

Tribological Characteristics of TiC, TiN and TiC/TiN Coatings

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TiC, TiN과 TiC/TiN 코팅의 트라이볼로지 특성

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Abstract The tribological properties of TiC, TiN and TiC/TiN coatings on steels prepared by the cathodic-arc (CA) ion plating technique were investigated. Experiments were carried out on a tribo-test machine using a Falex journal V block system. The friction and wear characteristics of the coatings were determined by varying the applied load and sliding speed. The TiC, TiN and TiC/TiN coatings markedly increased the tribological characteristics of the surface. As far as a single layer coating was concerned, TiN goes better results than TiC. However, the TiC/TiN multilayer coating performed better than either single layer coating. The major factor in the improved performance of the multilayer coating was the role of TiC in improving the adhesion between the external TiN layer and the substrate steel

요 약 CA 이온도금기술에 의한 TiC 와 TiN 그리고 TiC/TiN 코팅재를 비교하기 위하여 트라이볼로지 물성을 연구하였다. 실험은 Falex journal V block 시스템을 이용한 터보시험기에서 수행하였다. 코팅재의 마찰과 마모특성은 작용된 하중과 미끄럼 속도에 의하여 다양하게 결정되었다. TiC 와 TiN 그리고 TiC/TiN 코팅재는 표면에서 트라이볼로지 특성이 현저하게 증가하였다. 단층코팅에서는 TiC보다 TiN이 좋은 결과를 얻었다. 그러나, TiC/TiN의 다층코팅은 다른 어떤 단층코팅보다 좋은 성능을 보였다. 다층코팅의 성능이 향상된 핵심요소는 TiN층 외부와 강 사이에서 부착이 증가하게된 TiC의 역할 때문이다.

Key Words : Coating, TiC(Titanium carbide), TiN(Titanium nitride), TiC/TiN, Tribology

1. Introduction

The tribological characteristics of a coating are governed by several factors including the hardness of the coating and the substrate, friction coefficient, coating wear resistance, contact temperature and chemistry. A number of coating methods are in use. To prolong the life of a tool, coatings of TiC and TiN are made by chemical vapor deposition (CVD) or physical vapor deposition (PVD). To increase the wear resistance, a multilayer coating of TiC/TiN is used [1-5]. The ion plating with a

high degree of ionization is used to increase the adhesion between coating and substrate[6-8]. Bertocello et al.[9] studied the composition and microstructure of TiC, TiN and Ti(C,N) deposited by an industrial ion-plating system. Guu et al.[10-11] investigated the tribological characteristics of titanium coating formed by ion plating. The authors studied TiC preparation methods[12] and the tribological properties of TiC and TiN coatings [13,14].

In this study, the tribological performance of TiC, TiN and TiC/TiN films deposited on steels by a reactive ion plating method were investigated.

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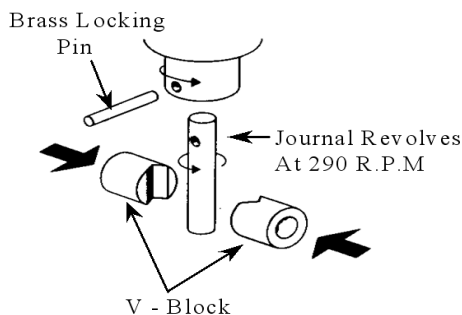
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2. Experimental

Tests were performed at room temperature using a journal and V block tester (Falex, ASTM D 2625) lubricated with mineral oil lubricants. Friction, wear, scar temperature were measured for various carrying loads and speeds[15].



[Fig. 1] Exploded view of V-blocks and Journal arrangement

As shown in Fig. 1, a journal rotates against two stationary V blocks to give a four time contact in this configuration. The journal (AISI 3135) was 6.35mm in diameter, 31.75mm in length and HRb 87-91 in hardness. The V block (AISI 4130) was HRc 20-24 in hardness and had a $96 \pm 1^\circ$ notch on its face. The characteristics of the journal and V block are summarized in Table 1.

[Table 1] Specimens Characteristics

Materials		Journal (AISI 3135)	V block (AISI 4130)
Composition mass (%)	C	0.15	0.30
	Si	0.20	0.20
	Mn	0.50	0.45
	Cr	0.35	0.80
Hardness (HRb, HRc)		87 - 91 HRb	20- 24 HRc
Surface roughness Ra (mm)		0.15	0.15

The coatings were deposited using a cathodic-arc (CA) ion plating method[16]. The pressure in the vacuum deposition chamber in which the coating was deposited was 10-4~10-5torr, the arc current was 100A, and the titanium ion bombardment was done at 1000V bias

voltage. The surface roughness Ra of the deposite layer was 0.3~0.4mm. its hardness HRc and thickness were , respectively, 55 ~ 63 and 5mm. Table 2 lists the properties of TiC and TiN films. The TiC/TiN multilayer coating was prepared by first coating the substrate with a 5mm layer of TiN followed by a 5mm layer of TiC.

[Table 2] Properties of TiC and TiN films

Property	TiC	TiN
Microhardness (HRc)	55	63
Thickness (mm)	5	5
Roughness (mm)	0.3	0.4
Bonding strength (N/cm2)	3,400	10,300
Young's modulus (Mpa)	500'103	260'103
Density (gcm-3)	4.9	5.2

The samples were tested under an incrementally increasing load between 1.1 ~ 6.7 kN for speed of 0.5 ~ 3.5m/s. the surface temperature was continuously measured with a thermocouple inserted into a hole drilled through the V-block.

The lubricating mineral oil had a viscosity of 30.19cst at 25°C and covered the entire friction surface. The wear volume was measured using a surface profilometer.

The worn surface was examined by scanning electron microscopy (SEM), and hardness was measured with a Rockwell hardness tester and a Vickers microhardness tester.

3. Results and Discussion

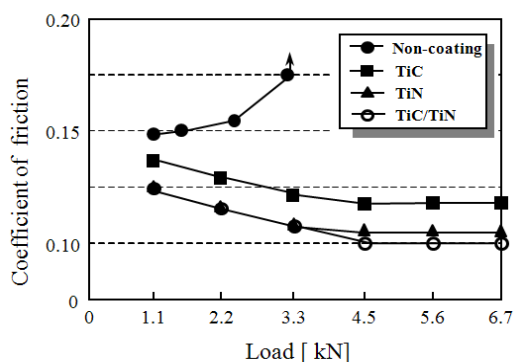
3.1 The effect of load in friction

The variation of friction coefficient of the substrate steel and TiC, TiN and TiC/TiN coatings with load is shown in Fig. 2.

The sliding speed was 1m/s for these test. It can be seen that the friction coefficient of the uncoated system increases with the load up to 3.3kN, at which point it starts to increase rapidly, leading to the eventual failure beyond 4.5kN. in the case of TiC, TiN and TiC/TiN coatings, however, the friction coefficient decreases with

the load until a much higher load is applied. The TiC/TiN coating showed the lowest friction coefficient at 0.1 ~ 0.115.

A dry, unlubricated surface usually follows the first law of friction, i.e. the friction coefficient is independent of load. The results of this work indicate that the uncoated steel surface follows this law, even when lubricated[17], up to a load at which seizure occurs. It is of interest, however, to note that TiC, TiN and TiC/TiN coatings display decreasing friction coefficient with increasing load.



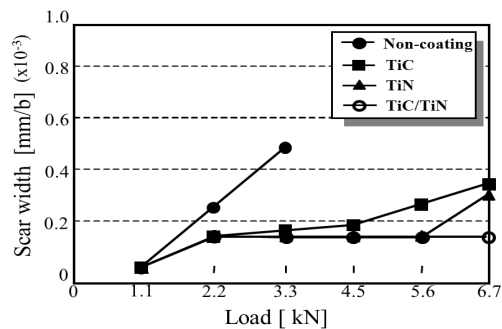
[Fig. 2] Coefficient of friction for load

3.2 The effect of load on scar width

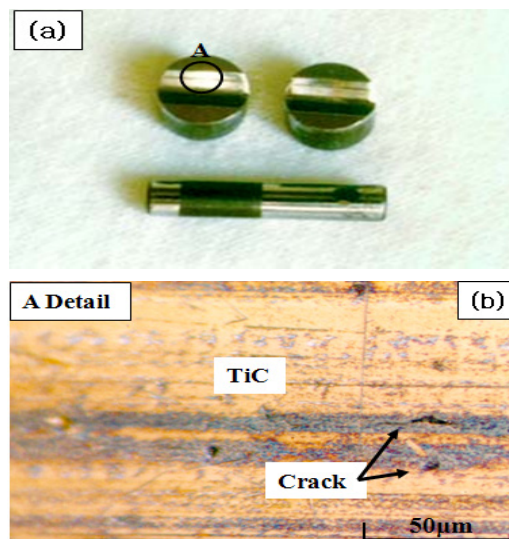
Fig. 3 shows the effect of load on scar width. The coated surfaces show considerably smaller scar widths than the uncoated steel surface. Furthermore, the coatings keep the scar width relatively unchanged (or very slowly increasing) with load until cracks or delamination occurs. As seen in Fig. 4, the TiC coating developed cracks at a load of 4.4kN, whereas Fig. 5 shows delamination of the TiN coating at 5.6kN loading. In contrast, the wear scars on multilayer coated specimens indicate considerably less wear than for the uncoated or single layer coated specimens. As shown in Fig. 6, the TiC/TiN multilayer coating had neither crack formation nor delamination at a load as high as 6.7kN.

Zhang et al.[18] suggested that microcracks already present in the coating lead to separation into different sheets and along different directions. Porat[5] proposed that the many advantages of multilayer coatings, including their high strengths, derive from the effect of the layer interfaces in stopping crack propagation. Thus, the role of

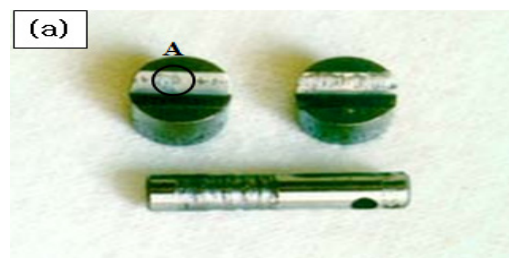
the intermediate TiC layer in the TiC/TiN multilayer is to promote the adhesion between the TiN layer and the substrate.

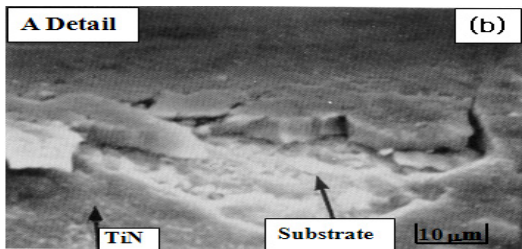


[Fig. 3] Scar width for load

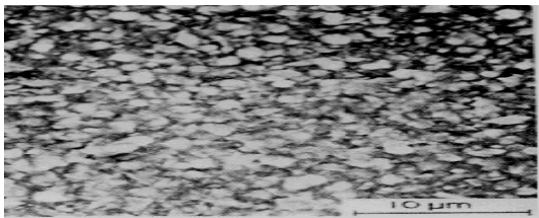


[Fig. 4] The SEM metallograph occurred crack of the TiC film (4445N)

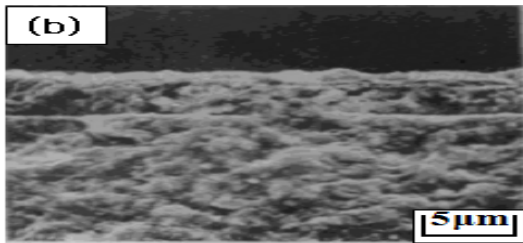




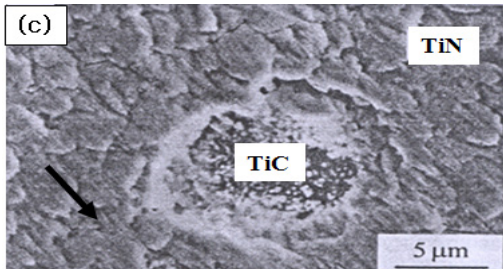
[Fig. 5] The SEM metallograph occurred delamination of the TiN film (5556N)



(a) The surface morphology



(b) The fracture cross section



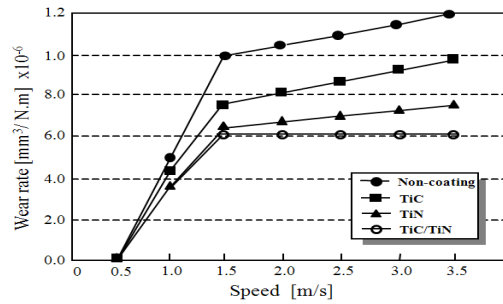
(c) Occurred delamination

[Fig. 6] The SEM metallograph of the TiC/TiN

3.3 The effect of sliding speed on wear

Fig. 7 shows the variation of the wear rate with sliding speed under a load of 2.2kN. the normalized wear rate is defined as $Wr = (\text{wear volume (mm}^3\text{)}/\text{normal force (N)}) \times \text{sliding distance (m)}$. It is seen that all specimens display a rapid increase in wear rates up to a 1.5m/s sliding speed. The specimen without any coating suffers seizure and failure at a sliding speed of 3.0m/s. In the case of

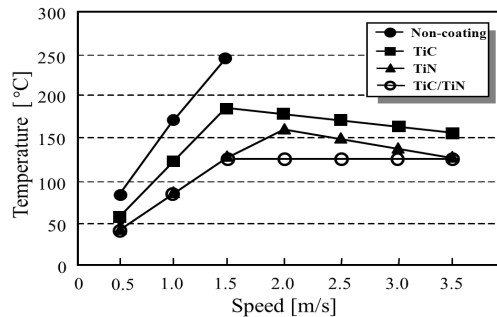
TiC and TiN coatings, the wear rate increased slowly beyond the sliding speed of 1.5m/s, with TiN having a lower wear rate than TiC. This is due to the fact that TiN has higher hardness than TiC and thus is less likely to deform plastically. The TiC/TiN coating showed a relatively unchanging wear rate beyond 1.5m/s.



[Fig. 7] Wear rate for speed(2223N)

3.4 The effect of sliding speed on contact temperature of the coating

The variation of contact temperature of TiC, TiN and TiC/TiN coatings with speed is shown in Fig. 8. It is seen that the temperature of the uncoated surface increases sharply beyond a sliding speed of 1.0m/s. On the other hand, with a TiC or TiN coating, the temperature reaches a maximum at a transition point at 1.5 and 2.0m/s, respectively, and then decreases with sliding speed. For a TiC/TiN coating, the transition point occurs at 1.5m/s speed, and the temperature remains relatively unchanged beyond this speed.

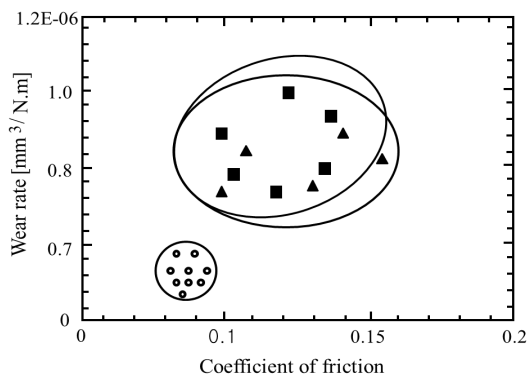


[Fig. 8] Temperature for speed(2223N)

3.5 Relations between Friction and Wear

In Fig. 9, wear rate is plotted against coefficient of

friction. As expected, a lower coefficient of friction results in a lower wear rate. A similar result was reported by Vancoille et al.[19] for TiN and TiC/Ti(C,N)/TiN coatings sliding against Al₂O₃ surface.



[Fig. 9] Wear rate for coefficient of friction

4. Conclusion

The tribological characteristics of TiC, TiN and TiC/TiN coatings were investigated. The results can be summarized as follows:

1. The TiC, TiN and TiC/TiN coatings, in that order, substantially lower the friction coefficient from the value for the uncoated surface of steel substrate.
2. The wear resistance of the TiC/TiN multilayer coating is higher than that of the TiC or TiN single layer coating, TiN providing better resistance than TiC. Temperature characteristics follow the same trend.
3. The coefficient of friction and surface temperature were also lowest for the TiC/TiN multilayer coating than the TiC or TiN coating, at all sliding speeds and loads.

Overall, the TiC/TiN coating has the best tribological characteristics of the three coatings tested. In terms of friction coefficients, scar width, wear rate and contact temperature, the properties of TiN and TiC/TiN coatings are quite similar before failure occurs. The important difference between these two coatings is that the TiC/TiN multilayer fails at much more severe conditions than the

TiN layer. Thus, it is concluded that the role of the intermediate TiC layer in the TiC/TiN multilayer is to promote the adhesion between the TiN layer and the substrate.

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<Research Interests>

Heat and Fluid mechanics and Automobile Materials