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Friction and wear of TiCN coatings deposited by filtered arc

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Abstract

A series of macroparticle-free TiN, TiCN and TiC coatings were deposited on 316 austenitic stainless steel using a titanium target in a filtered arc deposition system and reactive mixtures of CH_4 and N_2 gases. The microhardness of the coatings were measured by using an Ultra-Microhardness Indentation System (UMIS-2000). The wear and friction of the coatings were assessed under controlled test conditions in a pin-on-disc tribometer.

The results show a significant increase in microhardness and wear resistance as the CH_4 :N_2 gas flow rate ratio is increased. At lower load(14N), all coatings exhibited low friction and wear. At higher load(25N), the higher carbon content TiCN and TiC coatings showed a much lower friction and wear compared to TiN and low carbon TiCN. The topographical examination of coatings and worn surfaces established that the self-lubricating effect of the carbonaceous particles condensed from the plasma during the deposition was primarily responsible for the low friction and wear regime.

1. Introduction

Titanium nitride (TiN) thin films deposited by different PVD technologies are now widely accepted in arrange of industrial applications where high wear resistance and good adhesion to the substrate are critical[1,2]. However, there are mounting evidences that other transition metal nitrides and/or carbides may provide superior performance for some applications, such as cutting tool for interrupted cutting. Titanium carbonitride (TiCN), for instance, is known to perform better than TiN for interrupted cutting[3]. Although TiCN can be reactively deposited by a number of PVD techniques, it is believed that the best results, in terms of adhesion and coating microstructure, can be obtained by arc evaporation technique[4,5]. The high ionisation rate and high ion energy inherent in arc evaporation provide a wide window of operating parameters for obtaining the desired stoichiometry in the coating(i.e. C to N ratio) and excellent adhesion. Unfortunately, the presence of macroparticles in arc evaporated films, results in rough surfaces which seriously impair the applicability of these coatings for some applications. We have used a filtered arc source to eliminate the macroparticles and have succeeded in depositing smooth TiCN coatings with different carbon to nitrogen ratio. In this paper the results of tribological testing conducted on these coatings will be reported.

2. Experimental procedures

Austenitic stainless steel (AISI 316) discs (45mm in diameter and 4mm thick) were ground and polished to 1μm finish. The specimens were subsequently degreased and cleaned using Decon Neutracon detergent and distilled water in an ultrasonic bath. The coatings were deposited using the filtered arc deposition system (FADS). The coating chamber was pumped down to a base pressure less than $5x10^{-5}$ Torr. Prior to coating, the specimens were indirectly heated to approximately 400-450°C by a resistive heater whilst the temperature was monitored by a thermocouple. The specimens were initially sputter cleaned for one and half minutes with the titanium ion beam using a substrate bias voltage of -500V. To initiate the deposition the bias voltage was reduced to -100V, and the specimens were coated with Ti for one minute before the reactive gases were introduced into the chamber via mass flow controllers. The deposition pressure was monitored by a capacitance manometer, and maintained at 2 mTorr for all depositions.

The microhardness of the coatings were measured by using an Ultra-Microhardness Indentation System (UMIS-2000) at loads of 20, 30 and 50 mN. Wear testing was performed using a pin-on-disc tribometer, a ruby ball (6mm in diameter) served as the pin. Loads of 14N and 25N were applied parallel to the axis of rotation of the disc. A fixed linear velocity of 0.3m/s was used and samples were tested for 800 turns under dry sliding condition at ambient temperature and humidity. The wear track profiles were measured by an Alpha-step 200 profilometer.

3. Results

Table 1 lists the microhardness of the TiCN coatings obtained by the UMIS. The results show an increase in hardness with increasing carbon content in the coatings, going from pure TiN to pure TiC. Similar results have been reported by Randhawa on the cathodic arc plasma deposited films[5]

Table 1. The microhardness of the coatings as a function of CH_4/N_2 mass flow rate ratio.

Coatings (C:N Ratio)	TiN	TiCN (0.1:1)	TiCN (0.15:1)	TiCN (0.3:1)	TiCN (0.5:1)	TiCN (0.8:1)	TiCN (1:1)	TiC
Hardness (Hv)	2595	2628	2661	2835	2878	2884	2892	2970

Figs.1.(a) and (b) show the coefficient of friction (μ) of the coatings at 14 and 25N loads, respectively. At lower load, all the coatings irrespective of their carbon content, exhibited low friction coefficient (μ=0.015~0.020). At higher load (25N), the value of the coefficient of friction decreased as the carbon content increased from TiN to TiC. It should be pointed out that uncoated stainless steel substrate exhibited a coefficient of friction of 0.14 , tested under similar condition.

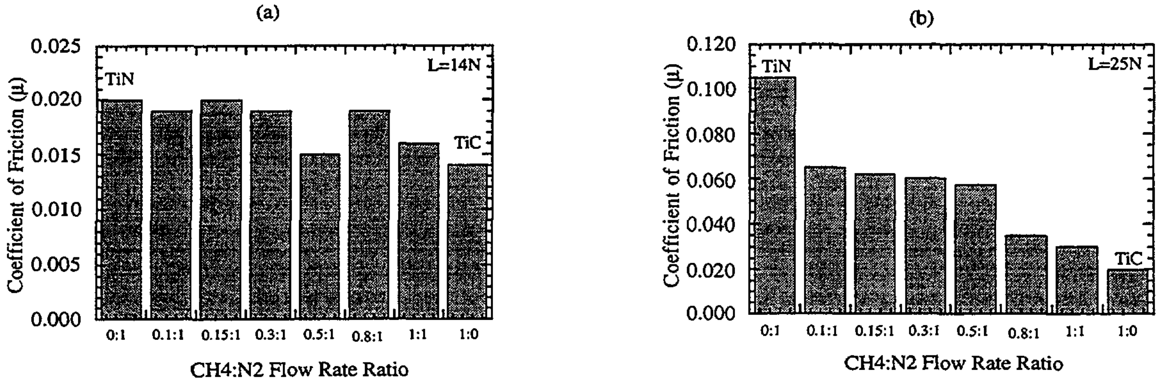
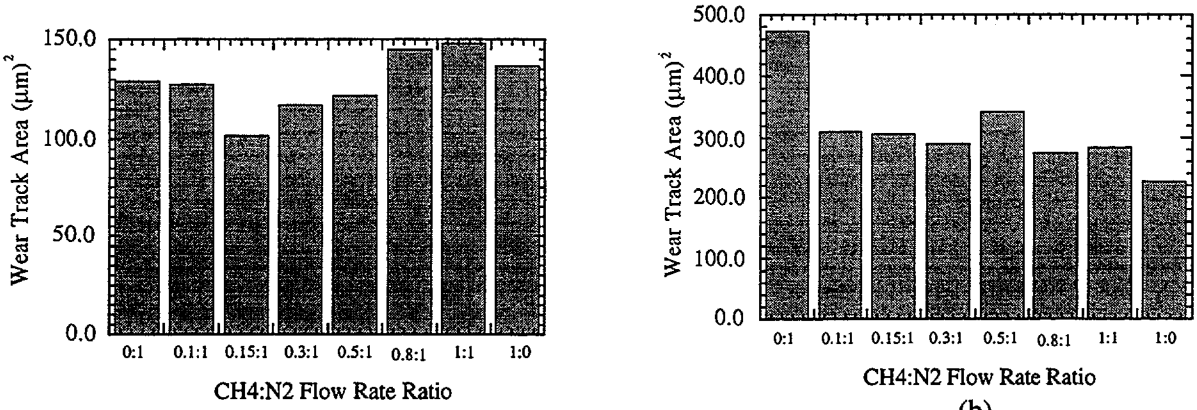


Fig.1. The variation in coefficient of friction for TiCN coatings at load: a)14N; b) 25N.

Figs.2 (a) and (b) show the cross-sectional areas of the wear tracks plotted for the coatings with different carbon content at 14N and 25N, respectively. At low load (14N), all the coatings experienced low and almost comparable wear. However, when the load was increased to 25N, the wear resistance was significantly influenced by the C and N ratio in the coating. The best performance was displayed by TiC, and the highest wear rate amongst all coatings was recorded for the TiN coatings. In other words, the higher the carbon content the better the wear resistance.

4. Discussion

The low friction/wear of TiCN coatings compared to TiN can be partly explained by the higher hardness of these coatings. The addition of carbon to TiN increases the amount of covalency in the coating and results in higher hardness[6]. The higher hardness, in turn, reduces the extent of plastic deformation at the asperities during sliding contact and therefore reduces the contribution of ploughing force to the overall friction force. However, reduction in friction obtained in this work is far greater than that attributed to this effect. Topographical examination of the coating and worn surfaces indicated that some carbonaceous particles(probably amorphous carbon) were deposited on the surface. It is not inconceivable that titanium ions in FADS are energetic enough to dissociate methane molecule and the released carbon can be condensed on the surface. The low friction of carbon and the fact that smeared particles reduce the likelihood of adhesive wear, may have resulted in low friction coefficient. Also, as indicated earlier, the addition of C to TiN increases the amount of covalently bonded species on the surface which also reduces the tendency for adhesion. This reduced tendency would also reduce the overall friction force.



(a) (b)

Fig.2. The results of the cross-sectional area of the wear tracks for the TiCN coatings at two loads: a) 14N; b) 25N.

4. Conclusions

The following conclusions are derived from this study:

- All the TiCN coatings, irrespective of the actual concentration of carbon, displayed a higher microhardness values than TiN coating. The highest hardness was achieved for the TiC coating. The more the carbon content on the coating, the higher the hardness.
- All coatings displayed excellent tribological properties(i.e. low friction and low wear) at low load. At high load, the friction and wear of TiCN coatings were superior to those of TiN. Generally speaking, the higher carbon content in the coating, the lower the friction and wear.

5. References

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