Int J Adv Manuf Technol (2013) 68:415–423
DOI 10.1007/s00170-013-4738-y

ORIGINAL ARTICLE

A fuzzy logic based model to predict surface hardness of thin film TiN coating on aerospace AL7075-T6 alloy

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Received: 21 December 2011 / Accepted: 4 January 2013 / Published online: 15 January 2013

Abstract 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 appropriate wear resistance. Therefore, improvement of surface properties is required in practical applications, especially when aluminum is in contact with other parts. In this work, first titanium nitride (TiN) is coated on aerospace Al7075-T6 in different conditions using PVD magnetron sputtering technique, and the surface hardness of TiN-coated specimens is measured using a micro hardness machine. Second, a fuzzy logic model is offered to predict the surface hardness of TiN coating on AL7075-T6 with respect to changes in input process parameters, direct current (DC) power, DC bias voltage, and nitrogen flow rate. Four membership functions are allocated to be connected with each input of the model. The predicted results achieved via fuzzy logic model are compared to the experimental result. The result demonstrated settlement between the fuzzy model and experimental results with 96.142 % accuracy. The hardness of titanium nitride-coated specimens is increased significantly up to 720 HV, while the hardness of uncoated specimens was 170 HV.

Keywords AL7075-T6 alloy · TiN coating · Surface hardness · PVD magnetron sputtering · Fuzzy logic model

1 Introduction

Aluminum alloy, which has superior mechanical properties, low cost, light weight, and reliability, has been widely used for aircraft engines, fuselage, and automobile parts. However, aluminum alloy is not above problems as it suffers problems from surface damage due to its softness and corrosion. Therefore, advances 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, however, subjecting to different working conditions. Wear and fretting normally begin when the substrate is in contact with other surfaces and rubbing each other under normal load, causing share force to act on the surface. Fretting fatigue is a phenomenon which occurs when the substrate is in contact with other parts subjected to cyclic loads and sliding movements at the same time [2]. The result of fretting in engineering components under cyclic load is the reduction of life by premature initiation and propagation of cracks within the contact area.

The advent of new technologies and materials has also attracted attention as with the advent of new technologies, such as vacuum processing, high power laser, and advances in materials, such as ceramics and composites; the surface

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modification techniques based on new technologies have attracted more attentions with respect to the traditional surface modifications ranging from glazing and painting to gas carburizing and electroplating over the past decade [3–5]. Vacuum coating techniques have the potential of applying coating that has higher hardness than any metal, and they find use in these systems that cannot tolerate even microscopic wear losses. 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. Now, this technology permits coating deposition at temperatures as low as 200 °C (390 °F) allowing materials to be coated without distortion, loss of hardness, or reduction in corrosion resistance, and the PVD coatings have no performance loss compared to those deposited at higher temperatures. This technology also improves durability; higher surface hardness and increased service temperatures can be achieved from less expensive things [5].There are three main techniques for applying PVD coatings: thermal evaporation, ion plating, and sputtering.

Many of the coatings that can be applied by thermal evaporation, sputtering, and ion plating are coatings used for some physical property, but the coatings that have importance in tribological systems are relatively few. Table 1 is a tabulation of some of the vacuum coatings that have been used to enhance the tribological properties of sliding system. Disadvantages of thermal evaporation and ion plating are deposits which may have poor adhesion. Deposition of alloys requires special evaporate compositions (to maintain stoichiometry of deposit), cannot deposit compound unaltered, and complex process control [6, 7]. PVD magnetron sputter coating is a vacuum coating process that is used in this investigation because of its flexible coating technique that can be used to coat virtually any material. Sputtering is basically the removal of atomised material from a solid by energetic bombardment of its surface layers by ions or neutral particles [6, 8]. Prior to the sputtering coating process, a vacuum of less than one ten millionth of an atmosphere must be achieved. Once the appropriate pressure has been reached to a controlled flow, an inert gas such as argon is introduced. This raises the pressure to the minimum needed to operate the magnetrons, although it is still only a few ten thousandth of atmospheric pressure.

Table 1 Thin film coatings for tribological and surface integrity applications

Thermal evaporation	Sputtering	Ion plating
Au	SiO	Cr
Ag	SiO2	Mo
MCrAlY's	Cr	TiC
Cr	Mo	TiN
Mo	Au	Au
	TiC	Ag
	TiN	Si3N4
	Al2O3	
	WS2	
	MoS2	
	Si3N4	
	PTFE	
	TiB2	

Titanium nitride (TiN) coating using PVD technique is a method used to improve the hardness of Al7075-T6 at different coating parameters condition 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. This coating is also promising from the standpoint of the possibility of achieving high hardness and strength in achieving longer service life in fretting fatigue application and simultaneously good protective-and-decorative surface properties [9–11]. The conventional method helps to achieve high hardness and strength at different coating parameters with a view to using the experimental "trial and error" approach. However, "trial and error" approach is very time-consuming due to the large number of experiments. Hence, a reliable systematic approach to predict the surface hardness at different parameters condition is thus required to cover all the parameters' range in a few numbers of experiments [12–14]. Soft computing techniques are useful when exact mathematical information is not available, and these 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 a significant role in input–output matrix relationship modeling. It is used when subjective knowledge and suggestion by the expert are significant in defining objective function and decision variables. Fuzzy logic is preferred to predicting coating performance based on the input variables due to nonlinear condition in coating process [15–19]. This paper applies the fuzzy logic to develop the rule model in order to predict the surface hardness performance of TiN based on parameter and performance interaction.

Dr. Lotfizadeh, an Iranian professor at the University of California in Berkley, pioneered in introducing the concept of fuzzy logic not only as a control methodology but also as a way to process data based on authorizing the use of membership in a small group instead of making use of membership in a cluster group [16]. Fuzzy logic is a simple rule based on: If *X* and *Y*, then *Z*. Fuzzy mathematics is a metaset of Boolean logic and denotes relative correctness. The fuzzy theory is still a prominent theory, although sometimes it describes uncertain and indefinite phenomena having the following structure as shown in Fig. 1: