TOOL WEAR OF LUMINUM/CHROMIUM/ TUNGSTEN- BASED-COATED CEMENTED CARBIDE IN CUTTING ALLOY STEEL

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Abstract - Coating properties of the (Al, Cr, W)-target are improved by adding tungsten to the (Al, Cr) target. Therefore, in this study, to clarify of the effectiveness of the (Al,Cr,W) -coating film for cutting alloy steel, the tool wear was experimentally investigated. The following results were obtained: (1) The wear progress of coated cemented carbide tool deposited using the (Al,Cr,W)-target was slower than that of the coated cemented carbide tool deposited using the (Al,Cr)-target. (2) The wear progress of the (Al64, Cr28,W8)N-coated tool was slower than that of the (Al60, Cr25,W15)N-coated tool. (3) In the case of the coated cemented carbide tool deposited using the (Al64,Cr28,W8)-target, although the adhesiveness of the (Al64,Cr28,W8)(C,N)-coated tool by adding carbon to the (Al64,Cr28,W8)N-coating film became higher, the wear progress of the (Al64,Cr28,W8)(C,N)-coated tool became faster than that of the (Al64,Cr28,W8)N-coated tool. (4) As compared to the wear progress of the (Al64,Cr28,W8)C-coated and that of the (Al64,Cr28,W8)(C,N)-coated tool, the wear progress of the (Al64,Cr28,W8)C coated tool was slightly slower. For this reason, it was considered that although the micro-hardness of the (Al64,Cr28,W8)C-coating film was lower than that of the (Al64,Cr28,W8)(C,N)-coating film, the average value of the friction coefficient of the (Al64, Cr28,W8)N coating film, 0.26, was about half of that of the (Al64, Cr28,W8)(C,N) coating film, 0.53.

Index Terms - (Al,Cr,W)-based-coating film, cutting, tool wear, alloy steel.

I. INTRODUCTION

$Ti_{1-x}Al_xN$ and $Cr_{1-x}Al_xN$ alloys are among the most widely used physical and chemical vapor deposited hard coating materials due to their outstanding functional properties [1]. In order to improve the properties of the CrAlN-coating film, there is a method of forming a multilayered coating film [2, 3]. In another method, the properties of the CrAlN-coating film can be easily improved by adding silicon (Si)[4-9] to the target. Adding tungsten (W) to the film other than silicon is also affective for improving the properties of the CrAlN-coating film [10-14]. That is, in order to improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, cathode material of an (Al,Cr,W)-target was used in adding tungsten to the cathode material of the (Al,Cr)-target [10]. In cutting hardened sintered steel, tool wear was experimentally investigated [10, 11]. Moreover, in cutting Sintered Steel [12] and hardened steel [13], tool wear was experimentally investigated. As a result, it was found that adding the tungsten composition to the (Al,Cr)-target has a considerable effect on the wear resistance of the cutting tool. However, the wear progress of the (Al,Cr,W)-based coated cemented carbide in cutting alloy steel have not been clarified.
In this study, to clarify of the effectiveness of the (Al,Cr,W) -coating film for cutting alloy steel, the tool wear was experimentally investigated.

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 scratch tester) of various coating films formed on the surface of a cemented carbide ISO K10 substrate formed by the arc ion plating process. The work material used was AISI 5120 alloy steel (JIS SCr420H, Low-carbon high-chromium Steel). The chemical composition of the alloy steel is shown in Table 1.

The tool material of the substrate was cemented carbide, and five types of PVD coated cemented carbide were used as shown in Table 2. Two types of (Al,Cr,W) nitride coating films with different target components, namely (Al64,Cr28,W8)N, (Al60,Cr25,W15)N. And three types of coating films with different reactive gases, namely (Al64,Cr28,W8)N, (Al64,Cr28,W8)(C,N), (Al64,Cr28,W8)C. Furthermore, (Al, Cr)N coating film was also used for comparison. The (Al64,Cr28,W8)N, (Al60,Cr25,W15)N, (Al64,Cr28,W8)(C,N) or (Al64,Cr28,W8)C is 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. 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}. Alloy steel was turned under the cutting conditions shown in Table 3. The tool wear was investigated.

The friction coefficient was measured using a pin-on-disk type friction and wear tester (Rhesca Corporation FPR-2100), and the test conditions are shown in Table 4.

Table 1 Chemical compositions and mechanical properties of workpiece (AISI 5120H)

Chemical composition [mass %]								
C	Cr	Si	Mn	p	S	Ni	Cu	Fe
0.21	1.1	0.19	0.83	0.02	0.01	0.03	0.02	Bal.
Mechanical properties								
Tensile strength				Brinell hardness				
550 MPa				153 HB				

Table 2 Tool material in turning of AISI 5120.

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

Table 3 Cutting conditions

Cutting speed	Vc= 5.00 m/s
Feed rate	f=0.10 mm/rev
Depth of cut	ap=0.1 mm

Table 4 Test conditions of the friction test (Pin-on-Disk type)

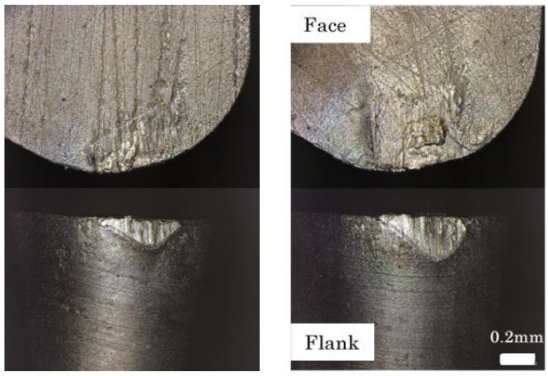
Material of ball	ISO C454 (JIS S45C), (R5.00 mm)
Sliding time	600 s
Sliding speed	100 mm/s
Normal load	490 mN
Temperature	295 K
umidity	28 %
Atmosphere	Air

III. RESULTS AND DISCUSSION

In cutting alloy steel using five types of coated tools, tool wear was investigated. Fig. 1 shows an example of the tool wear in turning alloy steel at a cutting speed of 5.00 m/s, a feed rate of 0.1 mm/rev and a cutting depth of 0.1 mm. Fig. 1(a) and Fig. 1(b) show the case of the (Al64,Cr28,W8)N- and the (Al,Cr)N-coated tool, respectively.

In this figure, "L" is the cutting distance. Observation under a microscope revealed, in the case of the both the (Al64,Cr28,W8)N- and the (Al,Cr)N-coated tools, there is a slight crater on the rake face, and there is no remarkable adhesion on either the rake face or flank. Furthermore, no remarkable flaking of the coating layer is found.

As a result of the turning test of other coated carbide tool, it emerged that the main tool failure of the five types of coated tools was the flank wear within the maximum value of the flank wear width of 0.2 mm. Therefore, the maximum value of the flank wear width (VBmax) was measured under a microscope.



(a) (Al64,Cr28,W8)N, L=24.0 km (b) (Al,Cr)N, L=13.6 km

Fig. 1 Tool wear in turning alloy steel at a cutting speed of 5.00 m/s, a feed rate of 0.1 mm/rev and a cutting depth of 0.1 mm in turning AISI 5120H alloy steel.

It is well known that chemical composition of a target affect the tool wear. In the case of the (Al,Cr,W)-target, two types of targets, namely the (Al64,Cr28,W8)-target and the (Al60,Cr25,W15)-target, were used. Moreover, the (Al, Cr)-target was also used to compare with the two types of (Al,Cr,W)-targets.

In cutting AISI 5120H alloy steel using the two types of (Al,Cr,W)N-coated tools, which had the different chemical composition of the target, namely the (Al64,Cr28,W8)-target and the (Al60,Cr25,W15)-target, the wear progress was investigated. The wear progress is shown in Fig. 2. The wear progress of two types of (Al,Cr,W)N-coated tool is slower than that of the (Al,Cr)N-coated tool. Thus, adding silicon to the (Al,Cr)-target is effective for improving the wear-resistance of cutting tool.

As compared to the wear progress the (Al64,Cr28,W8)N- and the (Al60,Cr25,W15)N-coated tool, the wear progress of the (Al64,Cr28,W8)N-coated tool is slower than that of the (Al60,Cr25,W15)N-coated tool.

Table 5 Characteristics of (Al,Cr,W)-based- and (Al,Cr)N-coating film

Coating film	Thickness of coating film [μm]	Micro-hardness of coating film [HV0.25 N]	Adhesiveness (Critical load*) [N]
(Al64,Cr28,W8)N	4.4	3140	93
(Al60,Cr25,W15)N [11]	4.4	3110	81
(Al64,Cr28,W8)(C,N) [11]	3.1	3050	>130
(Al64,Cr28,W8)C	2.7	1710	>130
(Al,Cr)N [12]	3.0	2760	77

* : Measured value of scratch test

So, the characteristics of the coating films were investigated. The results are shown in Table 5. Table 5 shows the characteristics of the (Al,Cr,W)-based- and the (Al,Cr)- nitride coating film. As compared with the two types of the (Al,Cr,W)N-coating films, the thickness of the two types of (Al,Cr,W)N-coated films is the same 4.4 μm. The micro-hardness of the two types of (Al,Cr,W)N coating films is the same about 3125±15 $HV_{0.25N}$. However, the critical scratch load of the (Al64,Cr28,W8)N- coating film 93 N is higher than that of the (Al60, Cr25,W15)N-coating film 81 N. Therefore, it is considered that the wear progress of the (Al64,Cr28,W8)N-coated tool was slower than of the (Al60,Cr25,W15)N-coated tool as shown in Fig. 2.

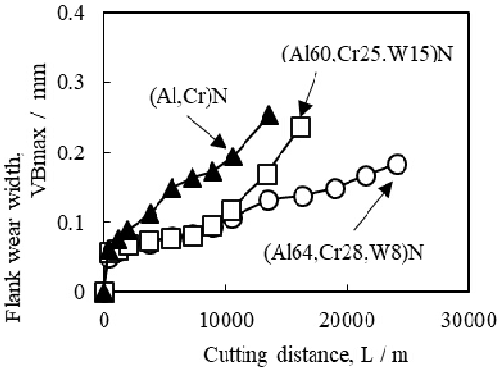


Fig.2 Wear progress of (Al64,Cr28,W8)N-, (Al60,Cr25,W15)N- and (Al,Cr)N-coated cemented carbide tool in turning alloy steel at a cutting speed of 5.00 m/s, feed rate of 0.1 mm/rev and cutting depth of 0.1 mm in turning AISI 5120H alloy steel.

The above results indicate that the effective target of the coated cemented carbide tool is the (Al64,Cr28,W8).

Next, the reactive gas during the deposition also affects tool wear. For this reason, the vapor deposition was performed on the cemented carbide substrate using two kinds of reactive gases, namely N_2 and CH_4. Fig.3 shows the wear progress of (Al64,Cr28,W8)N-, (Al64,Cr28,W8)(C,N)- and (Al64,Cr28,W8)C-coated cemented carbide tool in cutting AISI 5120H alloy steel at a cutting speed of 5.00 m/s, feed rate of 0.1 mm/rev and cutting depth of 0.1 mm.

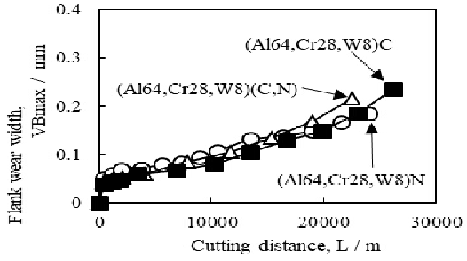


Fig.3 Wear progress of (Al64,Cr28,W8)N-, (Al64,Cr28,W8)(C,N)- and (Al64,Cr28,W8)C-coated cemented carbide tool in turning alloy steel at a cutting speed of 5.00 m/s, feed rate of 0.1 mm/rev and cutting depth of 0.1 mm in turning AISI 5120H alloy steel.

As compared to the wear progress of the (Al64,Cr28,W8)N-coated and that of the (Al64,Cr28,W8)(C,N)-coated tool, the wear progress of the (Al64,Cr28,W8)N coated tool is slightly slower than that of the (Al64,Cr28,W8)(C,N)-coated tool. This indicates that in the case of the (Al64,Cr28,W8)N-coating film, improvement of the adhesiveness can be expected, however the micro-hardness of coating film is lower as shown in Table 5. Thus, although the adhesiveness of the (Al64,Cr28,W8)(C,N)-coating film by adding carbon to the (Al64,Cr28,W8)N-coating film becomes higher, the wear progress of the (Al64,Cr28,W8)(C,N)-coated tool becomes faster than that of the (Al64,Cr28,W8)N-coated tool due to decrease of the micro-hardness of the (Al64,Cr28,W8)(C,N)-coating film. As compared to the wear progress of the (Al64,Cr28,W8)C-coated and that of the (Al64,Cr28,W8)(C,N)-coated tool, the wear progress of the (Al64,Cr28,W8)C-coated tool is slightly slower than that of the (Al64,Cr28,W8)(C,N)-coated tool. Thus, the adhesiveness of both the (Al64,Cr28,W8)C- and the (Al64,Cr28,W8)(C,N)-coated tool is the same over 130N. although the micro-hardness of the (Al64,Cr28,W8)C-coating film is lower than that of the (Al64,Cr28,W8)(C,N)-coated tool, the wear progress of the (Al64,Cr28,W8)C-coated tool becomes slower than that of the (Al64,Cr28,W8)(C,N)-coated tool. Therefore, the friction coefficient was investigated. The friction coefficient was measured with a pin-on-disk friction wear tester. Figure 4 shows the relationship between the sliding time and the friction coefficient under a sliding speed of 100 mm/s and a normal load of 490 mN. The maximum sliding time was 600 s.

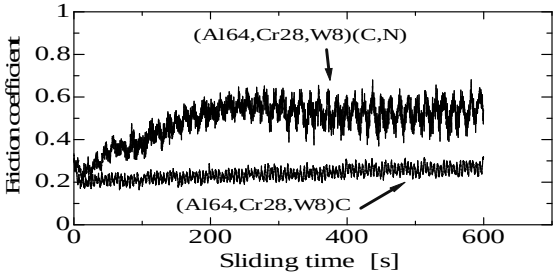


Fig. 4 Relationship between sliding distance and friction coefficient under a sliding time of 0 s to 600 s.

In the case of the (Al64,Cr28,W8)(C,N)-coating film, the average of the friction coefficient increases with the increase of the sliding time under the sliding time of 0 s to 300 s, after that, the average of the friction coefficient becomes almost constant under the sliding time of 300 s to 600 s.

On the other hand, in the case of the (Al64,Cr28,W8)C-coating film, the friction coefficient slightly increases with the increase of the sliding time under the sliding time of 0 s to 600 s. And both the average value and the fluctuation range of the friction coefficient of the (Al64,Cr28,W8)C-coating film becomes rather smaller than that of the

(Al64,Cr28,W8)(C,N)-coating film. Table 6 shows the average value of the friction coefficient under a sliding time of 300 s to 600 s. The average value of the friction coefficient of the (Al64, Cr28,W8)N coating film, 0.26, is rather smaller than that of the (Al64, Cr28,W8)(C,N) coating film, 0.53.

Table 6 Average value of the friction coefficient of the coating films (Average value of friction coefficient under a sliding time of 300 s to 600 s)

Coating film	Average value of friction coefficient
(Al64,Cr28,W8)C	0.26
(Al64,Cr28,W8)(C,N)	0.53 [11]

CONCLUSION

In this study, to clarify of the effectiveness of the (Al,Cr,W) -coating film for cutting alloy steel, the tool wear was experimentally investigated.
The following results were obtained:

1. The wear progress of coated cemented carbide tool deposited using the (Al,Cr,W)-target was slower than that of the coated cemented carbide tool deposited using the (Al,Cr)-target.
2. The wear progress of the (Al64, Cr28,W8)N-coated tool was slower than that of the (Al60, Cr25,W15)N-coated tool.
3. In the case of the coated cemented carbide tool deposited using the (Al64,Cr28,W8)-target, although the adhesiveness of the (Al64,Cr28,W8)(C,N)-coated tool by adding carbon to the (Al64,Cr28,W8)N-coating film became higher, the wear progress of the (Al64,Cr28,W8)(C,N)-coated tool became faster than that of the (Al64,Cr28,W8)N-coated tool.
4. As compared to the wear progress of the (Al64,Cr28,W8)C-coated and that of the (Al64,Cr28,W8)(C,N)-coated tool, the wear progress of the (Al64,Cr28,W8)C coated tool was slightly slower. For this reason, it was considered that although the micro-hardness of the (Al64,Cr28,W8)C-coating film was lower than that of the (Al64,Cr28,W8)(C,N)-coating film, the average value of the friction coefficient of the (Al64, Cr28,W8)N coating film, 0.26, was about half of that of the (Al64, Cr28,W8)(C,N) coating film, 0.53.

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