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A fuzzy logic predictive model for better surface roughness of Ti–TiN coating on AL7075-T6 alloy for longer fretting fatigue life

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ABSTRACT

In this study, the fretting fatigue resistance of AL7075-T6 alloy is investigated using surface treatment Ti–TiN multilayer coating by physical vapor deposition (PVD) magnetron sputtering technique. A fuzzy logic model was established to forecast the surface roughness of Ti–TiN coating on AL7075-T6 with respect to changes in the input process parameters of DC power, temperature, DC bias voltage, and nitrogen flow rate. The results indicate an agreement between the fuzzy model and experimental results with 95.349% accuracy. The fretting fatigue lives of Ti–TiN-coated specimens with the lowest surface roughness resulting from fuzzy logic were enhanced by 18% at low cyclic fatigue, while at high cyclic fatigue the result was reversed.

1. Introduction

Light-weight and high-strength aluminum alloys such as 7075 are widely utilized in aircraft engines, fuselage and automobile parts. Aluminum alloys themselves do not provide adequate mechanical strength for structural parts. Therefore, enhancing surface properties is vital in practical applications, particularly when aluminum is in contact with other components [1]. Ceramic coatings like TiN, CrN, and SiC are possibly effective in raising surfaces hardness, corrosion and wear resistance. However, coatings used for aluminum alloys via old-fashioned techniques such as hard anodizing, glazing and thermal spaying, are provided with little support from the underlying material besides the inadequate adhesion strength, decreasing their durability [2,3]. Fretting fatigue is a phenomenon which occurs when two components are in contact with each other and one or both are subjected to a cyclic load, often resulting in damage which may cause premature component failure.

Ti–TiN coating applied by PVD technique is a method of improving the hardness of Al7075-T6 surface by reducing wear and extending fretting fatigue service life [4–6]. The formation of TiN coating on the surface of materials is among the most effective techniques of improving material wear resistance. However, the characterization of surface topography is imperative in applications including abrasion, wear, and lubrication. Surface hardness and roughness are important when identifying the performance of a coated surface [7,8]. High surface quality is essential in achieving lower surface roughness, which affects the practical characteristics such as friction, fretting fatigue, wear, and light reflection [9]. The surface rough-

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ness of hard materials coated using PVD magnetron sputtering technique is mostly affected by the selecting of various coating parameters including DC bias voltage, nitrogen percentage, temperature, and DC power. Hence, for investigating and predicting the best surface roughness at different Ti–TiN coating parameters, a reliable systematic approach is required. Soft computing techniques are useful when exact mathematical information is not available. The techniques differ from customary computing in that they are tolerant of uncertainty, imprecision, approximation, partial truth and met heuristics. Fuzzy logic is a soft computing method that plays a significant role in input–output parameter relationship modeling [10–12]. Fuzzy modeling is called upon when subjective knowledge and expert suggestions may significantly define the objective function and decision variables. Fuzzy logic is ideal in predicting the coating characterization of surface topography based on the input variables due to the nonlinear condition in the coating process [13]. Fuzzy logic was established to develop the rule model for predicting the surface roughness value in Ti–TiN coating on AL7075-T6 alloy based on parameter and performance interaction.

The goal of this study is to evaluate the fretting fatigue life of Ti–TiN coated Al7075-T6 alloy with different surface roughness.

In this present work, multilayer Ti–TiN was coated on Al7075-T6 substrate at different parameter conditions. Each parameter comprises four levels, namely nitrogen percentage, power (DC), substrate temperature, and DC bias voltage. A fuzzy rule-based method was proposed to predict the surface roughness of Ti–TiN coating on AL7075-T6 alloy, after which the fretting fatigue lives of coated specimens with better surface roughness were investigated.

2. Experimental details

2.1. Surface treatment and measurement

Aluminum 7075-T6 alloy was employed in this research work. The material's composition was attained by Energy-dispersive X-ray spectroscopy (EDX) apparatus (Table 1). The ultimate strength and yield stress of Al7075-T6 were obtained by performing a number of tensile tests (σ_{ut} = 590 MPa and σ_y = 520MPa, respectively). All samples were polished with SiC paper of 800–2000 grit, and were surface-mirrored by diamond liquid. The substrate was cleaned with acetone in an ultrasonic bath for 14minutes, and then thoroughly rinsed with distilled water. An SG Control Engineering Pte Ltd. series PVD magnetron sputtering machine was used to experimentally deposit thin films of metal. DC generators were designed to facilitate metal sputtering. The chamber was evacuated to below 2.67×10^{-3} Pa (2×10^{-5} Torr) before the argon gas for sputtering was introduced. A constant sputtering pressure of 6.9×10^{-1} Pa (5.2×10^{-3} Torr) was maintained. Table 2 shows the parameters and levels throughout the experiment. The DC bias voltage, substrate temperature, nitrogen percentage and DC power as coating parameters, were arranged according to the experimental array provided in Table 3, to learn how to develop the sputtered Ti–TiN thin film roughness.

The TiN coating's surface roughness was determined using micro-roughness equipment (MAHR). The layers were characterized by scanning electron microscopy (SEM), focused ion beam technique (Quanta FEG250) and atomic force microscopy (AFM-NANOSCOPE DIMENSION D13000).

2.2. Fretting fatigue

All specimens for the fretting fatigue test were machined at an initial surface roughness of R_a = 0.6 ± 0.1 μm by lathe turning (CNC LATHE MACHINE, Miyano, BNC-42C5). The round shape samples utilized in this experimental work were prepared in accordance with ISO standard [14]. Fretting fatigue pads were fabricated from AISI 4140 steel plate with Vickers hardness of 346HV. Substrate material (179HV) is softer than the pads but Ti–TiN coating (540HV) is harder. Illustrations of the fretting fatigue samples and friction pads can be found in Fig. 1. A bridge-type friction pad and ring-type load cell were designed and manufactured to simulate the fretting fatigue conditions. Fig. 2 shows a schematic view of the fretting fatigue test setup used in this study.

The samples were loaded rotationally in a rotating bending fretting fatigue test apparatus (Fig. 2). The fretting fatigue tests were performed at a constant contact pressure of 100 MPa, while the samples comprised uncoated and Ti–TiN-coated AL7075-T6. Plain and fretting fatigue testing were carried out at laboratory temperature (25 °C) in a two-point loading rotating bending machine

Table 1
Chemical composition of AL 7075-T6.

Al	Cu	Si	Mg	Cr	Zn	Mn
91	1.85	0.47	1.8	0.28	4.6	0.06

Table 2
Parameters and levels used in the experiment.

Parameters		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