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ORIGINAL ARTICLE

Optimizing the PVD TiN thin film coating's parameters on aerospace AL7075-T6 alloy for higher coating hardness and adhesion with better tribological properties of the coating surface

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Abstract An optimization study on the parameters of titanium nitride coating on aerospace Al7075-T6 alloy, using magnetron sputtering technique is presented. The effects of the temperature, DC bias voltage, rate of nitrogen, and DC power on the surface hardness, adhesion, surface roughness, and microstructure of the coated samples are investigated. Taguchi optimization method is used with the orthogonal array of L_{16} (4^4). However, to obtain the most optimum parameters for the best surface hardness, adhesion, and surface roughness, the signal to noise (S/N) response analysis method is implemented. Finally, the confirmation tests were carried out to show the improvement using the best parameters combination obtained from the optimization process. The improvement of 14% in surface hardness, 4.15% in adhesion, and 9.43% in surface roughness are achieved.

Keywords Aluminium7075-T6 alloy · Titanium nitride coating · Taguchi optimization method · Coating surface characterization

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1 Introduction

Aircraft engines, fuselage, automobile parts, and energy saving strategies in general promoted the interest and the research in the field of lightweight materials, typically on alloys based on aluminum. Aluminum itself does not provide sufficient mechanical strength for structural parts. Therefore, improvements of surface properties are required in practical applications, especially when aluminum is in contact with other parts [1, 2]. Aluminum alloy 7075-T6 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 [3]. The creation of a titanium nitride coating on the surface of articles 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, strength, and simultaneously good protective-and-decorative surface properties [4].

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 [3, 5]. Vacuum coating techniques have the potential of applying coating that have 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). This lower temperature allows 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 improved durability, higher surface hardness, and increased service temperatures can be achieved from less expensive [6–8]. There are three main techniques for applying PVD coatings: thermal evaporation, ion plating, and sputtering.

Many of the coatings can be applied by thermal evaporation, sputtering, and ion plating, coatings used for some physical property, but the coatings that have importance in triboliogical systems are relatively few. Table 1 is a tabulation of some the vacuum coatings that have been used to enhance the tribologocal properties of sliding system. Disadvantages of thermal evaporation and ion plating are deposits may have poor adhesion, deposition of alloys requires special evaporate compositions (to maintain stoichiometry of deposit), cannot deposit compound unaltered, and complex process control [9, 10]. PVD magnetron sputter coating is a vacuum coating process that is used in this investigation. It is an extremely 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 [9, 11]. 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 a controlled flow of 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	

When power is supplied to a magnetron, a negative voltage of typically −300 V or more is applied to the target. This negative voltage attracts positive ions to the target surface at speed. Generally, when a positive ion collides with atoms at the surface of a solid an energy transfer occurs. If the energy transferred to a lattice site is greater than the binding energy, primary recoil atoms can be created which can collide with other atoms and distribute their energy via collision cascades. A surface atom becomes sputtered if the energy transferred to it, normal to the surface, is larger than about three times the surface-binding energy (approximately equal to the heat of sublimation).

The sputter process has almost no restrictions in the target materials, ranging from pure metals where a DC power supply can be used to semiconductors and isolators which require a RF power supply or pulsed DC. Deposition can be carried out in either nonreactive (inert gas only) or reactive (inert and reactive gas) discharges with single or multi-elemental targets [12].

Thin film sputtering has many advantages such as a wide choice of target materials, better step coverage, good uniformity over large area, small shadow effect, and good adhesion. One important feature of sputtering is its many parameters that can be controlled to influence the film characteristics, which include the hardness, roughness, film density, and adhesion strength. Typical control parameters include the process pressure, substrate temperature, process DC power, and substrate bias voltage [13]. This is the best accomplished by surface coating technique using hard materials, such as titanium alloys [3]. Titanium nitriding film is widely used for increasing the hardness of materials such as aluminum alloys. It is difficult to control the film properties, such as film thickness, grain size, and step coverage, and thus, it is not as controllable as the sputtering process [14, 15]. In addition, there are limited data on the effect of TiN-coating parameters on the hardness, roughness, scratch force, and microstructure of the deposited film [13, 16, 17]. However, a handful optimizing of the sputtering parameters can be investigated for the best surface integrity. Taguchi optimization method is an efficient and effective approach, in which the response parameters that affect surface hardness can be optimized to identify the most significant response variables with the minimum number of experiments. In this work, the effects of surface modification including TiN coating to optimize the film thickness, process power, and substrate temperature, DC bias voltage on the hardness, roughness, adhesion, and microstructure are studied.