AN INVESTIGATION OF FRETTING WEAR BEHAVIOUR OF A TERNARY (Zr,Hf)N COATING

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ABSTRACT

In this study, the wear behaviors of ZrN and (Zr, 21wt.% Hf)N coatings, deposited on hardened AISI D2 cold work tool steel by a arc-physical vapor deposition (PVD) technique were examined by a fretting wear tester. Wear tests were conducted by rubbing Al\textsubscript{2}O\textsubscript{3} and steel balls on the surfaces of the coatings under dry sliding condition. Characterization tests showed that, the hardness and the surface roughness of the examined coatings were almost the same. However, addition of 21wt.% Hf to ZrN improved the adhesion between the coating and the substrate. Fretting wear tests conducted by rubbing both Al\textsubscript{2}O\textsubscript{3} and steels balls revealed that, addition of 21wt.% Hf achieved an increment in the wear resistance of the ZrN coating. Steel ball encouraged oxidative wear, while wear of the coatings by Al\textsubscript{2}O\textsubscript{3} ball progressed by coating removal.

INTRODUCTION

Thin ceramic coatings are of interest in a number of technological fields because of physical, chemical and mechanical properties. Among these materials, nitride and carbide coatings are widely used because of their superior bonding to the substrate and excellent resistance to wear, erosion and corrosion. One of the commercially used and successfully applied thin ceramic coating technique is Physical Vapor Deposition (PVD). Especially, hard nitride coatings deposited by means of PVD technique are extensively used in many types of cutting operation, where they enhance tool life, improve surface finish and increase productivity [1-5].

Today, new thin ceramic coatings such as ZrN, CrN and HfN, continue to attract attention and tools with these coatings are on the market. However, alternating coatings are manufactured by deposition of two or more components to enhance adhesion and/or hardness and wear resistance [6-11].

Fretting wear occurs when two normally loaded surfaces suffer oscillatory motion with amplitudes less than 150 \(\mu\)m [12]. The fretting wear behavior of materials in vibrating contacts depend on the mechanical contact conditions, environmental conditions and materials properties making wear a complex system property [12-15]. In this study, we aimed to investigate fretting wear performance of a ZrN and a new (Zr, 21wt.% Hf)N coatings deposited on a hardened AISI D2 cold work tool steel by arc-PVD technique.

EXPERIMENTAL

The characteristics of the coatings were determined by X-ray diffraction (XRD) analysis, scanning electron microscopy (SEM) examinations, hardness and scratch tests as well as roughness and thickness measurements. The composition and microstructure of the coatings were determined by Scanning Electron Microscopy (SEM) equipped with EDS attachment. The crystal structure of the coatings was analyzed by X-ray diffractometer with thin film attachment using CuK\(_\alpha\) radiation. The coating thickness was determined by ball crating technique. Surface roughness of the coatings was examined with an optical profilometer. Hardness of the coatings was measured by ultramicrohardness tester. In order to investigate adhesion properties of ZrN and (Zr, 21wt.% Hf)N coatings, scratch tests were used.

Fretting wear tests were conducted on a fretting wear tester under dry sliding conditions at ambient atmosphere condition (20\(\pm\)1 °C and 50\(\pm\)5 %RH). Wear tests were performed by applying normal loads of 3 and 4.5 N to the samples with a 10 mm diameter Al\textsubscript{2}O\textsubscript{3} and steel (AISI 52100-55 HRC) balls. Displacement stroke and frequency were selected as 100 \(\mu\)m and 10 Hz, respectively. Each test consisted of 18000 cycles. After the test, the wear scars developed on the coatings and were detected by a light optical microscope (LOM) and a SEM. The wear volume (\(V\)) of the coatings and the balls were calculated by measuring the mean width (2a) of the wear scars by using following equation [15]:

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V = \frac{\pi a^4}{4R}
\]

where \(R\) is the ball radius (\(R = 5\) mm).

RESULTS AND DISCUSSION

X-ray analysis of the coatings showed that the XRD patterns of the examined coatings were consisted of only peaks of ZrN coating. These coatings’ crystal structure were identified as cubic system with Hf dissolved in ZrN to form solid solution even up to 21 wt.% of the peaks of the XRD peaks.
patterns of (Zr, Hf)N coatings were shifted to smaller angles due to the substitution of Zr by Hf.

The surface roughness ($R_s$) and thickness of the examined coatings were about 0.2 µm and 2 µm, respectively. According to the surface roughness measurements in terms of $R_s$, addition of Hf to ZrN coating did not cause any significant change in surface roughness under equivalent PVD conditions. Hardness measurements revealed that the hardness of the examined coatings varied in between 38 and 40 GPa. In the case of coatings examined in this study, addition of Hf to ZrN formed complete solid solution according to the results of XRD analysis. When the hardness of ZrN and (Zr, 21 wt.% Hf)N coatings are compared, very little and unnoticed effect of solid solution hardening can be declared by incorporation of 21% Hf into the ZrN. Since the atomic radius of Zr and Hf are similar (1.616 and 1.442 Å, respectively), solid solution strengthening mechanism does not have a noticeable effect on the hardness of (Zr, Hf)N coatings up to 21 wt.% Hf addition.

Scratch tests reveal that ZrN coatings showed heavy conformal cracking within the track, when compared to (Zr, 21 wt.% Hf)N coating. Critical cracking loads of ZrN and (Zr, 21 wt.% Hf)N were found as 45 and 60 N, respectively and also failure mechanism appeared as compressive cracking mode. Scratch tests showed that, alloying of ZrN with Hf improved the adhesion between the coating and substrate by improving the cracking resistance of the coating.

The results of the fretting wear test conducted by Al$_2$O$_3$ and steel balls on the ZrN and (Zr, 21% Hf)N coatings showed that wider wear scars were formed on ZrN coating than that of (Zr, 21 wt.% Hf)N coating. Fretting wear tests carried out by Al$_2$O$_3$ and steel balls revealed that alloying of ZrN with Hf resulted in formation of smaller wear volume on both the coatings and the balls. When compared to ZrN coatings, the wear volumes of (Zr, 21 wt.% Hf)N coating against Al$_2$O$_3$ balls are about 45% and 58% smaller. In the case of using the steel balls, the wear volumes of ZrN coatings are about 32% and 42% larger than that of (Zr, 21 wt.% Hf)N coatings. On the other hand, the wear volumes of counterface materials are proportional to the wear volumes of the examined coatings.

SEM examination of the wear scars produced by Al$_2$O$_3$ and steel balls showed that on the test against Al$_2$O$_3$ ball, wear progress by gradual removal of the coating and also some cracks formed on the wear scars of the examined coatings. On the other hand, rubbing of steel ball caused adhesive and oxidative damage on coatings.

CONCLUSIONS

Following conclusions can be drawn according to the results of fretting wear tests conducted on ZrN and (Zr, 21 wt.% Hf)N coatings under dry sliding conditions by utilizing Al$_2$O$_3$ and steel balls.

1. Fretting wear tests conducted by Al$_2$O$_3$ and steel balls revealed that 21 wt.% Hf caused a pronounced improvement in the wear resistance of (Zr, Hf)N coatings. Rubbing of the Al$_2$O$_3$ and steel balls, (Zr, 21 wt.% Hf)N coating yielded at least 45% and 32% smaller wear volume when compared to ZrN coatings, respectively.

2. During wear testing, Al$_2$O$_3$ ball removed the coatings and encouraged oxidation of the coating and the substrate. Wear of the coatings against steel ball is progressed by mass transfer from the ball and oxidation.

3. During fretting wear testing, steel balls were subjected to heavier wear than Al$_2$O$_3$ balls. The wear of both balls were less when rubbing on (Zr, 21 wt.% Hf)N coating compared to ZrN coating.

REFERENCES