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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.

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

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.

2 Design of experiment

The most important stage in the design of an experiment using Taguchi approach lies in the selection of control factors and identifying the orthogonal array (OA) [18]. In this experiment with four factors and four levels each, the fractional factors design used is a standard L_{16} (4^4) orthogonal array. This orthogonal array is chosen due to its capability to check the interactions among factors. The factors and levels are assigned as in Table 2. The 16 experiments with the details of combination of the experiment of condition levels for each control factor (A–D) are shown in Table 3.

3 Test specimens and coating preparation

Aluminum alloy 7075-T6 was used in this research work. The material's composition obtained using EDX is given in Table 4. The surface of all samples were polished with SiC papers grit 800–2,000; after that, all samples were surface mirrored 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. An SG Control Engineering Pte Ltdseries magnetron sputtering system was used to experimentally deposit thin films of metal. This system contained 600 W RF and 1,200 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 cosputtering deposition. Titanium target with 99.9955% purity was used in this purpose. 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 film thickness, temperature, DC bias voltage, rate of nitrogen, and DC power are investigated for their influences on the hardness, roughness, adhesion, and microstructure of the sputtered TiN thin film. The sputtering rates and thickness of the films were determined using a Micro Material Ltd, Wrexham, UK. The data are stored in a digital computer and can be displayed on a screen. The layers were characterized using scanning electron microscopy and atomic force microscopy (AFM-Nanoscope Dimension D13000), focused ion beam techniques (Quanta FEG250). In addition, the hardness of the layers was determined using microhardness equipment (HMV Micro Hardness Tester Shimadzu). The roughness of TiN-coated samples was characterized with roughness tester machine.

Table 2 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 flow rate (%)	3	4	5	6
D	Substrate biases voltage (V)	25	50	75	100

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

Experiment	Control factors and levels			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

4 Experimental result and data analysis

4.1 Experimental result

After the orthogonal array has been identified, the next step in Taguchi optimization method is running the experiment based on that OA. The hardness, roughness, and scratch force of the surface layers were measured using the equipment mentioned above. Each measurement were repeated three times and the measured values are summarized in Table 5. 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 show the diffusion rate of Ti and nitrogen, chemical composition of AL 7075-T6, and the interfacial layer of titanium and TiN and aluminum. The

Table 4 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 5 The experimental result

Experiment	Measured surface hardness (HV)			Micro Hardness (HV)	Measured scratch force (mN)			Scratch force (mN)	Measured surface roughness (µm)			Roughness (µm)
	1st	2nd	3rd		1st	2nd	3rd		1st	2nd	3rd	
1	192	215	205	204	783	645	697	708	0.048	0.065	0.04	0.051
2	210	205	215	210	754	685	731	723	0.042	0.055	0.071	0.056
3	189	207	208	201	1,051	752	779	850	0.065	0.082	0.072	0.073
4	769	741	650	720	504	406	345	418	0.032	0.056	0.53	0.047
5	152	201	191	180	1,285	1,658	1,269	1,404	0.033	0.025	0.065	0.041
6	174	196	186	185	765	696	679	713	0.055	0.063	0.059	0.059
7	291	305	260	285	1,269	1,500	1,607	1,458	0.188	0.201	0.223	0.204
8	213	188	168	190	908	1,115	1,067	1,030	0.022	0.038	0.045	0.035
9	436	398	397	410	2,558	2,299	2,482	2,446	0.051	0.062	0.055	0.056
10	192	198	210	200	371	305	267	314	0.062	0.059	0.077	0.066
11	402	380	419	400	1,640	568	1,624	1,611	0.118	0.131	0.12	0.123
12	699	276	214	720	1,379	570	1,551	1,500	0.046	0.038	0.09	0.058
13	229	276	216	240	991	1,120	102	1,071	0.111	0.121	0.119	0.117
14	321	300	279	300	2,115	2,670	2,661	2,482	0.064	0.071	0.069	0.068
15	411	415	395	410	1,865	2,231	1,834	1,977	0.058	0.061	0.073	0.064
16	258	216	232	235	680	749	715	715	0.241	0.252	0.374	0.289

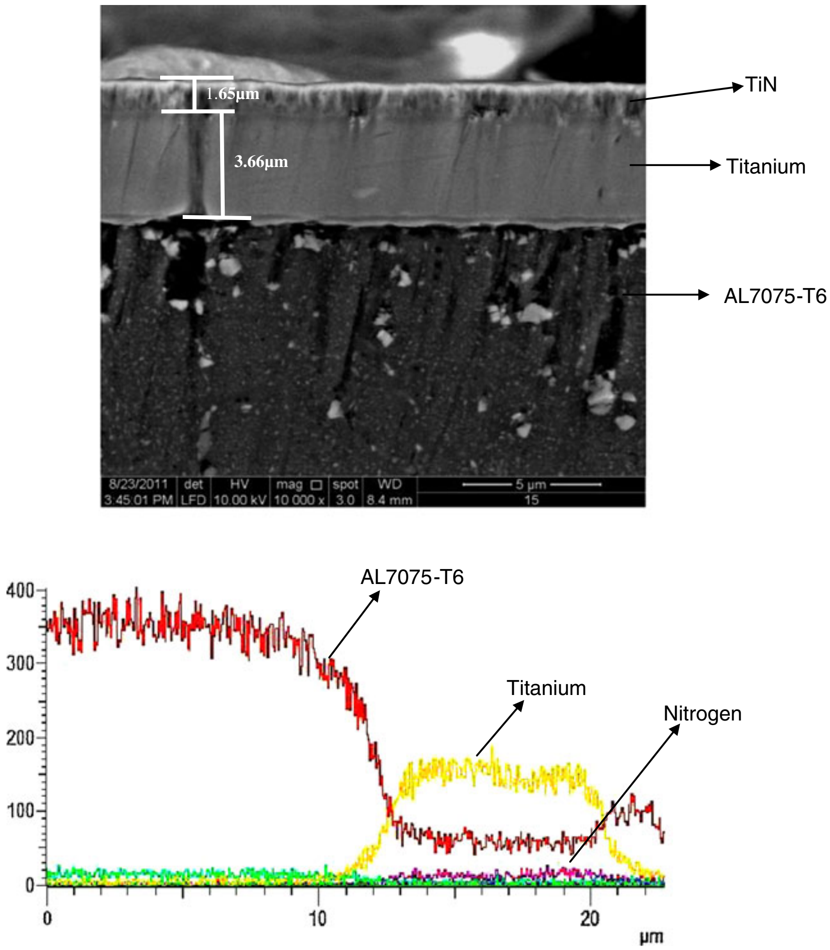


Fig. 1 Cross-sectional SEM and EDX micrograph of the TiN-coated AL7075-T6

thicknesses of TiN coating at different conditions are illustrated in Table 6. The influence of film morphology on the electrochemical properties shall be illustrated on titanium nitride. A study of Fig. 2 shows that with increasing DC bias voltage and DC power, the coating of surface is denser with compared to the low DC bias voltage and DC power. Also, Fig. 2a indicate that in low DC bias voltage, the distance between atoms are big while both the surface roughness and surface hardness are increased with increasing the density (Fig. 2b).

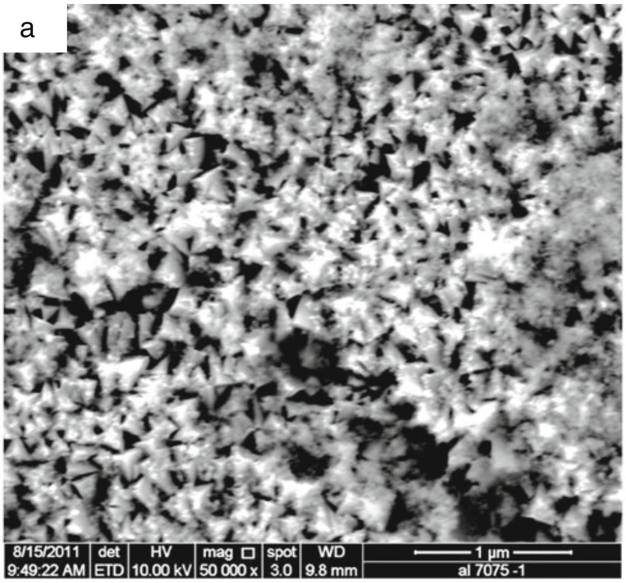
The film-to-substrate adhesion strength was measured quantitatively using a scratch tester. A diamond indenter (Rockwell type) of 25 μm radius applied an initial load zero onto a sample. The sliding velocity was 5 μm/s. The load was increased gradually by 9.2 mN/s. The scratch's length during scratch test was 1,000 μm. In the scratch test, critical load (Lc) could be used to calculate the adhesion strength. In order to obtain the magnitude of the critical load, acoustic signal, friction curve, and microscope observation were utilized. Acoustic signal produced by the delamination of the film could be used to characterize Lc. Scratch adhesion testing was performed on a coated sample to measure Lc. Four various images with various critical loads are shown in Fig. 3a, b. These images basically are showed the character of failure of TiN coating on AL7075-T6.

4.2 Data analysis

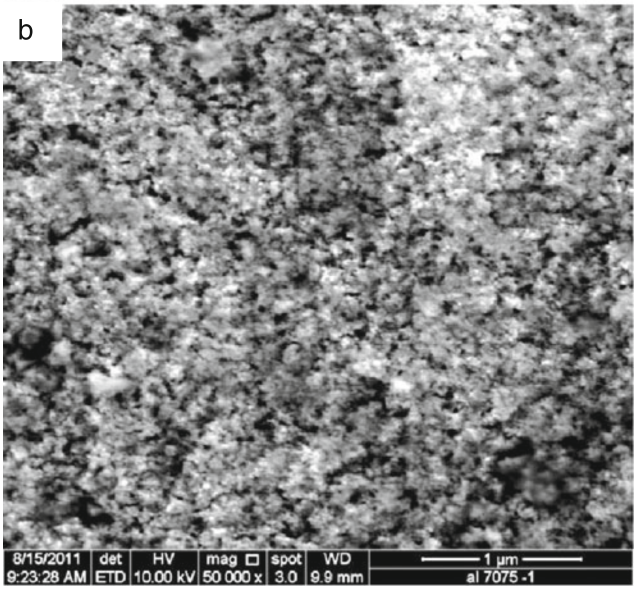
The procedures after the experimental runs are to analyze data to optimize the parameters and to identify which process parameters are statistically significant. Analyzing data is conducted using signal to noise (S/N) response analysis.

Table 6 The thickness of TiN coating on different samples

Sample	TiN thickness(μm)
1	3.1
2	2.3
3	2.1
4	3.6
5	3.4
6	3.8
7	8.4
8	3.7
9	7.5
10	1.6
11	7.8
12	8.7
13	4.6
14	6.8
15	5.3
16	3.6



(a) Low substrate bias voltage (25V)

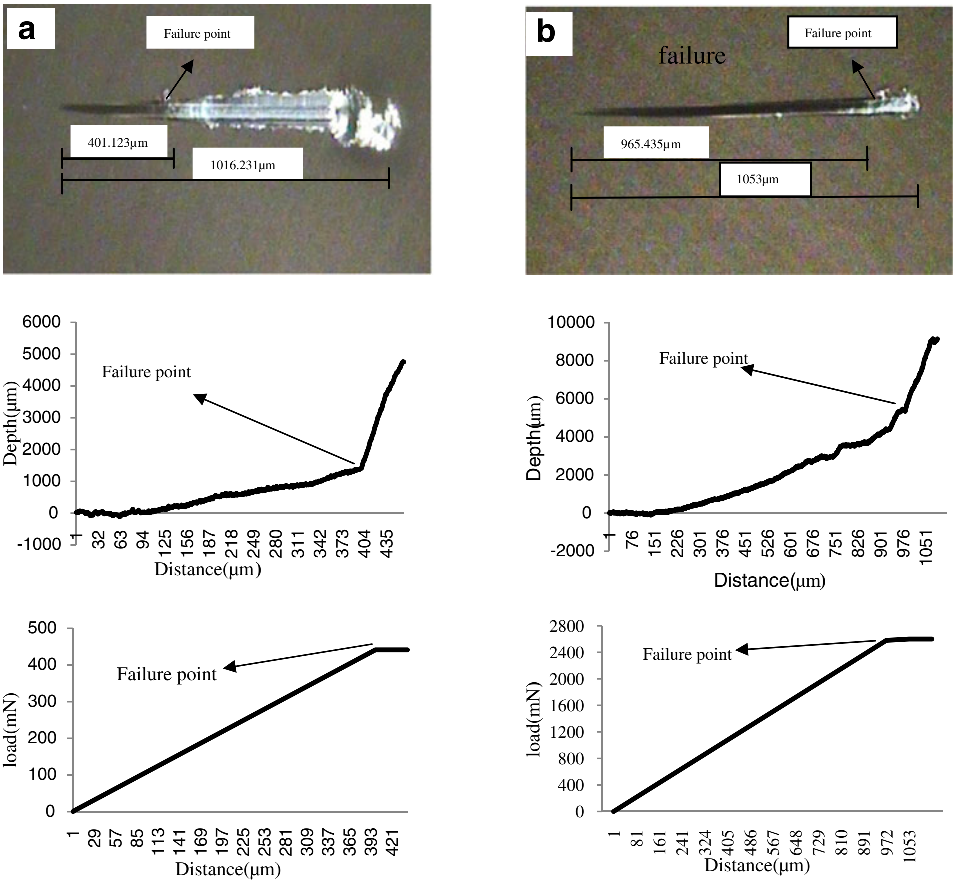


(b) High substrate dc bias voltage (75V)

Fig. 2 Typical microstructure of TiN coating at different conditions. **a** Low substrate bias voltage (25 V), **b** high substrate dc bias voltage (75 V)

The method for calculating the S/N ratio are classified into three main categories, depending whether the desired quality characteristics is smaller the better, larger the better, or nominal the better. In the case of surface hardness and scratch force, the larger values are required and for surface roughness the smaller values are needed. The equation for calculating the S/N ratio for the smaller the better characteristic, and, larger the better characteristic (in decibel) are as the following.

Fig. 3 Scratch adhesion testing on a coated sample and the critical load accompany with their force and depth versus distance graphs. **a** Weakest coating adhesion (scratch force), 2,482 mN, DC power (300 W), DC bias voltage (25 V); **b** strongest coating adhesion, 2,588 mN, DC power (500 W), DC bias voltage (75 V)



(a) Weakest coating adhesion (scratch force), 2482mN, DC power (300W), DC bias voltage (25V)

b) Strongest coating adhesion, 2588mN, DC power (500W), DC bias voltage (75V)

Smaller the better characteristics:

$$S/N = -10\ \log\frac{1}{n}\left(\sum y^2\right) \tag{1}$$

And larger the better characteristic:

$$S/N = -10\ \log\frac{1}{n}\left(\sum \frac{1}{y^2}\right) \tag{2}$$

where, y is the observed data, and n is the number of observations. For each type of characteristic, with the above S/N ratio transformation, the higher the S/N ratio the better is the result. The S/N values function as a performance measurement to develop processes insensitive to noise factors. The degree of predictable performance of a product or process in the presence of noise factors could be defined from S/N ratios. Table 5 shows the measured data, and Table 7 indicates the calculated S/N ratio for surface hardness, scratch force, and surface roughness. Whereas Tables 8, 9, and 10 shows the S/N response values for each levels of measured data, respectively. These data were plotted as shown in Figs. 4, 5, and 6, respectively. As for example of S/N response calculation, A_i in Fig. 4 is the average of all S/N ratio in Table 5 that has same experimental level (i) under A, shown in Table 3. In this case,

Table 7 The calculated (S/N) ratio

Experiment	Calculated S/N ratio		
	Micro hardness	Scratch force	Roughness
1	46.193	57.001	25,848
2	46.444	57.182	25.036
3	46.064	58.588	22.733
4	57.266	52.423	26.588
5	45.105	62.947	24.744
6	45.343	57.061	24.583
7	49.1	63.275	13.807
8	45.575	60.256	29.118
9	52.255	67.769	25.036
10	46.021	49.94	23.61
11	52.041	64.142	18.202
12	57.266	63.521	27.894
13	46.85	60.595	18.636
14	49.542	67.896	23.35
15	52.255	65.918	23.876
16	47.421	57.086	10.872

Table 8 The (S/N) response values for surface hardness

Symbol	Coating parameters	S/N response			
		Level 1	Level 2	Level 3	Level 4
A	DC power	45.252	46.280	52.1215	49.017
B	Temperature	47.60	46.836	49.865	58.3215
C	Nitrogen flow rate	47.75	50.5	50.512	53.122
D	Substrate DC bias voltage	50.571	47.73	46.153	52.040

(*i*) is equal to 1, 2, 3, or 4 corresponding to four parameter levels. Similarly, the S/N response values are calculated for B_i, C_i, and D_i. The desired "higher the better criteria" implies that the highest S/N would reflect the best response, which result in the lowest noise influence on the machine setup. This is the criteria employed in this study to determine the optimal coating parameters for highest surface hardness. As can be seen in Fig. 4 and according to the higher (S/N) response base, the DC power (factor A), temperature (factor B), nitrogen flow rate (factor C), and substrate DC bias voltage (factor D) are significant to determine the best surface hardness.

The DC power parameter level (A_3), temperature level (B_4), nitrogen flow rate level (C_4), and substrate DC bias voltage level (D_4) appear to be the best choices to get high value of surface hardness. Therefore, the optimal combination to get high value of surface hardness is $A_3B_4C_4D_4$ within the tested range. At this level, the confirmation test is carried out using the best parameter combination to validate the finding. The surface hardness obtained from this confirmation test is found to be 840 HV. The result shows an improvement of 14% compared with the highest value of the surface hardness obtained during the experiments shown in Table 5. A study of Fig. 5 suggest the optimal combination to get the higher value of scratch force is $A_4B_3C_3D_3$. The confirmation test is performed to validate the best condition result obtained for scratch force. Measurements are reported as the average of three measurements. The scratch force result achieved from this confirmation test is found to be 2,588 mN. The result shows an improvement of 4.1% compared with the highest value of the scratch force obtained during the experiments shown in Table 6. While Fig. 6 shows that the optimal combination to get the lower surface roughness is $A_1B_1C_3D_1$. The confirmation test at this level is achieved to be 0.0317 μm. There is an improvement of about 9.43% in comparison with result obtained or the best condition during the experiment shown in Table 5.

5 Discussion

The selection of the deposition conditions is essential for fabricating composite thin films. The most important conditions are the nitrogen flow rate, DC bias voltage, temperature, DC power, and pressure of the chamber. A titanium target was selected for investigating the optimum sputtering conditions for Al 7075-T6 alloy. The sputtering power was varied from 300 to 500 W. The pressure was 5.2×10^{-3} Torr during experiments. The effect of TiN coating on AL7075-T6 was observed at different conditions for the best surface hardness with combination of $A_3B_4C_4D_4$.

The sputtering chamber pressure is interlinked to the sputtering power [12]. For low sputtering powers, a high chamber pressure reduces the energy of the sputtered atoms and covers the substrate with charged particles [13]. If the pressure is kept constant, with increasing power, the ion density increases. The sputtering rate increases with increasing power. If power is further increased, the sputtering rate decreases owing to back diffusion as shown in Fig. 4. When the DC power was increased to 300 and 400 W, the ionized and sputtered particles became more energetic, and the sputtering rate increased. On the other hand when it increases more to 500 W, collisions of sputtered particles with chamber particles (argon gas and ions) increased. Hence, a drastic fall in the sputtering rate for high power sputtering is seen. Temperature also has an important role in surface hardness. The hardness of substrate coated from 150 to 180°C is decreased; this may be result from slow movement of atoms in low temperature. While with improving the temperature the movements between atoms are increased,

Table 9 The (S/N) response values for scratch force

Symbol	Coating parameters	S/N response			
		Level 1	Level 2	Level 3	Level 4
A	DC power	56.3	60.884	61.343	62.873
B	Temperature	62.078	58.02	63	59.3
C	Nitrogen flow rate	58.822	63.367	63.627	56.558
D	Substrate DC bias voltage	60.792	61.544	64	61.14

Table 10 The (S/N) response values for surface roughness

Symbol	Coating parameters	S/N response'			
		Level 1	Level 2	Level 3	Level 4
A	DC power	25.051	23.813	23.685	19.183
B	Temperature	24.316	24.145	19.654	23.618
C	Nitrogen flow rate	19.876	24.137	25.06	23.66
D	Substrate DC bias voltage	25.021	22.784	21.217	22.725

atoms can fill the vacant spaces and the surface is denser. This event happened while increasing the DC power promoted this phenomenon (density of surface). The result shown in Fig. 4 is supported by the results which are shown in Fig. 2a, b.

The DC bias voltage as it was mentioned above plays important roles in TiN coating to get high value of hardness. The hardness of coated samples is decreased with increasing substrate bias voltage from 25 to 75 V, but it is increased from 75 to 100 V as revealed in Fig.4. Thus, uniformity of the TiN coating was improved with substrate biasing up to an optimal value and the renucleation was observed to start above a critical bias value. In addition, substrate temperature was believed to control the delusions of atoms during the TiN growth [13, 19]. This interpretation of the best condition for hardness of surface is obtained at maximum temperature point (B4) which it represents 220°C. Furthermore, there is also relationship between coating hardness and nitrogen content in argon–nitrogen gas mixture (represented by nitrogen percentage in the sputtering atmosphere). The hardness values of the Ti interlayers were also measured as a function of nitrogen content in argon–nitrogen gas mixture. An important observation that can be made is that without nitrogen doping, the pure Ti interlayer is very soft, with hardness value around 255 HV, and nitrogen mixing is effective in enhancing the hardness and strength of the interlayer [20]. There is a general trend that the hardness of the Ti interlayer increases with increasing degree of nitrogen doping. This is obviously due to the dissolution of nitrogen in the α-Ti lattice, causing solid solution hardening in the interlayer [19].

The effect of TiN coating on AL7075-T6 was investigated at different conditions for the best surface roughness with combination of $A_1B_1C_3D_1$. With increasing substrate DC bias voltage, the coating became more compact, denser, and rougher. Surface roughness increased with an increase of substrate bias voltages from 25 to 75 V, but the surface roughness decreased from 75 to 100 V as shown in Fig. 6. The surface morphologies of the TiN coatings were studied using AFM. The 3D surface morphologies of TiN coatings are shown in Fig. 7. The root mean square of roughness value of the TiN coatings for surface roughness's confirmation test and its value at temperature (B1), nitrogen flow rate (C3), DC bias voltage (D1), and DC power (A1) was calculated as 6.465 nm (Fig. 7b). Also, typically higher surface roughness and its value at temperature (B2), nitrogen flow rate (C1), DC bias voltage (D3), and DC power (A4) was calculated at 21.888 nm. The different coating surface roughness and morphology can be attributed to the ion energy/ion flux change. The increase of substrate bias voltages results in an increased mobility of the adatoms and a higher nucleation density. In addition, the highly mobile adatoms can move or diffuse into the intergrain voids under the high energy ion bombardment and a denser structure is attained [21]. The best amount of DC bias voltage to achieve the best surface roughness is point D1.

Combination of $A_4B_3C_3D_3$ is a condition to get the best coating adhesion of TiN on AL 7075-T6 which the result is shown in Fig. 5. The results clearly indicate that application of DC bias (in the range of 25–75 V) improves adhesion properties of the coating. Similar beneficial effect of DC bias voltage on adhesion characteristics were also reported

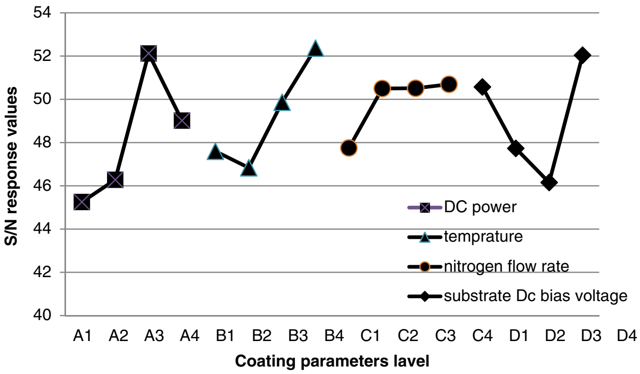


Fig. 4 The (S/N) response graph for surface hardness

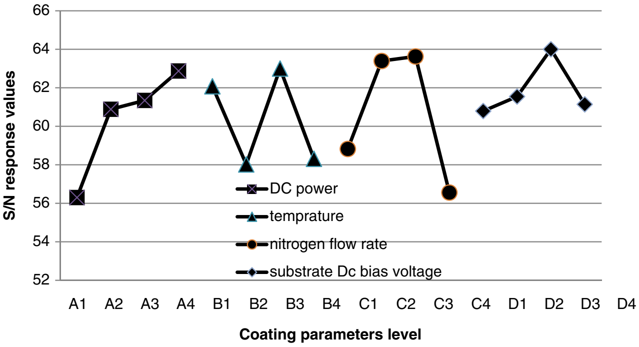


Fig. 5 The (S/N) response graph for scratch force

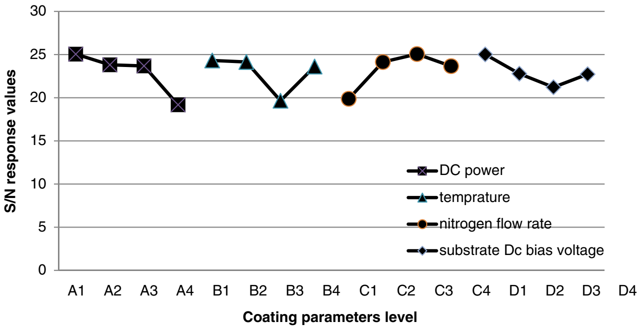
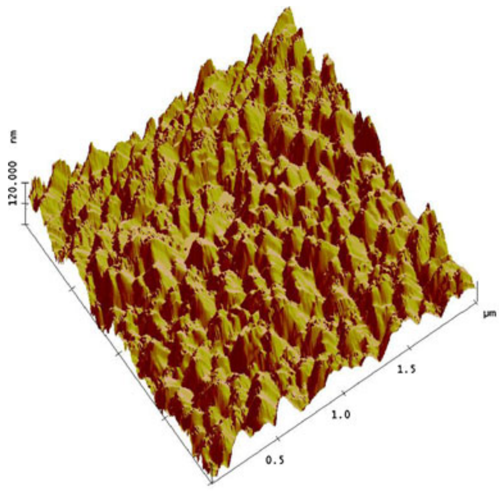
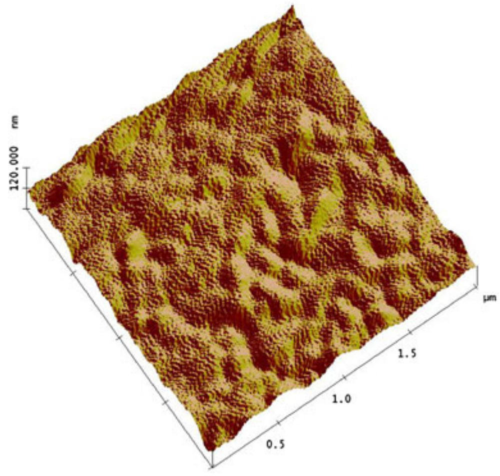


Fig. 6 The (S/N) response graph for surface roughness



(a) Typically high surface roughness at DC power A4, temperature B3, nitrogen flow rate C1, and DC bias voltage D3.



(b) Confirmation surface roughness test at DC power A1, temperature B1, nitrogen flow rate C3, and DC bias voltage D1.

Fig. 7 AFM surface morphologies of TiN thin film. **a** Typically high surface roughness at DC power A4, temperature B3, nitrogen flow rate C1, and DC bias voltage D3; **b** confirmation surface roughness test at DC power A1, temperature B1, nitrogen flow rate C3, and DC bias voltage D1

in earlier literature. This improvement in coating adhesion with increase in DC bias voltage can be attributed to the additional energy available to the growing film. Thus, high-energy atoms have greater mobility to find the low energy sites on the surface to maximize the adhesion characteristics. It was observed that maximum coating adhesion was obtained with a critical load of 2,482 mN. The best condition for scratch force of surface is achieved at maximum DC bias voltage point (D3). However, further increase in DC bias voltage would result in very high-energy bombardments that made the growing film full of defects and lower the coating adhesion to a certain level [22]. Temperature has no significant effect on scratch force (adhesion).

Nitrogen is another important parameter to effect on adhesion between substrate and coating. The observed enhancement in adhesion strength can be attributed to the increased strength of the nitrogen influenced on Ti interlayer. The titanium interlayer serves as an oxygen getter to decompose the native oxide film on the substrate surface, thus promoting adhesion between the coating and the substrate. The nitrogen gas does not significantly change the chemical nature of α-Ti, because no TiN compound is formed and nitrogen is dissolved in the α-Ti lattice. It is thus expected that the Ti interlayer, influenced by nitrogen gas, also plays a similar role as an oxygen getter. However, if the interlayer is too soft, such as a pure Ti interlayer, it will deform too easily and provide less support to the TiN coating. With nitrogen gas, the Ti interlayer becomes stronger and thus can provide increased support to the TiN coating, leading to enhanced adhesion strength. But, with further increasing nitrogen content, the interlayer becomes too strong and brittle to accommodate the interfacial stresses, leading to the observed reduction in adhesion strength. The nitrogen gas with 5% N2 seems to produce the optimum value of strength for adhesion enhancement in the present deposition conditions [8].

6 Conclusion

In this research work, Taguchi optimization method is used with the orthogonal array of L_{16} (4^4), to obtain the most optimum parameters for the best surface hardness, scratch force (adhesion), and surface roughness. From the analysis of result by magnetron sputter coating using conceptual S/N ratio approach, the following conclusion can be derived from the present study:

1. Taguchi's robust design method is suitable to analyze the TiN coating using magnetron sputtering machine on Al 7075.
2. In the TiN coating on Al 7075 by sputtering machine, use of DC power (400 W), temperature (220°C), nitrogen flow rate (4%), and substrate DC bias voltage

(100 V) are recommended to obtain better surface hardness for the specific test range.

3. DC power (300 W), temperature (150°C), nitrogen flow rate (5%), and DC bias voltage (25 V) are suggested to get the best surface roughness for the specific test range.
4. To obtaine high scratch force for indicating the adhesion strength in TiN coating, DC power (500 W), temperature (200°C), nitrogen flow rate (5%), and substrate DC bias voltage with amount of (75 V) are recommended.
5. The hardness and strength of the interlayer is increased due to nitrogen dissolution in the α-Ti lattice. The hardness of TiN-coated AL7075-T6 samples was increased up to 840 HV, while the hardness of uncoated samples was 170 HV.
6. Confirmation tests are indicated the improvement of 14 % in surface hardness, 4.1% in adhesion, and 9.43% in surface roughness in comparison with the highest amounts obtained during experimental tests.

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