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Tool Wear of Aluminum/Chromium/Tungsten-Based-Coated Cemented Carbide Tools in Cutting Sintered Steel

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***Abstract*—**In this study, to clarify the effectiveness of an aluminum/chromium/tungsten-based-coated tool for cutting sintered steel, tool wear was experimentally investigated. The sintered steel was turned with the (Al60,Cr25,W15)N-, (Al60,Cr25,W15)(C,N)- and (Al64,Cr28,W8)(C,N)-coated cemented carbide tools according to the physical vapor deposition (PVD) method. Moreover, the tool wear of the aluminum/chromium/tungsten-based-coated item was compared with that of the (Al,Cr)N coated tool. Furthermore, to clarify the tool wear mechanism of the aluminum/chromium/tungsten-coating film for cutting sintered steel, Scanning Electron Microscope observation and Energy Dispersive x-ray Spectroscopy mapping analysis were conducted on the abraded surface. The following results were obtained: (1) The wear progress of the (Al64,Cr28,W8)(C,N)-coated tool was the slowest among that of the five coated tools. (2) Adding carbon (C) to the aluminum/chromium/tungsten-based-coating film was effective for improving the wear-resistance. (3) The main wear mechanism of the (Al60,Cr25,W15)N-, the (Al60,Cr25,W15)(C,N)- and the (Al64,Cr28,W8)(C,N)-coating films was abrasive wear.

***Keywords*—**Cutting, physical vapor deposition coating method, tool wear, tool wear mechanism, sintered steel.

I. Introduction

An aluminum/chromium-based-coating film, namely (Al,Cr)N coating film, has been developed. The aluminum/chromium-based-coated tool was evaluated through the machining of sintered steel, and exhibited markedly improved performance [1]. Therefore, the effectiveness of the aluminum/chromium-coating film is apparent when cutting hardened sintered steel [2]. This result clarified that the wear progress of the (Al,Cr)N coated cemented carbide tool was slower than that of the (Ti,Al)N coated cemented carbide tool, and (Al,Cr)N coated cemented carbide is an effective tool material for cutting hardened sintered steel [2]. However, the results of our study indicate that the critical scratch load, which is the measured value by the scratch test, of the (Al,Cr)N coating film is 77 N and the micro-hardness is 2760 $HV_{0.25N}$. Therefore, in order to improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, cathode material of an aluminum/chromium/tungsten-target was used to add tungsten (W) to the cathode material of the aluminum/ chromium-target [3]. The hardened sintered steel was turned with the aluminum/chromium/tungsten-based-coated cemented carbide tool. Compared with commercial (Al,Cr)N and (Ti,Al)N coated cemented carbide tools, the wear progress of the aluminum/chromium/tungsten-based-coated tool was slower than that of the (Al,Cr)N coated tool [3]. Furthermore, the wear progress and the wear mechanism of the aluminum/chromium/tungsten-based-coated tool were investigated [4], [5]. However, the wear progress and the tool wear mechanism of aluminum/chromium/tungsten-based-coated cemented carbide in cutting sintered steel have not been clarified.

In this study, to clarify the wear progress and the tool wear mechanism of the aluminum/chromium/tungsten-based-coated tool for cutting sintered steel, the sintered steel was turned. Scanning Electron Microscope (SEM) observation and Energy Dispersive x-ray Spectroscopy (EDS) mapping analysis were conducted on the abraded surface.

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II. Experimental Procedure

Coating deposition was performed by an arc ion plating system (KOBE STEEL, LTD. AIP-S40). Various coating films were deposited on WC-Co cemented carbide ISO K10.

We measured the thickness, hardness and scratch strength (critical scratch load measured by a scratch tester) of the various coating films formed on the surface of the substrate, which was a cemented carbide ISO K10 by the arc ion plating process.

The work material used was sintered steel. The chemical composition and mechanical properties of the sintered steel are shown in Table I. The tool material of that substrate was cemented carbide, and four types of PVD coated cemented carbide were used as shown in Table II. Namely, the coating films used were (Al60,Cr25,W15)N-, (Al60,Cr25,W15)(C,N)-, (Al64,Cr28,W8)(C,N)- and (Al,Cr)N-coating film. The (Al60,Cr25,W15)N-, (Al60,Cr25,W15)(C,N)- and (Al64,Cr28,W8)(C,N)-coating film are a new type of coating film whereas (Al,Cr)N is a conventional and commercial type. The configurations of the tool inserts were ISO TNGA160408. The insert was attached to a tool holder MTGNR2525M16. In this case, the tool geometry was (-6, -6, 6, 6, 30, 0, 0.8 mm). The turning tests were conducted on a precision lathe (Type ST5, SHOUN MACHINE TOOL Co., Ltd.) by adding a variable-speed drive. The driving power of this lathe is 7.5/11kW and the maximum rotational speed is 2500 min^{-1}. Sintered steel was turned under the cutting conditions shown in Table III. The tool wear was investigated.

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TABLE I
CHEMICAL COMPOSITION AND PROPERTIES OF THE SINTERED STEEL

Chemical composition [mass %]				
C	Cu	Ni	Mo	Fe
0.3 - 0.7	1 - 2	3 - 5	0.2 - 0.8	Bal.

Properties	
Hardness	Density
70 HRB (129 HB)	7.1 Mg/m^3

TABLE II
TOOL MATERIAL IN TURNING OF HARDENED SINTERED STEEL

Tool type	Tool material
Coated tool	Substrate: Cemented carbide ISO K10 Coating layer: (Al60,Cr25,W15)N, (Al60,Cr25,W15)(C,N), (Al64,Cr28,W8)(C,N), (Al,Cr)N

TABLE III
CUTTING CONDITIONS

Cutting speed	5.0 [m/s]
Feed speed	0.1 [mm/rev]
Depth of cut	0.1 [mm]
Cutting method	Dry

III. RESULTS AND DISCUSSION

In cutting the sintered steel using the four types of coated tools, the wear progress was investigated. The wear progress is shown in Fig. 1. The wear progress of the three types of aluminum/chromium/tungsten-based-coated tool is slower than that of the (Al,Cr)N coated tool. This indicates that the aluminum/chromium/tungsten-based-coating film is formed on the aluminum/chromium/tungsten-target by adding tungsten (W) to the aluminum/chromium-target and can be used for cutting the sintered steel.

As compared to the wear progress of the (Al60,Cr25,W15)N- and the (Al60,Cr25,W15)(C,N)-coated tool, the wear progress of the (Al60,Cr25,W15)(C,N)-coated tool is slightly slower than that of the (Al60,Cr25,W15)N-coated tool, so SEM observation was conducted on the worn surface.

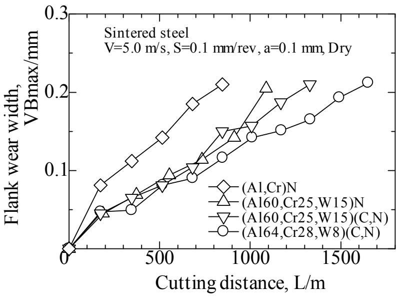
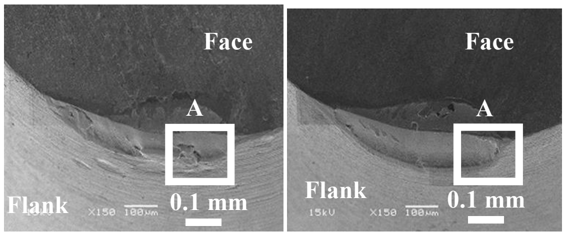


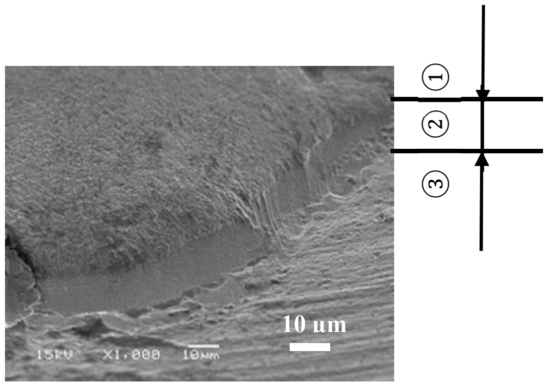
Fig. 1 Wear progress of various coated cemented carbide at a cutting speed of 5.0 m/s

Fig. 2 shows the tool wear in turning sintered steel with the two types of aluminum/chromium/tungsten-based-coated tools, namely the (Al60,Cr25,W15)N- and the (Al60,Cr25,W15)(C,N)-coated tools at a cutting speed of 5.0 m/s, a feed rate of 0.1 mm/rev and a depth of cut of 0.1 mm.

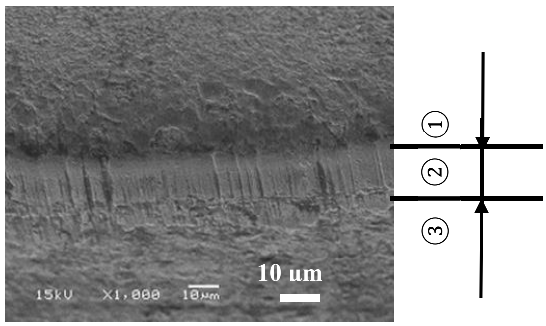
There was a crater on the rake face, and no remarkable adhesion on either the rake face or flank. No remarkable flaking of the coating layer was found either as shown in Fig. 2 (i).



(a) (Al60,Cr25, W15)N, Cutting distance:1.1 km
(b) (Al60,Cr25,W15)(C,N), Cutting distance:1.3 km.
(i) Tool wear



(a) (Al60,Cr25, W15)N, Cutting distance:1.1 km



(b) (Al60,Cr25,W15)(C,N), Cutting distance:1.3 km.
(ii) Details of A shown in (i)

①: Abraded surface of substrate
②: Abraded coating film
③: Surface of coating film

Fig. 2 Tool wear at a cutting speed of 5.0 m/s, feed rate of 0.1 mm/rev, depth of cut of 0.1 mm and cutting method of dry cutting

Figs. 2 (ii) (a) and (b) show the details of A shown in Figs. 2 (i) (a) and (b), respectively. In these figures, surface "①" is the abraded surface of the substrate, surface "②" is the abraded surface of the coating film and surface "③" is the surface of the coating film. On the abraded surface of both the (Al60,Cr25,W15)N- and the (Al60,Cr25,W15)(C,N)-coating film indicated by "②" shown in Figs. 2 (ii) (a) and (b), many striae scratched by a hard material were evident. Therefore, the main wear mechanism of the aluminum/chromium/tungsten-based-coating film was abrasive wear. In the case of abrasive wear, the wear-resistance of the coating film often depends on both the hardness and critical scratch load of the coating film. That is, a coating film with both higher hardness and stronger critical scratch load has good wear-resistance. So, the characteristics of the coating films were investigated. The results are shown in Table IV. Table IV shows the characteristics of the aluminum/chromium/tungsten-based-coating films. These are compared among the three types of coating films, namely (Al,Cr)N-, (Al60,Cr25,W15)N- and (Al60,Cr25,W15) (C,N)-coating film. The thickness of the three types of coating films was 3.0 µm, 4.4 µm or 3.3 µm, respectively. However, the micro-hardness of the (Al60, Cr25,W15)N- or the (Al60, Cr25,W15)(C,N)-coating film is 3110 $HV_{0.25N}$ or 3080 $HV_{0.25N}$, respectively. That is, the micro-hardness of the three types of aluminum/chromium/ tungsten-based-coating film for 3100 $HV_{0.25N}$ is higher than that of the (Al,Cr)N 2760 $HV_{0.25N}$. Therefore, the wear progress of the (Al,Cr)N coated tool was faster than that of the (Al60,Cr25,W15)N- or the (Al60,Cr25,W15)(C,N)-coated tool as shown in Fig. 1.

Comparing the critical scratch load of the (Al60,Cr25, W15)N- and the (Al60,Cr25,W15)(C,N)-coating film, the critical scratch load of the (Al60,Cr25,W15)(C,N)-coating film over 130 N is larger than that of the (Al60,Cr25,W15)N-coating film 81 N. Therefore, the wear progress of the (Al60,Cr25, W15)(C,N)-coated tool was slightly slower than that of the (Al60,Cr25,W15)N-coated tool as shown in Fig. 1.

Thus, adding carbon (C) to the aluminum/chromium/ tungsten-based-coating film is effective for improving the wear-resistance.

TABLE IV
CHARACTERISTICS OF THE COATING FILMS [5]

Coating material	Thickness of film [µm]	Micro-hardness [$HV_{0.25N}$]	Critical scratch load* [N]
(Al,Cr)N	3.0	2760	77
(Al60,Cr25,W15)N	4.4	3110	81
(Al60,Cr25,W15)(C,N)	3.3	3080	>130
(Al64,Cr28,W8)(C,N)	3.1	3050	>130

*: Measured value by scratch test

The wear progress of the (Al64,Cr28,W8)(C.N)- coated tool was slower than that of the (Al60,Cr25,W15)(C,N)-coated tool as shown in Fig. 1. The reason for this is as follows. Fig. 3 shows the tool wear of the (Al64,Cr28,W8)(C,N)-coated tool. In Fig. 3 (a), there is a crater on the rake face, and no remarkable adhesion on either the rake face or flank. No remarkable flaking of the coating layer is found either as shown in Fig. 3 (a). Moreover, Fig. 3 (b) shows the details of A shown in Fig. 3 (a), on the abraded surface of (Al64,Cr28,W8) (C,N)-coating film indicated by "②" shown in Fig. 3(a), many striae scratched by a hard material are evident. Therefore, the main wear mechanism of the (Al64,Cr28,W8)(C,N)-coating film was abrasive wear. That is, as a result of the SEM observation, the tool wear mechanism of both the (Al60,Cr25,W15)(C,N)- and the (Al64,Cr28,W8)(C,N)-coating films was abrasive wear.

From the results as shown in Table IV, the thickness of coating of the (Al64,Cr28,W8)(C.N)-coating film is about 3 µm, which is the same as that of the (Al60,Cr25,W15)(C.N)-coating film. Both the micro-hardness and the critical scratch load of the (Al64,Cr28,W8)(C.N)-coating film are 3050 $HV_{0.25N}$ and over 130 N, which is the same as that of the (Al60,Cr25,W15) (C.N)-coating film, too. That is, there is little difference between the mechanical properties of the (Al64,Cr28,W8) (C,N)- and that of the (Al60,Cr25,W15)(C,N)-coating film. Therefore, the EDS analysis was conducted.

Fig. 4 shows the EDS analysis. Figs. 4 (a) and (b) show the EDS analysis in the case of the oxygen (O) mapping on the cutting part shown in Fig. 3 (b) and Fig. 2 (ii) (b), respectively.

As compared with the oxygen element on the worn surface of the (Al64,Cr28,W8)(C,N)-coated tool shown in Fig. 4 (a) and that of the (Al60,Cr25,W15)(C,N)-coating film shown in Fig. 4 (b), the oxygen element of the (Al64,Cr28,W8)(C,N)-coated tool, which was turned at a long cutting distance, is less than that of the (Al60,Cr25,W15)(C,N)-coated tool. Therefore, the cutting temperature of the (Al64,Cr28,W8)(C,N)-coated tool is lower than that of the (Al60,Cr25,W15)(C,N)-coated tool, and the wear progress of the (Al64,Cr28,W8)(C,N)-coated tool was slower than that of the (Al60,Cr25,W15)(C,N)-coated tool.

One reason for the lower cutting temperature of the (Al64, Cr28,W8)(C,N)-coated tool is that the friction coefficient was measured with a pin-on-disk friction and wear tester [5]. Table V shows the mean value of the friction coefficient. The mean value of the friction coefficient of the (Al64,Cr28,W8)(C,N)-coating film, 0.53, is smaller than that of the (Al60,Cr25,W15) (C,N)-coating film, 0.63. That is, the (Al64,Cr28,W8)(C,N)-coating film has a lower coefficient of friction as compared with the (Al60,Cr25,W15)(C,N)-coating film. Therefore, in the case of cutting sintered steel by the (Al64,Cr28,W8)(C,N)-coated tool, the cutting force decreases with the decrease of the friction force between the tool and the work-piece. And the cutting temperature is lowered. This is considered to be the reason why there is less tool wear of the (Al64,Cr28,W8)(C,N)-coated tool.

As mentioned above, the (Al64,Cr28,W8)(C,N)-coating film was found to have superior properties for coating material compared to the (Al64,Cr28,W8)(C,N)-coating film in cutting sintered steel.

TABLE V
MEAN VALUE OF THE FRICTION COEFFICIENT OF THE COATING FILMS [5]

Coating film	Mean value of friction coefficient
(Al64,Cr28,W8)(C,N)	0.53
(Al60,Cr25,W15)(C,N)	0.63

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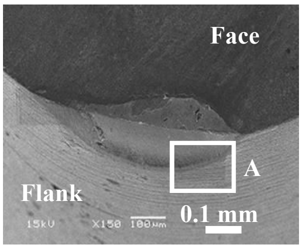
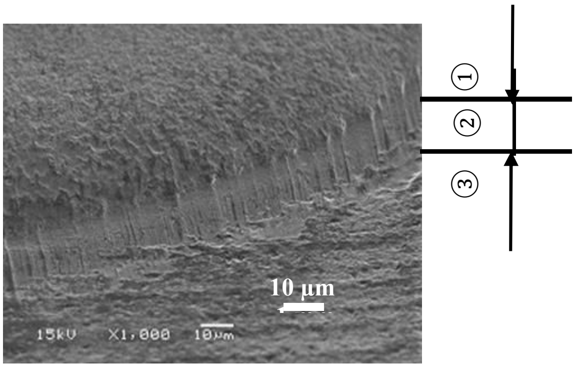


(a) Tool wear



(b) Details of A shown in Fig. (a)

①: Abraded surface of substrate
②: Abraded coating film
③: Surface of coating film

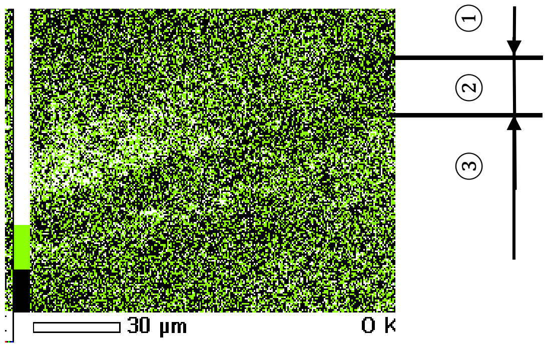
Fig. 3 Tool wear of (Al64,Cr28,W8)(C,N)-coated tool at a cutting speed of 5.0 m/s, feed rate of 0.1 mm/rev, depth of cut of 0.1 mm, cutting method of dry cutting and cutting distance of 1.7 km.

IV. Conclusion

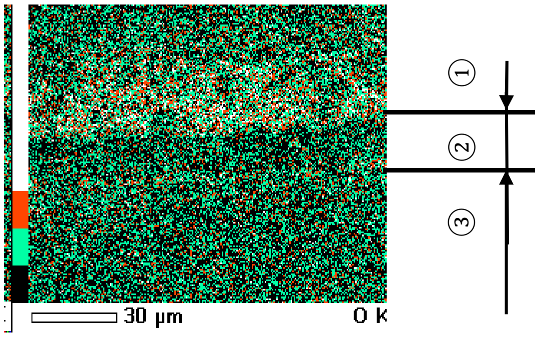
In this study, to clarify the effectiveness of the aluminum/chromium/tungsten-based-coated tool for cutting sintered steels, tool wear was experimentally investigated. The sintered steel was turned with the (Al60,Cr25,W15)N-, (Al60, Cr25,W15)(C,N)- and (Al64,Cr28,W8)(C,N)-coated cemented carbide tools according to the physical vapor deposition (PVD) method. Moreover, the tool wear of the aluminum/chromium/ tungsten-based-coated item was compared with that of the (Al,Cr)N coated tools. Furthermore, to clarify the tool wear mechanism of the aluminum/chromium/tungsten-coating film for cutting sintered steel, SEM observation and EDS mapping analysis were conducted on the abraded surface.

The following results were obtained:

1. The wear progress of the (Al64,Cr28,W8)(C,N) coated tool was the slowest among that of the five coated tools.
2. Adding carbon (C) to the aluminum/chromium/tungsten-based-coating film was effective for improving the wear-resistance.
3. The main wear mechanism of the (Al60,Cr25,W15)N-, the (Al60,Cr25,W15)(C,N)- and the (Al64,Cr28,W8)(C,N)-coating films was abrasive wear.



(a) (Al64,Cr28,W8)(C,N)



(b) (Al60,Cr25,W15)(C,N)

①: Abraded surface of substrate
②: Abraded coating film
③: Surface of coating film

Fig. 4 SEM observation and EDS mapping analysis of oxygen mapping on the flank surface

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