a reliable systematic approach to investigate and predict the surface adhesion strength at different

TiN coating parameters is thus required.

Soft computing techniques are useful when exact mathematical information is not available. The techniques differ from conventional computing in that it is tolerant of imprecision, uncertainty, partial truth, approximation, and met heuristics. Fuzzy logic is one of the soft computing techniques that play an important role in input-output parameter relationship modeling.[6-9] The fuzzy modeling technique is used when subjective knowledge and suggestion by the expert are significant in defining objective function and decision variables. Fuzzy logic is preferred in predicting coating characterization of surface topography based on the input variables due to nonlinear condition in coating process.[10]

In this present work, TiN was coated on Al7075-T6 substrate in different parameters condition. Each parameter has four levels which, these parameters include; the DC power, substrate temperature, the nitrogen flow rate and DC substrate biases voltage. Fuzzy rule base method was proposed to predict surface adhesion of TiN coating on AL7075-T6 alloy.

2. Design of experiments

The most important stage in the design of an experiment lies in the selection of parameters and identifying the experimental array. In this experiment with four parameters and four levels each, the fractional factors design used is a standard L_{16} (4^4) experimental array. This array is chosen due to its capability to check the interactions among parameters. The parameters and levels are assigned as in Table 1. The sixteen experiments with the details of combination of the experimental levels for each parameter (A-D) are shown in Table 2.

Table 1 Factors and levels used in the experiment

Control factors		Experimental condition levels			
		1	2	3	4
A	DC Power (w)	300	350	400	500
B	Temperature (˚C)	150	180	200	220
C	Nitrogen low rate (%)	3	4	5	6
D	Substrate biases voltage (v)	25	50	75	100

Table 2 Standard L_{16} (4^4) experimental array

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

3. Test specimens and coating preparation

Aluminum alloy 7075-T6 was used in this research work. The surface of all samples were polished with SiC papers grit 800-2000, after that all samples were surface mirroring by diamond liquid and the substrate were ultrasonically cleaned in acetone for 14 min, thoroughly rinsed with distil water and dried using nitrogen gas to avoid contamination. A SG Control Engineering Pte Ltd series magnetron sputtering system was used to experimentally deposit thin films of metal. This system contained 600W RF and 1200 W DC generators with 4" × 12" electrodes 15 cm away from the target. To easily sputter metals we designed DC generators. The substrate carrier was circular and was rotatable at various speeds for required co-sputtering deposition. The chamber was evacuated to below 2×10^{-5} Torr before the argon gas for sputtering was introduced. Here, we used constant sputtering pressure 5.2×10^{-3} Torr. The deposition time for first or interfacial layer (Pure titanium) and second layer (Titanium nitride) was adjusted as 3 and 1.5 hours respectively. The substrate temperature, DC bias voltage, nitrogen flow rate and DC power as coating parameters are arranged according to the experimental array shown in Table 2 to learn how to improve the adhesion of the sputtered TiN thin film. A pure titanium 99.995% target was selected for investigating the sputtering conditions for Al 7075-T6 alloy. The layers were characterized using scanning electron microscopy (FE/SEM-FEG), focused ion beam techniques (Quanta FEG250). Adhesion of surfaces was determined using micro scratch force equipment (Micro Material Ltd., Wrexham, U.K.).

4. Experimental result

The adhesion of the surface layers was measured using micro scratch force equipment. Each measurement repeated three times and the averages are calculated and summarized in Table 3. Figure 1, shows a typical example of a TiN coating, it can be seen under SEM that the coating structure is columnar. Figure 1 is also shown the diffusion rate of Ti and Nitrogen, chemical composition of AL 7075-T6, the interfacial layer of Titanium, TiN and Aluminum. The

Table 3 The measured scratch force

Experiment	Measured scratch force (μm)			Average scratch force (μm)
	1st	2nd	3rd	
1	774	654	697	708
2	754	685	731	723
3	959	793	797	850
4	504	406	345	418
5	1285	1658	1269	1404
6	765	696	679	713
7	1269	1500	1607	1458
8	908	1115	1067	1030
9	2558	2299	2482	2446
10	468	405	368	414
11	1640	1568	1624	1611
12	1379	1570	1551	1500
13	1012	1140	1060	1071
14	2115	2670	2661	2482
15	1865	2231	1834	1977
16	680	749	715	715