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TOOL WEAR OF (AL, CR, W) N-COATINGS ON CEMENTED CARBIDE TOOLS PREPARED BY ARC ION PLATING IN DRY CUTTING OF SINTERED STEEL

Tadahiro Wada
Professor, Department of Mechanical Engineering, Osaka Sangyo University, Nakagaito Daito Osaka, Japan
t.wada@ge.osaka-sandai.ac.jp

Abstract

To improve both the critical scratch load and micro-hardness of (Al, Cr) N coating film, (Al, Cr, W) N coating film was developed. In this study, to clarify the tool wear of the coated tool in the cutting of sintered steel using four types of (Al, Cr, W) N coated tools, the wear progress and the wear mechanism of the coating film were investigated. By using two types of the (Al, Cr, W)-target and three types of bias voltage, the (Al, Cr, W) N coating film was deposited on cemented carbide ISO K10. To clarify the wear mechanism of the (Al, Cr, W) N coating films, scanning electron microscope (SEM) observation and Energy Dispersive X-ray spectrometry (EDS) mapping analysis of the abraded coating film were performed. The cutting conditions were a cutting speed of 3.33 m/s, feed rate of 0.1 mm/rev, and cutting depth of 0.1 mm. The following results were obtained: (1) The wear progress of the (Al64, Cr28, W8) N coated tool was slower than that of the

(Al60, Cr25, W15) N coated tool. (2) When nitride coating films were deposited on the cemented carbide ISO K10 with a bias voltage of -80 V, -150 V, or -300 V using the (Al64, Cr28, W8)-target, the wear progress of the (Al64, Cr28, W8) N coated tool with a bias voltage of -80 V was the slowest.

Keywords

Cutting, Physical Vapor Deposition Coating Method, Tool Wear, (Al,Cr,W)N Coating Film, Sintered Steel

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1. Introduction

Machine parts with complex shapes are mass-produced by powder metallurgy technology. However, after sintering, cutting is performed in order to improve dimensional accuracy. The tool life in cutting sintered steel is shorter than that in cutting molten steel such as carbon steel. Moreover, as sintered mechanical parts are often cut at high cutting speeds for mass-production, the tool material needs to have effective wear resistance.

Cubic boron nitride (c-BN) is an effective tool material for cutting sintered steel. However, although c-BN has higher hardness, it has the drawback of lower toughness. For this reason, when a large cutting force or impact force is applied to the cutting tool, for example, turning with a high feed rate and/or depth of cut, milling, drilling, etc., c-BN causes a defect and cannot be used as a tool material. Therefore, coated tools having a hard coating film such as TiN, TiAlN, and AlCrN with wear-resistance deposited on a cemented carbide with excellent fracture resistance are generally used.

Comparing the tool life of the (Al, Cr) N coated tool and the TiN coated tool, the tool life of the (Al, Cr) N coated tool is generally longer than that of the TiN coated tool. The film characteristics of the (Al, Cr) N coating film differ depending on the composition ratios of Al and Cr, but the critical scratch load, which is the value measured by the scratch test of the (Al, Cr) N coating film, is 77 N, and the micro hardness is 2760 $HV_{0.25\,N}$ (Wada T., & Hanyu H., 2015(1)). Therefore, in order to improve both the critical scratch load and the micro hardness of the (Al, Cr) N coating film, the cathode material of the (Al, Cr, W)-target with tungsten (W) added to the cathode material of the (Al, Cr)-target was used (Wada T., & Hanyu H., 2015(1)). As a result, the critical scratch load of the (Al, Cr, W) N coating was improved to 81 N and the micro hardness was improved to 3110 $HV_{0.25\,N}$ (Wada T., & Hanyu H., 2015(1)).

The wear progress and the wear mechanism of (Al, Cr, W)-based coated tool wear were investigated (Wada T., & Hanyu H., 2015(1); Wada T., & Hanyu H., 2015(2); Wada T., & Hanyu H., 2015(3); Wada T., 2018(1); Wada T., 2018(2)). Therefore, many studies have been conducted to investigate tool wear by cutting with such a (Al, Cr, W)-based coated tool. The characteristics of coating film are affected not only by the target (Tomaszewski et al. 2015) and the reaction gas (Narasimhan et al. 1995; Karlsson et al. 2000), but also by the bias voltage (Lim et al. 2002; Choi et al. 2004; Houška et al. 2007; Zhang et al. 2019).

However, the influence of the compositions of the (Al, Cr, W)-target and the bias voltage on the tool wear has not been clarified. Therefore, in order to clarify the composition of the (Al, Cr, W)-target and the bias voltage on the tool wear, the alloy steel AISI 5120H was turned and the tool wear was investigated (Wada T., 2020). In cutting, it is very important to select the tool material suitable for the work material. Even with the same tool material, " Work material: X" is effective, but "Work material: Y" is often ineffective. Therefore, it is necessary to clarify the effect of the (Al, Cr, W)-target composition and bias voltage on tool wear in turning sintered steel.

In this study, to clarify the tool wear of the (Al, Cr, W) N coated tool in the cutting of sintered steel using three types of (Al, Cr, W) N coated tools, the wear progress was investigated. By using two types of the (Al, Cr, W)-target and two types of bias voltage, the (Al, Cr, W) N coating film was deposited on cemented carbide ISO K10. To clarify the wear mechanism of the (Al, Cr, W) N coating films, scanning electron microscope (SEM) observation and Energy Dispersive X-ray spectrometry (EDS) mapping analysis of the abraded coating film were performed.

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

The work material used was sintered steel. The chemical composition of the sintered steel is shown in Table 1. The tool material of the substrate was cemented carbide, and four types of PVD coated cemented carbide were used as shown in Table 2. Two types of (Al, Cr, W)-target components, namely the (Al64, Cr28, W8)- and (Al60, Cr25, W15)-target, were used. The component ratios for targets (Al64, Cr28, W8) and (Al60, Cr25, W15) were determined as follows: For the target (Al64, Cr28, W8), the ratio of (Al70, Cr30) and W was set to 92:8. For the target (Al60, Cr25, W15), the ratio of (Al70, Cr30) and W was set to 85:15. In the case of the (Al64, Cr28, W8)N-coating film, the bias voltages of -80 V, -150 V and -300 V were used. In the case of the (Al60, Cr25, W15) N-coating film, the bias voltage of -150 V was used.

The configurations of the tool inserts were ISO TNGA160408. The insert was attached to a tool holder MTGNR2525M16. 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 3. The tool wear was investigated.

Table 1: *Chemical Compositions and Mechanical Properties of The Sintered Steel*

<table>
<tr><th colspan="5">Chemical composition [mass %]</th></tr>
<tr><th>C</th><th>Cu</th><th>Ni</th><th>Mo</th><th>Fe</th></tr>
<tr><td>0.3 - 0.7</td><td>1 - 2</td><td>3 - 5</td><td>0.2 - 0.8</td><td>Bal.</td></tr>
<tr><th colspan="5">Properties</th></tr>
<tr><th colspan="2">Hardness</th><th colspan="3">Density</th></tr>
<tr><td colspan="2">70 HRB (129 HB)</td><td colspan="3">7.1 Mg/m^3</td></tr>
</table>

(Source: Authors' Own Illustration)

Table 2: *Tool Material*

Tool type	Coating film	Bias voltage
Type A	(Al64, Cr28, W8)N	-150 V
Type B	(Al60, Cr25, W15)N	-150 V
Type L	(Al64, Cr28, W8)N	-80 V
Type M	(Al64, Cr28, W8)N	-300 V

(Source: Authors' Own Illustration)

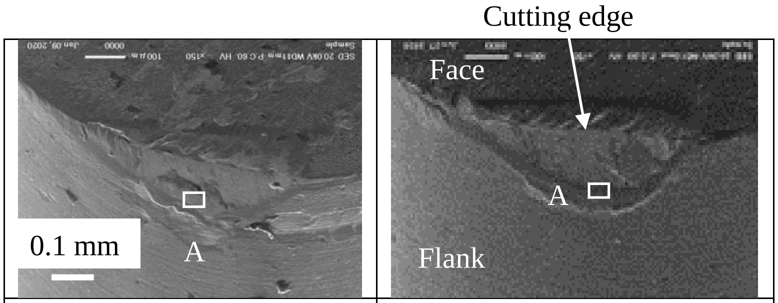
Table 3: *Cutting Conditions*

Cutting speed	Vc= 3.3 m/s
Feed rate	f=0.1 mm/rev
Depth of cut	ap=0.1 mm

(Source: Authors' Own Illustration)

3. Results and Discussion

In the cutting of sintered steel, the tool wear of the three types of coated tools was investigated with a Scanning electron microscope (SEM). Figure 1 shows the tool wear at a cutting speed of 3.33 m/s, feed rate of 0.1 mm/rev and cutting depth of 0.1 mm. In the case of all coated tools, a slight crater is found on the rake face, no remarkable adhesion of the work-piece is observed on both the rake face and the flank face, and no remarkable flaking of the coating layer is observed as shown in Fig. 1.



(a) Type A,
C. D.=0.8 km

(b) Type L,
C. D.=1.4 km

C. D.: Cutting distance

Figure 1: *Tool Wear at a Cutting Speed of 3.33 m/s, Feed Rate of 0.1 mm/rev and Cutting Depth of 0.1 mm*

(Source: Authors' Own Illustration)

The above results indicate that the main tool failure of all coated tools was the flank wear up to the cutting distance where the maximum value of the flank wear width is about 0.2 mm. Therefore, the maximum value of the flank wear width was measured under a microscope.

First, the tool wear of coating films, which were prepared by changing the component ratio of the (Al, Cr, W)-target, was examined. Two types of (Al, Cr, W)-targets, namely (Al64, Cr28, W8)- and (Al60, Cr25, W15)-target, were used in cutting the work-piece. Using these two types of targets, two types of nitride coating films were formed at a bias voltage of -150V. Figure 2 shows the wear progress of the Type A and the Type B coated cemented carbide tools at a cutting speed of 3.33 m/s, feed rate of 0.1 mm/rev and cutting depth of 0.1 mm in turning sintered steel. Comparing the wear progress of the Type A and Type B coated tools, the wear progress of Type A is slower than that of Type B. In the case of the cutting of AISI 5120H at a cutting speed of 5.0 m/s, feed rate of 0.1 mm/rev and depth of cut of 0.1 mm [3], the wear progress of the Type A coated tool was also slower than that of the Type B coated tool. Also, in this study, the progress of wear of the type A coated tool is slower than that of the type B coated tool. The reason is as follows.

Table 4 shows the characteristics of the coating films. Comparing the Type, A and Type B coating film, the thickness of both coating films is the same at 4.4 μm. The micro-hardness of both films is the same at about 3125±15 $HV_{0.25N}$. However, the critical scratch load of the Type A coating film at 93 N is higher than that of the Type B coating film at 81 N. Therefore, it was considered that the wear progress of the Type A coated tool was slower than of the Type B coated tool as shown in Fig. 2.

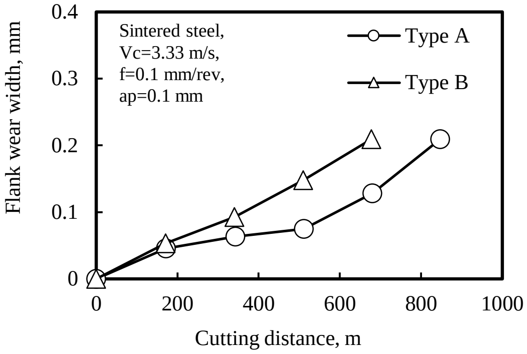


Figure 2: *Wear Progress of Type A and Type B Coated Cemented Carbide Tools at a Cutting Speed of 3.33 m/s, Feed Rate of 0.1 mm/rev and Cutting Depth of 0.1 mm in Turning Sintered Steel*

(Source: Authors' Own Illustration)

Therefore, the (Al64, Cr28, W8)-target used in the Type A coated tool has better wear resistance than the (Al60, Cr25, W15)-targets used in the Type B coated tool. However, the bias voltage during vapor deposition has an influence on the characteristics of the coating film. So, when a nitride film is deposited on the cemented carbide ISO K10 using a (Al64, Cr28, W8)-target, the effect of the bias voltage on the tool wear is investigated.

Figure 3 shows the wear progress of the Type A, Type L, and Type M coated cemented carbide tools at a cutting speed of 3.33 m/s, feed rate of 0.1 mm/rev, and cutting depth of 0.1 mm in turning sintered steel. The three types of coated cemented carbide tools, Type A, Type L, and Type M, have the same target of (Al64, Cr28, W8) as shown in Table 2. The bias voltage of Type A, Type L, and Type M is -150 V, -80 V, and -300 V, respectively. A comparison of the two coated cemented carbide tools shows that the wear progress of the Type L tool is slow.

Figures 4(i) and (ii) show the EDS mapping analysis on the abraded surface of the coating film of the Type A and Type L coated tools, respectively. The elements analyzed were carbon (C), nitrogen (N), oxygen (O), aluminum (Al), chromium (Cr), iron (Fe), and tungsten (W). The results of the analysis of Fe and Al are shown in Fig. 4. Al is a component of the coating film, and Fe is the main chemical component of the work material. The SEM and the EDS observation results of the two types of coated tools were compared as shown in Fig. 4.

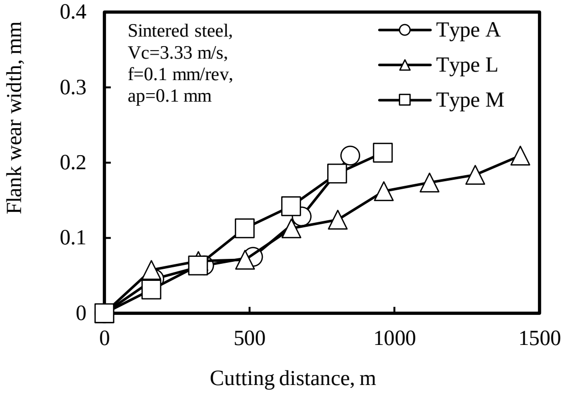


Figure 3: *Wear Progress of Type A, Type L, and Type M Coated Cemented Carbide Tools at a Cutting Speed of 3.33 m/s, Feed Rate of 0.1 mm/rev, and Cutting Depth of 0.1 mm in Turning Sintered Steel*

(Source: Authors' Own Illustration)

Figure 4 shows the area of "A" as shown in Fig. 1. Comparing the SEM observation on the abraded surface of the coating film of the Type A and Type L coated tools as shown in Fig. 4 (i)(a) and Fig. 4(ii)(a), there are many striate lines scratched by hard materials on the abraded surface in the case of all types of coating layers. In the case of all types of coated tools, there is no noticeable difference in the mapping state of the Al elements.

In the case of all types of coated tools, the Fe elements on the abraded surface of the coating film are observed.

Therefore, the wear mechanism of the abraded surface of the coating film of the Type A and Type M coated tool is both abrasive wear and adhesion wear. For abrasive wear, the wear-resistance of the coating film often depends on the hardness of the coating film. For adhesion wear, the wear-resistance of the coating film often depends on the critical scratch load between the substrate and the coating film.

As shown in Table 4, when the characteristics of the (Al,Cr,W)-based coating film of Type A, Type L, and Type M are compared, the coating thickness of the Type L coating film is the thickest among the three types of coating films. The micro-hardness of the coating film of Type A and Type L is slightly higher than that of Type M. However, the critical load of Type A and Type L is slightly lower than that of Type M.

Therefore, the reason for the slowest wear progression of the Type L coated tool cannot be clarified from the coating characteristics of the tools shown in Table 4.

The reason for the slowest wear progression of the Type L coated tool will be explained in detail in the next report.

Table 4: *Characteristics of The Coating Films*

Tool type	Thickness of film [µm]	Micro-hardness [$HV_{0.25N}$]	Critical scratch load* [N]
Type A	4.4	3140	93
Type B	4.4	3110	81
Type L	6.0	3100	95
Type M	3.6	2880	103

(Source: Data of Type A by Wada T., 2018(1); Data of Type B by Wada T., & Hanyu H., 2015(2))

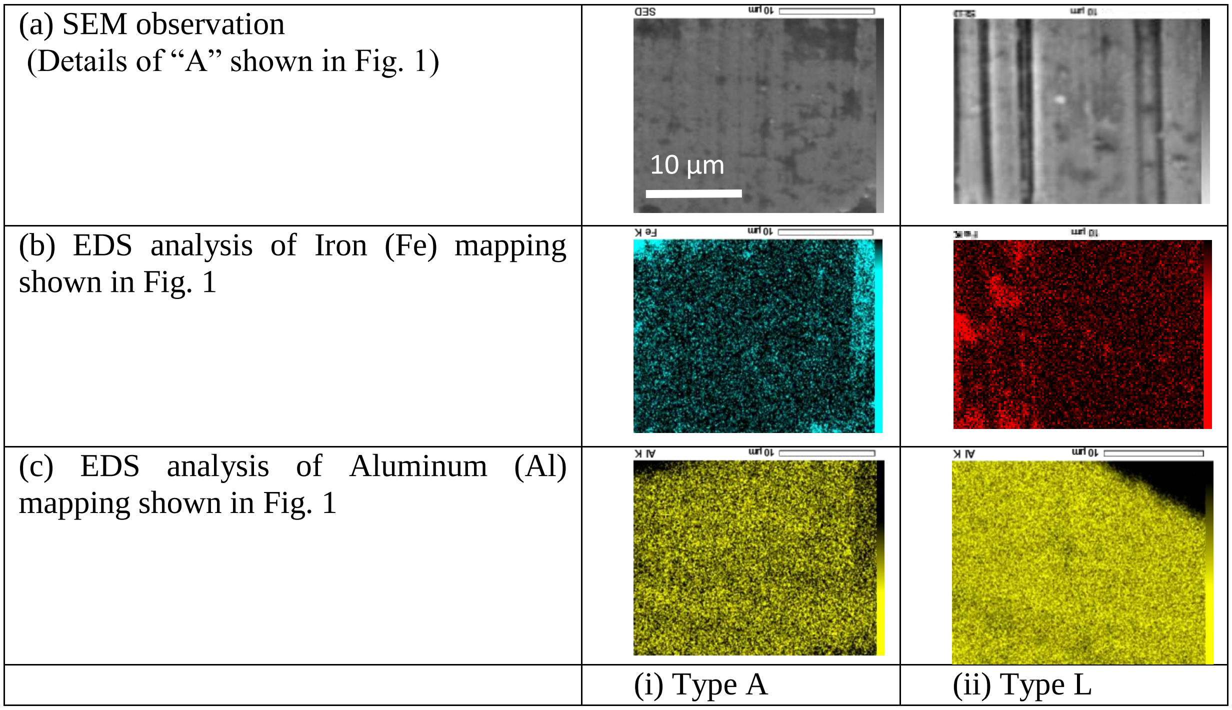


Figure 4: *SEM Observation and EDS Mapping Analysis on The Abraded Surface of The Coating Film of The Type A and Type L Coated Tools Shown in Fig. 1*

(Source: Authors' Own Illustration)

4. Conclusions

In this study, to clarify the tool wear of the coated tool in the cutting of sintered steel using four types of (Al, Cr, W) N coated tools, the wear progress and the wear mechanism of the coating film were investigated. The cutting conditions were a cutting speed of 3.33 m/s, feed rate of 0.1 mm/rev, and cutting depth of 0.1 mm.

The following results were obtained:

(1) The wear progress of the (Al64, Cr28, W8) N coated tool was slower than that of the (Al60, Cr25, W15) N coated tool.

(2) When nitride coating films were deposited on the cemented carbide ISO K10 with a bias voltage of -80 V, -150 V, or -300 V using the (Al64, Cr28, W8)-target, the wear progress of the (Al64, Cr28, W8) N coated tool with a bias voltage of -80 V was the slowest.

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*This paper is an extension to my already published paper and has new experiments. Also, this is not to be considered plagiarism.