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ORIGINAL ARTICLE

Multilayer thin film CrN coating on aerospace AL7075-T6 alloy for surface integrity enhancement

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Abstract Chromium nitride (CrN) coating has emerged as a new alternative in machining applications. CrN has good thermal stability, low deposition temperature, and excellent wear and corrosion resistance. However, no precise information exists yet regarding the ideal coating parameter conditions that lead to higher surface integrity. For this reason, an optimization study is desired—a study on the parameters of CrN coating on aerospace Al7075-T6 alloy using physical vapor deposition magnetron sputtering. The present research work investigates the effects of temperature as well as nitrogen flow rate and DC power on coated samples' surface hardness, adhesion, surface roughness, and microstructure. To carry out the investigation, the Taguchi optimization method with L_{16} (3^4) orthogonal array was applied. However, to obtain optimum parameters for superior surface integrity, signal/noise (S/N) response analysis method was employed. Finally, confirmation tests with the best parameter combinations attained in the optimization process were carried out to demonstrate the progress made. Ultimately, surface hardness of coated Al7075-T6 was enhanced by 15.33 %, adhesion by 24.3 %, and surface roughness by 7.22 %.

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1 Introduction

It is widely recognized that aluminum is now the most commonly used metallic material along with steel. Aircraft engines, fuselage, automobile parts, and energy saving strategies, in general, have promoted interest and research in the field of lightweight materials, typically on alloys based on aluminum. The mechanical characteristics of aluminum offer expanding application horizons, particularly where lightweight construction is required. On its own aluminum does not provide sufficient mechanical strength for structural parts. For this reason, the development of surface properties in practical applications is vital, especially for cases when aluminum comes in contact with other components [1, 2]. The demand for superior characteristics such as higher strength and greater durability can be met by developing novel aluminum alloys. Ongoing 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. Aluminum alloy 7075-T6, which is used in this research work, has low specific weight, high strength/weight ratio, and high electrical and thermal conductivity. This alloy is popular in industry, particularly in aircraft structures and pressure vessels [3]. Because of their environmental benefits, modern physical vapor deposition (PVD) processes represent a better alternative to a number of conventional coating processes to deposit wear-resistant films onto aluminum surfaces. Coating the surface of articles with CrN is among the most effective methods of enhancing wear resistance. CrN coating is also promising from the standpoint of the potential to simultaneously attain

hardness, strength, and excellent protective and decorative surface properties [4].

PVD has aroused great interest in recent years. PVD facilitates the deposition of denser, more compact coatings compared to chemical vapor deposition, the result being improved chemical and mechanical properties. The PVD technique may be used on a wide range of coatings and hard nitrides or carbides that are extensively employed in tool manufacturing and mold formation with high wear resistance and low chemical inertia [5, 6]. Of these, TiN coatings are the most highly established at an industrial level. Nevertheless, CrN coatings have emerged as an alternative in machining applications thanks to their thermal stability, low deposition temperature, excellent abrasive, and adhesive wear resistance, as well as fine corrosion resistance [7]. This combination of CrN coatings properties is especially attractive in applications in which tools are routinely subjected to high temperatures and aggressive atmospheres (for instance in the plastic injection industry where such coatings may substantially prolong the service life of coated parts) [8, 9]. Thin film sputtering has several advantages such as a broad choice of target materials, better step coverage, uniformity over large areas, small shadow effect, and good adhesion. A significant feature of sputtering is its many possible-to-control parameters in influencing film characteristics including hardness, roughness, film density, and adhesion strength. Meanwhile, typical control parameters consist of process pressure, substrate temperature, process DC power, and substrate bias voltage [10]. Superior control parameters can be the best achieved via a surface coating technique with a hard coating material like CrN [11]. But since it is challenging to control film properties including film thickness, grain size, and step coverage, this method is not as manageable as sputtering [12]. In addition, data regarding the effects of CrN coating parameters on the hardness, roughness, scratch force, and microstructure of deposited film is quite limited [13–15]. However, a handful optimizing of the sputtering parameters can be investigated in the search for optimum surface integrity. For this, Taguchi optimization is an efficient and effective approach, in which the response parameters that affecting surface hardness may be optimized to identify the most significant response variables via the least number of experiments. Therefore, this work explores the effects of surface modifications including coating with CrN, with the prospect of optimizing the nitrogen flow rate, process power, and substrate temperature with respect to hardness, roughness, adhesion, and microstructure.

2 Design of experiment

The most important stage in designing an experiment involving the Taguchi approach comprises selecting the control factors and identifying the orthogonal array (OA) [9]. This experiment looks at three factors with four levels each (Table 1). The fractional factors design is a standard L_{16} (3^4) orthogonal array. We selected this particular orthogonal array because it has the capability to check the interactions among factors. Table 2 represents the 16 experiments along with the details on the experimental condition level combination for each control factor (A–C).

Table 1 Factors 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 flow rate (%)	3	6	9	12

3 Test specimens and coating preparation

The material investigated in this work is 7075-T6 aluminum alloy with the following chemical composition (in wt%): 4.6Zn, 1.8 Mg, 1.85Cu, 0.06Mn, 0.47Si, and 0.28Cr. 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

Table 2 L_{16} (3^4) orthogonal array

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