

# The high temperature and varying temperature tribological performance of TiC coatings

Zeyong Wang<sup>1</sup>, Shengshuang Hu<sup>2</sup>, Changjie Feng<sup>1,\*</sup>, En Chen<sup>1</sup>

<sup>1</sup>School of Materials Science and Engineering, Nanchang Hangkong University, Nanchang, Jiangxi Province, 330063, China

<sup>2</sup>AVIC Xi'an Aircraft Industry(GROUP) Company LTD, Xi'an, Shanxi Province 710089, China

\*Email: chjfengniat@126.com

**Abstract.** TiC coatings were deposited on the AISI304 sheets by cathodic arc ion plating using pure Ti target in Ar/CH<sub>4</sub> atmosphere. The surface morphology, hardness and tribological properties were investigated by scanning electron microscope(SEM), micro-hardness tester and ball-on-disc rotating tribometer. The results show that the thickness of the coatings was about 6µm. The hardness was 2000Hv0.05. The tribological tests were carried out at RT, 200°C, 400°C and RT-400°C against alumina balls. The friction coefficient was stable at 0.57 at RT, while the coefficient fluctuated largely at 200°C and RT-400°C due to the lower relative humidity.

## 1. Introduction

TiC is a kind of transition metal carbide with typical NaCl face-centered cubic structure. TiC coatings were widely used in the field of mechanical processing, mineral metallurgy and aerospace fields due to its good thermal stability, lower friction coefficient, higher hardness, better wear resistance and corrosion resistance<sup>[1-3]</sup>.

Physical vapor deposition method was employed to prepare coatings due to the even composition and lower deposition temperature<sup>[4]</sup>. F.Santerre et al.<sup>[5]</sup> prepared TiC coatings by pulsed laser deposition technology using TiC target. M.P. Delplancke et al.<sup>[6]</sup> prepared DLC/TiC composite coatings by arc ion plating technology using C target and Ti target. O.A.Fouad et al.<sup>[7]</sup> prepared TiC coatings by magnetron sputtering using Ti target in the Ar/CH<sub>4</sub> mixed atmosphere.

Compared with other coating preparation technology, the coatings deposited by arc ion plating have higher density and better adhesive strength with substrates<sup>[8-10]</sup>. In this paper, TiC coatings deposited by arc ion plating technology using Ti target in the Ar/CH<sub>4</sub> mixed atmosphere. The tribological performance of coatings was investigated against Al<sub>2</sub>O<sub>3</sub> balls at RT, 200°C, 400°C and RT-400°C.

## 2. Experimental Details

### 2.1 Coatings deposition.

TiC coatings were deposited on the 304 stainless steel sheets, 20mm × 30mm × 2mm, by arc ion plating using pure Ti target in the Ar/CH<sub>4</sub> atmosphere. Before deposition, the substrates were ground and polished, degreased, and ultrasonically cleaned in ethanol. A rotational substrate holder was located in the vacuum chamber, with a 100 mm distance (substrates from the target). In order to achieve better adhesion between the coatings and the substrates, the substrates were sputtered in argon



atmosphere for 10 min under -800V d.c bias voltage. During all the sputtering process, the substrate temperature, the holder rotational speed, the working pressure and the target electric current, substrates bias voltage were kept constant at 250°C, 13 rpm, 1.2Pa, 55A and -600V, respectively. The TiC coatings deposition time was 120 min.

### 2.2 Coatings characterization.

The surface and cross-section micromorphology of the coatings was observed by scanning electron microscopy (quanta 200). The wear tracks morphology was analyzed by SEM and optical microscopy.

The hardness of the coatings were characterized by Vickers microhardness tester. The load and loading time were 50g and 10s, respectively.

The composition of the TiC coatings prepared by arc ion plating at different CH<sub>4</sub> flow rates was analyzed by XPS.

### 2.3 Tribological tests.

The tribological properties of TiC coatings were investigated by a ball-on-disc rotating tribometer against Al<sub>2</sub>O<sub>3</sub> (diameter 5mm) at RT, 200°C, 400°C and RT-400°C, respectively. The tests were performed with a sliding speed of 196 rpm under a load of 2.2 N. The rotational radius and sliding time were 3 mm and 20 min, respectively.

## 3. Results and Discussions

### 3.1 Morphology of TiAlN-Ag Coatings.

The surface micromorphology was shown as Figure 1(a), some typical particles generated from cathode arc were distributed on the coating surface. From Figure 1(b), the Ti middle layer of 1μm was clearly distinguished, The thickness of the coatings was about 6μm.

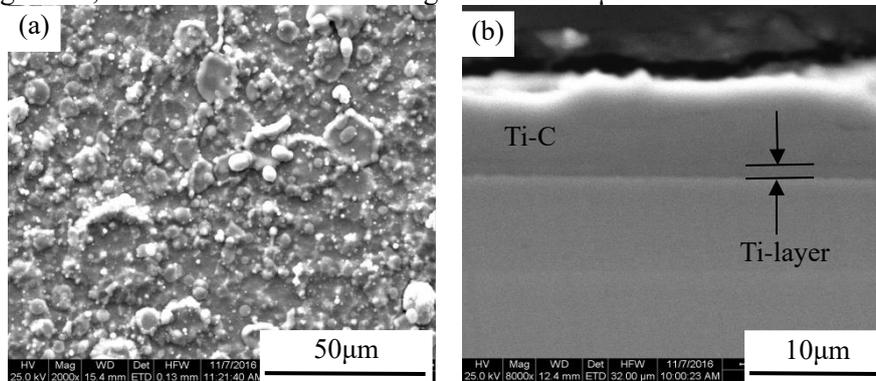


Figure 1 surface and cross-section micromorphology of TiC coatings  
(a) surface morphology (b) cross-section morphology

### 3.2 XPS analysis.

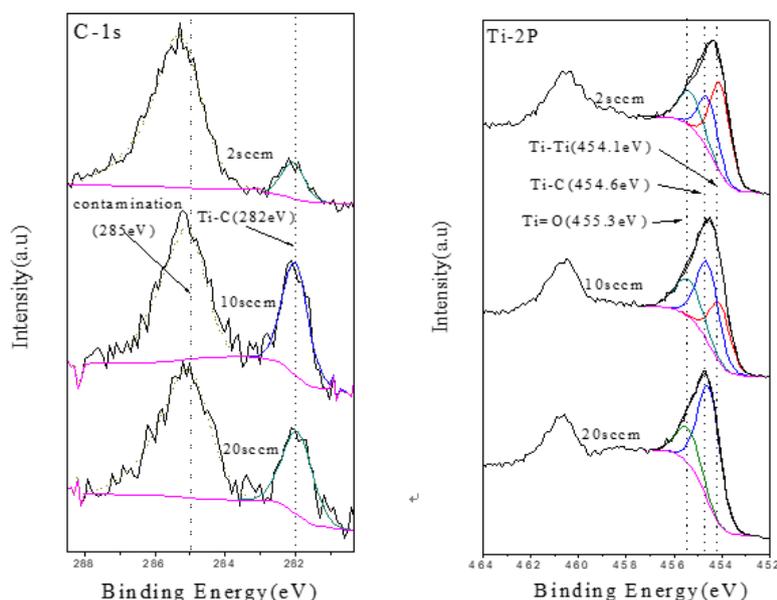


Figure 2 XPS spectra of C-1s, Ti-2p regions of samples with different CH<sub>4</sub> flow

Figure 2 shows the XPS spectra of C-1s and Ti-2p on the surface of the coating after Ar ion cleaning. During the test, the bond energy of contaminated carbon is about 285 eV, and the bond energy of C-1s in metal carbides is about 282 eV<sup>[11,12]</sup>. It can be seen from the C-1s spectrum that the Ti-C (282eV) peak of the coating prepared at a flow rate of 2sccm is weakest and the area is the smallest, which means that the Ti-C content in the coating is the lowest.

In the Ti-2p spectrum, the Ti-2p<sub>3/2</sub> peaks are located at three bond energies of Ti=O (455.3eV), Ti-Ti (454eV) and Ti-C (454.6eV)<sup>[11,12,13]</sup> after fitting peak processing. At the CH<sub>4</sub> flow rate of 2sccm and 10sccm, the coating still contains part of the metal Ti. This is mainly because the lower concentration of CH<sub>4</sub> is not sufficient to completely carbonize the Ti atoms emitted from the cathode target. It can be found that as the flow rate of CH<sub>4</sub> increases, the Ti-Ti peak intensity in the coating decreases continuously and the Ti-C peak intensity increases continuously. The bond energy of the Ti atom in the coating continuously transforms into higher energy. When the CH<sub>4</sub> flow rate increases to 20sccm, the peak of Ti-Ti (454eV) disappears and the Ti-C (454.6eV) peak continues to increase. This is mainly because the CH<sub>4</sub> concentration is enough to carbonize the Ti ions. Because of the high bond energy between the C atoms of Ti atoms, ionization of the cathode target surface needs more energy, so that the Ti ions emitted per unit time decrease, resulting in a decrease of the coating deposition rate. Ti=O can be detected in the coating prepared under the three flow conditions, probably due to the combination of O and Ti released from the inner wall of the vacuum chamber during the preparation of the coating<sup>[11]</sup>.

### 3.3 Tribological properties.

The hardness of the TiC coatings was about 2000Hv0.05, which was lower than that reported in the refereces<sup>[14]</sup>, and the reason may be ascribed to the partially carbonization of the Ti ions during the deposition process as depicted in Figure 3.

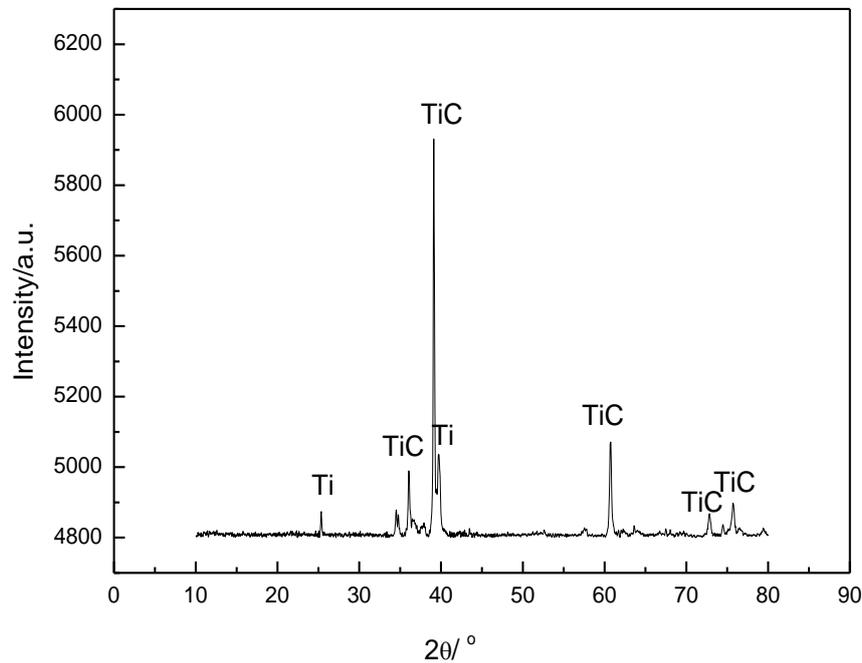


Figure 3 Typical XRD pattern of the TiC coating

The friction coefficient of TiC coatings against  $\text{Al}_2\text{O}_3$  balls at RT, 200°C, 400°C and RT-400°C was shown in Figure 4. The friction coefficient was most steady and had the lowest value of 0.57 at RT. When at 200°C and 400°C, the friction coefficient increased in 5 minutes, which resulted from that the water film was broken at higher temperature, due to the lower relative humidity. Then, the friction coefficient began to decrease, which maybe resulted from the lubricating  $\text{TiO}_x$  generated on the wear tracks due to the oxidation of coating<sup>[15]</sup>. The process was known as “running-in” stage<sup>[16]</sup>. When at 400°C, the friction coefficient was more steady with respect to that of 200°C, due to the higher ambient temperature<sup>[17]</sup>.

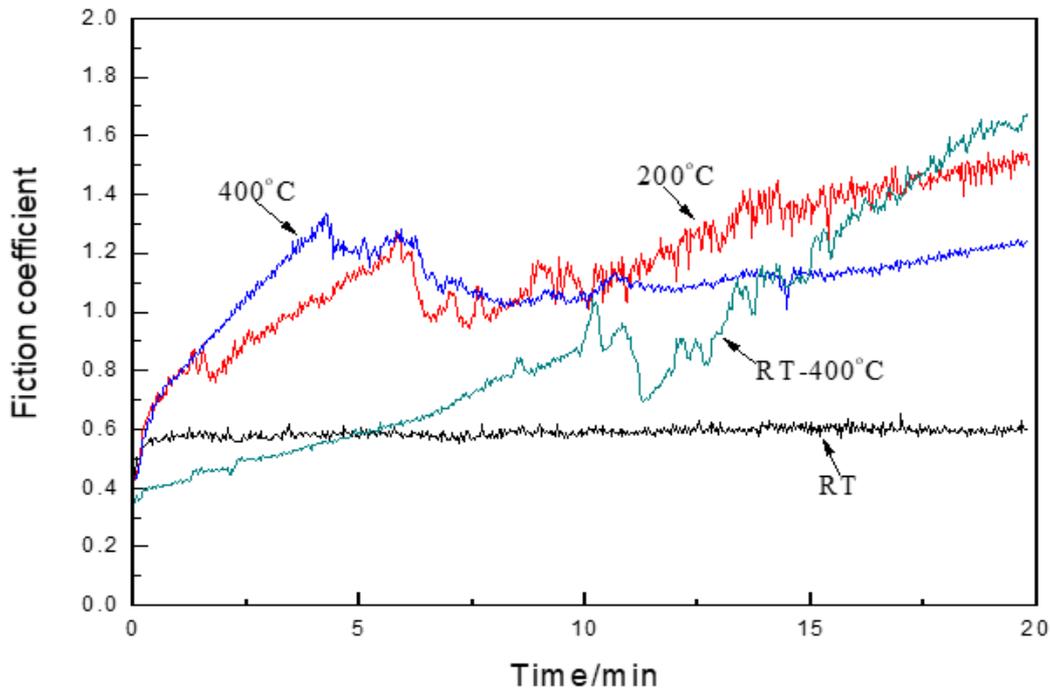


Figure 4 Function curves of friction coefficient and time of TiC coatings at different temperatures

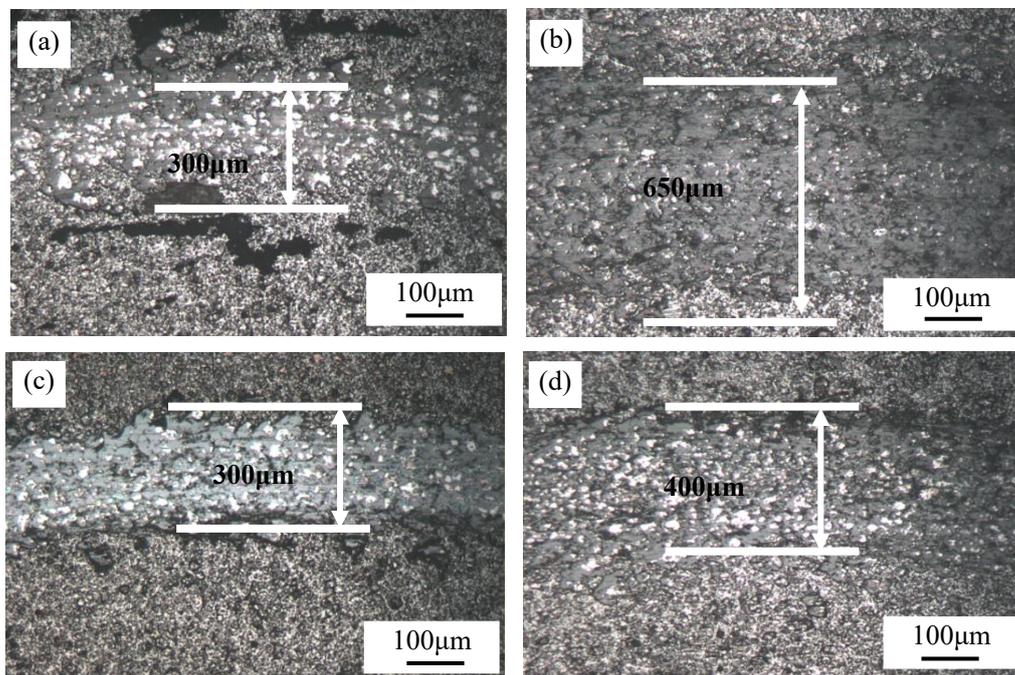


Figure 5 Wear tracks morphology of TiC coatings at different temperatures:  
(a) RT; (b) 200°C; (c) 400 °C; (d) RT-400°C

As shown in Figure 5, the wear tracks surface was rougher and the width was wider (650µm) at 200°C, which resulted from the larger wear tracks area of  $\text{Al}_2\text{O}_3$  balls due to the severe wear between  $\text{Al}_2\text{O}_3$  balls and coatings. Compared with 200°C, the wear tracks of TiC coatings at 400°C was more

narrow(300 $\mu$ m), which because of that the TiO<sub>x</sub> generated easier at the higher ambient temperature<sup>[18]</sup>. When at RT-400°C, the “ running-in” stage time was longer, which the friction increased with the decreasing relative humidity, due to that the coatings temperature increased slowly with the increasing ambient temperature.

#### 4. Conclusions

- (1) TiC coatings were deposited by arc ion plating. The thickness of the coatings was about 6 $\mu$ m.
- (2) The friction coefficient was lowest and the wear track was the most narrow at RT, which means the TiC coatings have the best wear resistance at RT. The severe wear occurred at 200°C and RT-400°C, due to the lower relative humidity. The friction coefficient fluctuated largely, and the wear tracks were wider. The wear tracks were more narrow at 400°C due to the lubricating TiO<sub>x</sub> generated at higher temperature.

#### Acknowledgements

The authors express their gratitude to the financial support of the National Natural Science Foundation of China (No.51365041).

#### References

- [1] Rasool G, Mridha S, Stack M M. Mapping wear mechanisms of TiC/Ti composite coatings[J]. *Wear*, 2015, 328-329: 498–508.
- [2] Du B, Wang X, Zou Z. Microstructure and tribological behavior of laser in situ synthesized TiC-reinforced Fe-based composite coatings[J]. *Tribology Letters*, 2011, 43: 295-301.
- [3] Ushashri K, Masanta M. Hard TiC coating on AISI304 steel by laser surface engineering using pulsed Nd:YAG laser[J]. *Materials and Manufacturing Processes*, 2015, 30: 730-735.
- [4] Wang F ZH, Ma W C. Vapor deposition technique[M]. Beijing. China Machine Press,2006:10(in Chinese).
- [5] [F Santerre, M Chaker, et al. Properties of TiC thin films grown by pulsed laser deposition[J]. *Applied Surface Science*, 1999, 148(1–2): 24–33.
- [6] Delplancke-Ogletree M, Monteiro O R. Wear behavior of diamond-like carbon/metal carbide multilayers[J]. *Surface and Coatings Technology*, 1998, 108-109: 484-488.
- [7] Fouad A, Abdul K Rumaiz, S Ismat Shah. Reactive sputtering of titanium in Ar/CH<sub>4</sub> gas mixture: Target poisoning and film characteristics[J]. *Thin Solid Films*, 2009, 517: 5689–5694.
- [8] Cai Y, Wang R Y, Liu H D, et al. Investigation of (Ti:N)-DLC coatings prepared by ion source assisted cathodic arc ion-plating with varying Ti target currents[J]. *Diamond and Related Materials*, 2016, 69: 183-190.
- [9] Shu Xiao, Zhongzhen Wu, Liangliang Liu, et al. Protection against lead-free solder in wave-soldering by Ti/TiC coatings prepared by filtered cathodic arc deposition[J]. *Surface and Coatings Technology*, 2017, 312: 7-12.
- [10] Xia Liu, Yulong An, Shuangjian Li, et al. .An assessment of tribological performance on NiCoCrAlYTa coating under corrosive environments[J]. *Tribology International*, 2017, 115: 35-44.
- [11] Chaliyawala H A, Gupta G, Kumar P, et al. Structural and mechanical properties of reactively sputtered TiAlC nanostructured hard coatings[J]. *Surface & Coatings Technology*, 2015: 276: 431-439.
- [12] Lindquist M, Wilhelmsson O, Jansson U, et al. Tribofilm formation and tribological properties of TiC and nanocomposite TiAlC coatings[J]. *Wear*, 2009, 266: 379-387.
- [13] Li H, Zhang G, Wang L. The role of tribo-pairs in modifying the tribological behavior of the Mo S<sub>2</sub>/Ti composite coating[J]. *Journal of Physics D: Applied Physics*, 2016, 49(9): 095501.
- [14] Leiste H, Dambacher U, Ulrich S, et al. Microstructure and properties of multilayer coatings with covalent bonded hard materials[J]. *Surface and Coatings Technology*, 1999, 116–119: 313-320.

- [15] Ajikumar P K, Vijayakumar M, Kamruddin M, et al. Effect of reactive gas composition on the microstructure, growth mechanism and friction coefficient of TiC overlays[J]. *International Journal of Refractory Metals and Hard Materials*, 2012, 31: 62-70.
- [16] Haitao Chi, Longtao Jiang, Guoqin Chen, et al. The tribological behavior evolution of TiB<sub>2</sub>/Al composites from running-in stage to steady stage[J]. *Wear*, 2016, 368–369.
- [17] Deng Jianxin, Zhang Hui, Wu Ze, et al. Unlubricated friction and wear behaviors of Al<sub>2</sub>O<sub>3</sub>/TiC ceramic cutting tool materials from high temperature tribological tests[J]. *International Journal of Refractory Metals and Hard Materials*, 2012, 35: 17-26.
- [18] Parchovianský M, Balko J, Švančárek P, et al. Mechanical properties and sliding wear behaviour of Al<sub>2</sub>O<sub>3</sub>-SiC nanocomposites with 3–20 vol% SiC[J]. *Journal of the European Ceramic Society* 2017, 37(14): 4297-4306.