

Influence of nanostructured-TiC Coating on the Mechanical Properties of Ti6Al4V Alloys Grown by RF Magnetron Sputtering

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Abstract

Hard coating ceramics are gaining prominent applications in many industries due to their astonishing and favourable properties. Titanium alloys are regarded as the material of the 21st century with excellent mechanical and metallurgical properties. Titanium and its alloys have the ability to form a protective oxide that prevents it from susceptibility to corrosion in the presence of oxygen but has poor wear-resistant. Coating with TiC will enhance the surface properties and increases its application life span and range. In this research work, TiC ceramic coating was deposited on the surface of commercially pure Titanium using RF magnetron sputtering. The behaviour of the evolving mechanical properties was characterized using different mechanical characterization techniques. Nanoindentation was used to determine the hardness and Young modulus. The coefficient of friction was also investigated using a tribometer. The hardness of the coating was improved, and the lowest coefficient of friction was found at the highest hardness value.

Keywords

Hardness, Coefficient of friction, RF sputtering, Titanium carbide, Young Modulus

1. Introduction

Mechanical properties like hardness, young modulus and coefficient of friction are very crucial in making a material acceptable and sustainable for industrial and domestic application. The mechanical properties can be enhanced by alloying with reinforcement or coating with the material of superior qualities. The challenge with the alloying process is the formation of the intermetallic phase during the process which can deteriorate the mechanical properties. Magnetron sputtering, a physical process which is a type of the coating process can be used for improving the mechanical properties. It has favourable advantages like low deposition temperature and easy to use.

Titanium carbide (TiC) is a synthetic superhard material often used as a protective coating due to its tribological properties such as low friction coefficient and low wear rate. In addition, TiC possesses qualities such as high hardness, high melting point (3067 °C), thermal and chemical stability (Galevsky, Rudneva et al. 2015). A common way of depositing TiC is by chemical vapour deposition (CVD) (Zergioti, Fotakis et al. 1997, Rie, Gebauer et al. 1996), where gaseous precursors react on heated substrates (often cemented carbides) at about 1000 °C (Cho, Bhat et al. 1986). In order to deposit TiC on materials that are sensitive to elevated temperatures, such as most steels, other deposition techniques must be used. Several physical vapour deposition (PVD) techniques have been developed which utilise a lower deposition temperature. Another benefit of employing PVD rather than CVD is the greater freedom to control the composition of the films (Wiklund, Nordin et al. 2000, Coronel, Wiklund et al. 2009, Helmersson, Lattemann et al. 2006).

The coatings studied in this work exhibited different properties under different process parameters and the different coating properties might be suitable for several applications. The aim of this work is to study the effect of TiC coating on the mechanical properties of CpTi substrate under different sputtering parameters with emphasis on the tribology behaviour, hardness and Young modulus.

2. Methodology

2.1 Substrate and the coating preparation

TiC thin films were grown on commercially pure titanium (CpTi) using HHV TF500 versatile RF Magnetron Sputtering Coater. Before deposition of the film, the substrate (CpTi) was ground using Silica carbide paper and then polished to remove any surface impurities. Further cleansing of the surface was done by using acetone to remove any form of lubricant or contaminant on the surface. The purity of the TiC target used is 99.99%. During the sputtering process, the sputtering time and temperature were varied while other sputtering parameters were kept constant. Three runs of experiments were conducted, and the experimental matrix is presented in table 1. The sputtering apparatus was first evacuated to a base pressure of 1.13×10^{-5} mbar. The reason for the low pressure is to provide a long mean free path for a collision between the target and substrate and allows for the control and minimization of contaminants. After the evacuation, the system is refilled with argon to a partial pressure of 2.5×10^{-3} mbar. The flow rate of argon was kept constant at 12 sccm while the sputtering time was maintained at 2.5 hrs. The working pressure was constant throughout the experiments. Maintaining constant pressure helps to place many argon atoms in the path of the ions and ejected coatings. The experimental matrix used is shown in table 1.

Table 1. The experimental matrix of the Process Parameters for thin film deposition

S/N	RF Power (W)	Temperature (°C)	Sputtering time
L1	250	100	2.0
L2	250	80	2.5
L3	250	90	3.0

2.2 Sample Characterization

The Young's modulus and hardness thin film of the nanomechanical properties were obtained using Hysitron TI950 Triboindenter. The control mode used was load controlled and the load pattern was modelled to follow a trapezoidal geometry of loading-dwelling and unloading profile with a dwelling time of 15 sec at peak load. The loading and unloading rate of $10 \mu\text{N s}^{-1}$ and a maximum load of $300 \mu\text{N}$ were used. Berkovich tip was used as the diamond indenter with a tip radius of curvature of 100 nm. From the analyzed load-displacement curves, Oliver and Pharr analysis method was used to calculate Young's modulus of the thin film. (Oliver, Warren Carl, Pharr 1992, Oliver, Warren C., Pharr 2004, Fang, Jian et al. 2004). The depth of penetration for all the samples was limited to 10% of the coating thickness to eliminate the effect of the substrate on the thin film properties (Bec, Tonck et al. 1996, Mani, Aubert et al. 2005). The hardness and Young's modulus reported corresponds to an average of 10 measurements performed on the thin film coating. The tribological properties which represent the macro scratch of the thin film coatings were achieved on a Rtec Universal ball-on-disk tribometer at ambient condition. (temperature, pressure, and humidity). An E521000 Alloy Steel Grade 25 ball (6.350 mm in diameter) was used as the counter body while the

surface of the thin films coating serves as the disk. The movement of the motion is translational with maximum stroke displacement of 1 mm. The sliding velocity was kept constant at 1 mm/s for 2 mins at a normal load of 10 N for all the experiments. The friction coefficient was monitored throughout the experiment by a linear variable displacement transducer and recorded on a data acquisition computer attached to the tribometer. After completion of the wear, the wear tracks were examined on the microscope for further analysis of the surface deformation and failure. All process parameters were repeated three times and the average values were reported.

3. Result and Discussion

The curve of the force vs displacement graph is shown in figure 1. The curve follows the loading, holding and unloading pattern with no abnormal behaviour.

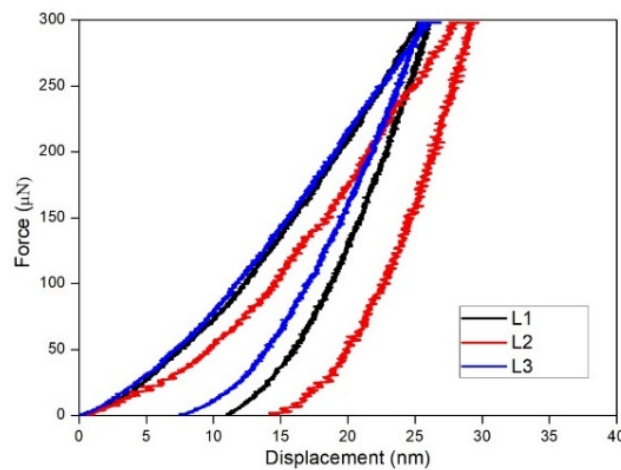


Figure 1: Force Vs Displacement curve

From the curve of the force vs displacement graph, the hardness and Young modulus of the film was calculated. The highest value of hardness was found for sample L3, which also has the lowest elastic modulus. The relationship between the hardness and the young modulus tend to be inverse as seen in figure 2. As the hardness increases, the young modulus decreases and vice-versa. The high value of hardness is a good sign of resistance to deformation by external load acting on the films.

Table 2: Statistical analysis of the Hardness and Young Modulus results

Sample	Young Modulus E (GPa)	Hardness H(GPa)	Wear Resistance H^3/E^2 (GPa)	Plasticity index H/E	H_{MAX}	H_F	% RECOVERY	PLASTICITY
L1	159.46	9.28	0.031	0.058	26.38	10.86	58.82	41.18
L2	163.41	9.19	0.030	0.056	29.70	13.98	52.95	47.05
L3	145.08	10.13	0.050	0.070	26.91	7.96	70.41	29.59

H_{max} = total displacement

H_f = final residual indent displacement

$$\% \text{ recovery} = \frac{h_{\max} - h_f}{h_f} \times 100$$

$$\text{Plasticity} = \frac{h_f}{h_{\max}} \times 100$$

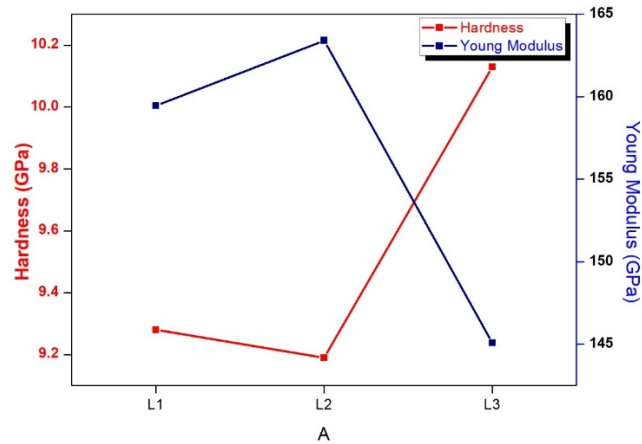


Figure 2: Graph of correlation between hardness behaviour and Young Modulus

The percentage recovery and plasticity of the films were also calculated. From the results obtained, the percentage recovery increases directly with an increase in hardness while the plasticity exhibits an inverse relationship with the film hardness. This shows that films with higher hardness tend to recover faster from deformation and have reduced deformation behaviour under loading condition. The creep strain against time was plotted and presented in figure 3. The creep graph was obtained during the dwelling period of the load on the coating. All the coatings show no failure and slippage of the indenter under a constant load of 300 μN for the total duration of the dwelling time. This shows good resistance to failure under uniform load and good bonding affinity between the coating and the substrate.

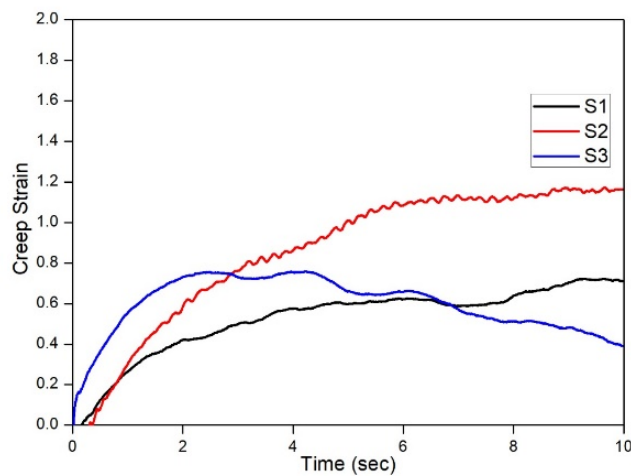


Figure 3: Graph of Creep strain Vs Time

To determine the tribology behaviour, wear tests were performed on the samples. The graph of the Coefficient of friction (COF) against sliding time is presented in figure 4. The range of the coefficient of friction is between 0.540 to 0.570. The lowest COF was found at sample L3 with the highest hardness value. Archard (Archard 1953) method was used to determine the wear rate. The wear rate increases with decreases in hardness value. Further analysis was done on the wear scar to determine the failure mode. The wear scar micrographs are shown in figure 5.

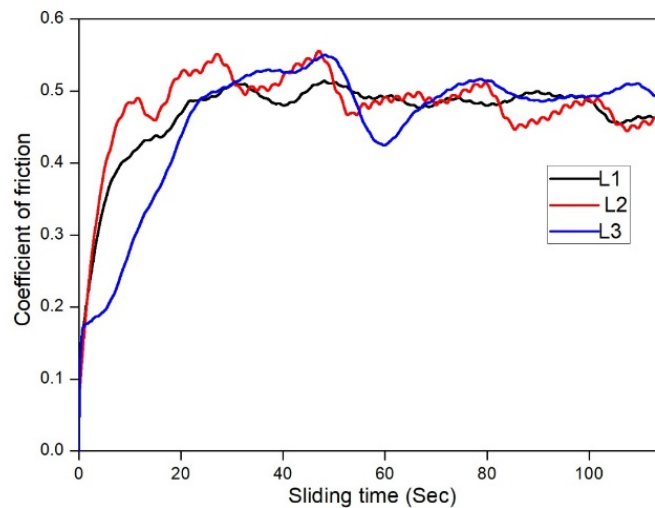


Figure 4: Graph of COF vs Sliding time

Table 3: Statistical analysis of the Wear results

EXPERIMENTAL	COF	WEAR DEPTH (mm)	WEAR VOLUME (mm ³)	WEAR RATE (mm ³ /Nmm)
L1	0.545	0.0165	0.002684108	2.23676E-06
L2	0.570	0.0246	0.00596118	4.96765E-06
L3	0.540	0.0135	0.001797367	1.49781E-06



Figure 5: Micrograph of the wear scar

Conspicuous film coating failure of different modes like spallation, delamination of the film and bending cracks were observed on the wear scar. Chipping out of the TiC thin film were seen at the edges of the wear track. The results from

the rubbing interaction between the steel indenter ball and the surface film coating. The size of the wear scar and degree of TiC coating removed reduce for sample L3 with the highest hardness when compared to the other two samples. This is due to highly resistant to deformation, thereby limiting the rate of TiC coating removal from the surface of the coating.

Conclusion

From the experimental observation, it can be concluded that the process parameters affect the mechanical properties of the TiC thin film coating. The hardness improves with increase in temperature and the same trend was noticed for the Young Modulus. The COF of the TiC thin film coatings reduces as the hardness of the film increase and delamination of the films were noticed under micrographic observation.

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