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Dry Sliding Behaviour of AlCrN and TiN Coatings

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Abstract. This paper examines the friction behaviour of AlCrN and TiN PVD coatings in atmospheric air and vacuum using a ball-on-disc and a reciprocating tribotesters. Comparative study on the coating sliding in air and in high vacuum environment provides important insight on the effect of oxidation on the friction behaviour of the coatings. Other important factors such as load, sliding velocity, temperature effects on the frictional behaviour of these coatings were also investigated. In the ball-on-disc tests carried out in vacuum, (i) TiN gave lower coefficient of friction (COF) than AlCrN, indicating that TiN was more lubricous, (ii) higher speed resulted in lower COF, and (iii) the COF of both coatings were lower than that produced in air. In ambient air, (i) AlCrN gave lower COF than TiN with high wear debris retention on the sliding interface due to the effect of oxidation, and (ii) higher speed resulted in lower COF, similar to that observed in vacuum. In the reciprocating tests, at low load, increasing the temperature from room temperature to 150 °C resulted in a reduction in the COF. However, at high load, the temperature virtually did not affect the COF. Higher nominal load resulted in lower COF while higher speed resulted in higher COF.

Introduction

The factors controlling the friction behaviour of materials include mechanical stresses, temperature and oxidation phenomena [1]. The complexity of sliding friction arises from the fact that all these three controlling factors are interrelated and influenced by load and sliding velocity as well as the sliding environment. The chemical composition has significant effect on the type and physical characteristics of the tribolayer formation which in turn control the friction behaviour and thus the wear rate of the coating [2-3]. This layer plays a protective role as it reduces material loss rate by reducing or eliminating direct contact of the two surfaces. In ambient environment, the type of layer formed is typically in oxide form, yielded from the reaction between the coating and oxygen. Hence, the partial pressure of oxygen during sliding is important for an effective oxidation process since the rate of oxidation is controlled by the diffusion of oxygen into the metal lattice.

TiN started the success story of nitride hard coatings in various dry and high-speed cutting tool applications about thirty years ago due to its high hardness and wear resistance. However, its poor oxidation resistance at high temperature is the main limitation for many applications. In recent years, AlCrN has been reported as a promising coating as it exhibited good hardness and better resistance to chemical breakdown than TiAlN, TiCN, and TiN coatings. It had been found that the high oxidation resistance of AlCrN was due to the formation of dense oxide mixture layers of Cr_2O_3 and Al_2O_3 at the surface, preventing further oxidation that could decompose the cubic AlCrN phase [4]. Many researchers demonstrated that AlCrN coating, which had been developed recently, gave better wear protection and exhibited lower friction coefficient than TiN and TiAlN coatings. Gant et al. [5] observed that under ambient air sliding using a pin-on-disc machine, AlCrN produced lower COF compared to TiAlN and TiN, and the type of debris formed was governed by the atmosphere.

Mo et al. [6] concluded that hard chromium oxide formed as a result of tribo-chemical reaction of chromium with the oxygen accounted for the high abrasion resistance and low friction coefficient of AlCrN coating. This paper aims to investigate the friction behaviour of this new and conventional type of coating –AlCrN and TiN, respectively – under different factors of load, sliding speed, temperature and oxidation effects. The experimental results obtained in vacuum and air give valuable information on the role played by the formation of oxide on the friction coefficient produced during sliding.

Experimental

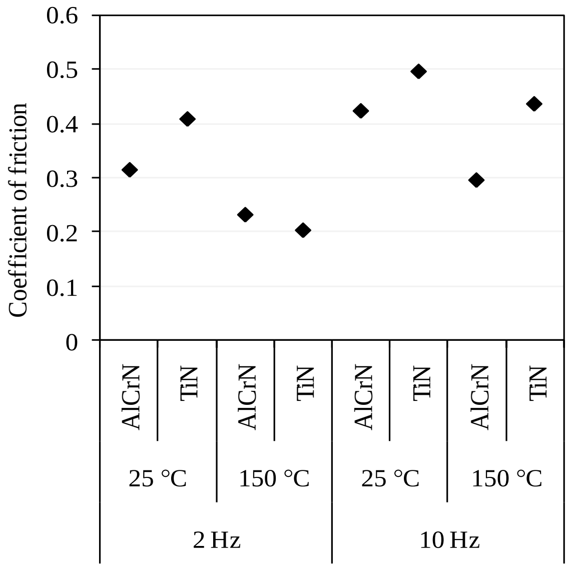
Cemented carbide (6wt% Co and 94% WC; grade ISO K10) with a hardness 1600 HV was used as the substrate material for the coatings. Uncoated cemented carbide balls were used to slide on (i) the coated carbide plates with the dimensions of 10 mm × 10 mm × 4 mm in the reciprocating sliding tests, and (ii) coated discs with 100 mm diameter and 8 mm thickness in the ball-on-disc tests. Prior to coating deposition, the specimens were polished to a surface roughness of less than 0.04 µm. Two types of commercially available coatings of AlCrN and TiN were deposited using a standard Balzers PVD arc technology by Oerlikon Balzers Coating Singapore Pte. Ltd., Singapore.

The reciprocating tests were carried out on a Ducom TR-285-M8 Linear Reciprocatory Tribometer using a normal load of 5 and 20 N, frequency of 2 and 10 Hz, temperature of 25 and 150 °C, stroke range of 2 mm with total testing time of 30 minutes. Ball-on-disc test were carried out on a Ducom TR-20EV-M3 wear tester using a speed of 2.5 and 10 m/min, normal load of 5N, wear track diameter of 80 mm and sliding distance of 200 m in ambient air and high vacuum (1×10^{-5} Pa). The pin-on disc machine had a LVDT sensor with 1 µm accuracy to measure the displacement of the pin during sliding. The COF was continuously measured throughout the tests by a load cell.

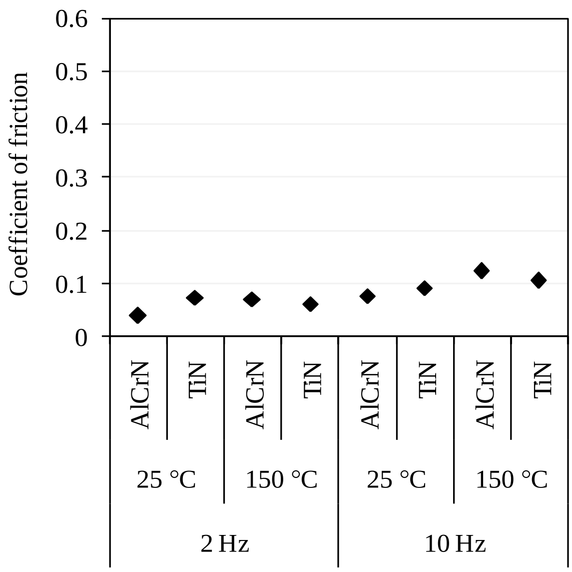
Results and Discussion

Reciprocating Tests. Fig. 1 shows the steady state COF of AlCrN and TiN obtained under various nominal load, sliding speed and temperature. At the nominal load of 5 N, (i) the COF reduced with an increase in the temperature from 25 to 150 °C, and increased with an increase in the sliding frequency from 2 Hz to 10 Hz and (ii) the AlCrN coating exhibited lower COF than TiN (Fig. 1(a)). The increase in the COF due to an increase in the sliding frequency could be attributed to an increase in the hardness by the very high strain rate generated. Increasing the nominal load from 5 to 20 N resulted in a significant reduction in the COF. At 20N, (i) the COF produced on both coatings at 25 and 150^0C were essentially the same and (ii) only a marginal increase in COF was measured as the sliding frequency was increased from 2 to 10 Hz.

Ball-on-Disc Tests. Fig. 2 shows the steady state COF of AlCrN and TiN in vacuum and ambient air under different sliding speeds. The COF values obtained in vacuum were much lower than those obtained in air. The marked difference could be attributed to the effect of the oxides formed at the interface. In the sliding tests involving TiAlN and AlCrN coatings under benign conditions, i.e. low speeds (<5 m/min) and loads (<20 N), Mo et al. [6] found that oxides such as Cr_2O_3, Al_2O_3 and TiO_2 were formed and the wear resistance and frictional behaviour of the coatings were governed by the type of oxide formed. It is postulated that the hard tribo-oxide layer formed on the wear track resulted in an increase in the COF [7]. This shows that the non-oxidized coating is more lubricous. High strain rate caused by high sliding speed could produce strain hardening effect, giving rise to high COF. On the other hand, increasing the speed increased the local temperature, leading to a reduction in the hardness of the coating and thus the COF. The fact that the COF reduced with an increase in the speed shows that the later effect on the COF was more dominant. In vacuum, AlCrN gave higher COF than the TiN coating. It is interesting to note that in air, the COF of AlCrN was lower. This results shows that oxidized AlCrN is more lubricous than the oxidized TiN.



(a)



(b)

Fig. 1: The steady state COF of AlCrN and TiN obtained in the recripocrating tests using a constant nominal load of (a) 5 N and (b) 20 N.

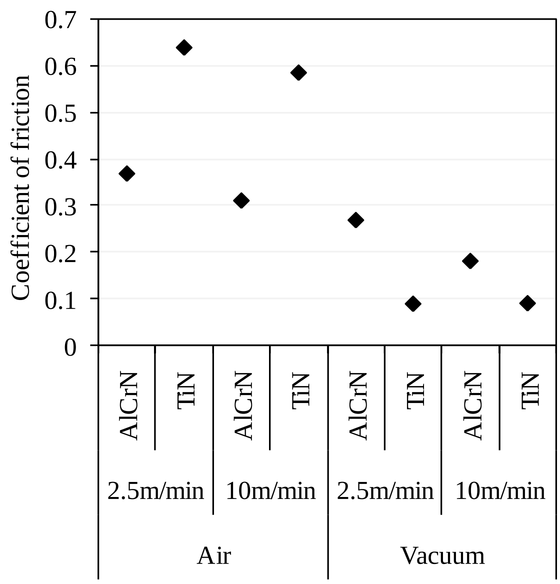


Fig. 2: The steady-state COF of AlCrN and TiN coating under ambient air and high vacuum environment at sliding speeds of 2.5 m/min and 10 m/min.

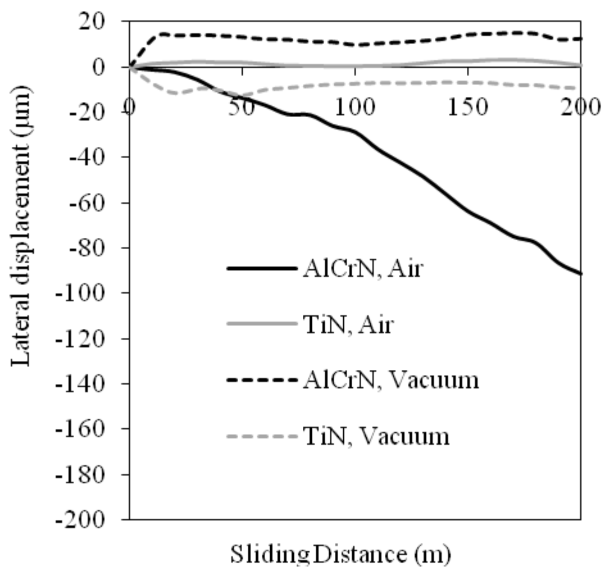
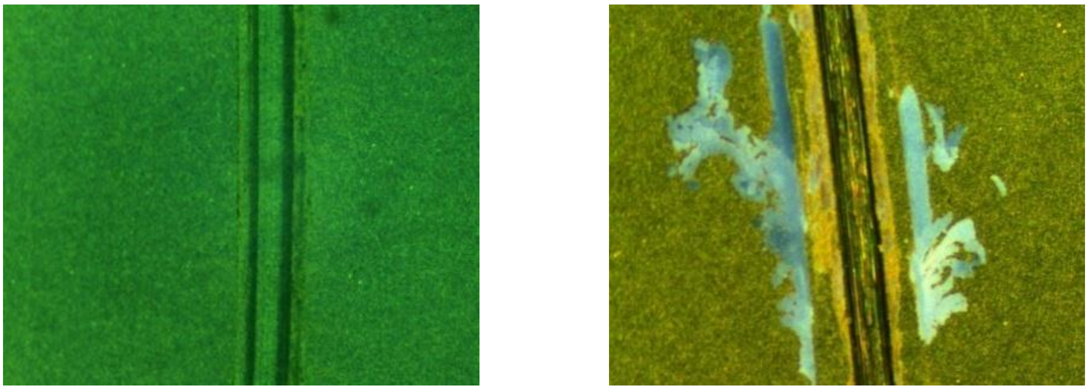


Fig. 3: The ball displacement at the sliding interface in ambient air at 2.5 m/min.

Fig. 3 shows the vertical displacement of the ball during sliding. Progressive negative displacement was observed in the test carried out on AlCrN in ambient air. This implies a continuous lift up of the ball from the initial position during sliding. In Fig. 4, wear debris was observed along the edge of the sliding track on TiN but was not observed on AlCrN sliding track due to higher degree of wear debris being retained at the interface during sliding. Thus, the observed difference in the displacement behaviour between the two coatings in ambient air was also due to different type of oxidized wear debris generated which could have make significant contribution to the COF.



(a) (b)

Fig. 4: Optical images of the wear track on the (a) AlCrN and (b) TiN coated discs tested in ambient air at 2.5 m/min.

Conclusions

- The atmospheric condition and sliding parameters significant affect the COF of AlCrN and TiN.
- In the ball-on-disc tests carried out in vacuum, the COF of TiN was lower than AlCrN, indicating that TiN was more lubricious. However, in ambient air, AlCrN gave lower COF than TiN, and the COF of both coatings was higher than that produced in vacuum. The frictional behaviour was not only governed by the type of oxide formed but also by the nature of the debris formed. Higher speed resulted in lower COF.
- In the reciprocating tests using a nominal load of 5 N, increasing the temperature from room temperature to 150 °C resulted in a reduction in the COF. However, at the higher load of 20 N, the temperature virtually did not affect the COF. Higher nominal load resulted in lower COF while higher speed resulted in higher COF.

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