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Citation	琉球大学教育学部紀要(64): 207-219
Issue Date	2004-02
URL	http://hdl.handle.net/20.500.12000/948
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Characteristics of Corrosive Wear of Coated High-Speed Steel Tools

Hideaki FUKUDA*[1] Kaoru BANSHOYA*[2] Yasuhide MURASE*[3]

ABSTRACT

To clarify the characteristics of corrosive wear of coated high-speed steel tools in high moisture-content Douglas-fir (*Psuedotsuga menziesii* Franco) cutting, tool-life tests were conducted with a whirling disc-machine. Three kinds of coated tools and uncoated tools were prepared. Both rake faces and clearance faces of the tools were coated with either TiN, TiCN, or CrN by physical vapor deposition (PVD) method. The thickness of thin-film for each coated tool was 2-3 μm. In the tool-life tests, electrical-potential of +1 kV, 0 V, or −1 kV was applied to the tool by use of a direct-current power supply. From scanning electron microscope observations conducted after the tool-life tests, delamination of thin-film for each coated tool was viewed. The degree of delamination was the largest under +1 kV, and the smallest under −1 kV. Among measurements of tool wear, edge recession under 0 V for CrN-coated tools was the smallest among all of the tools. The CrN-coated tool was superior to the other tools in reducing the progression of edge recession. The differences in edge recession under −1 kV for the three kinds of coated tools were not detectable. The tool-wear progression under +1 kV for all tools occurred quickly. By regarding edge recession at −1 kV as being caused by a mechanical wear mechanism, the ratio of corrosive wear to the total edge recession under 0 V could be obtained. The value for uncoated tools was 55% and was the largest. The value for CrN-coated tools was 43% and was the smallest.

1. INTRODUCTION

The authors have continued researching this subject for the purposes of clarifying the characteristics of corrosive wear, and for obtaining fundamental information on the selection of tool material and the development of corrosive-resistant wood cutting tools. In our first report, machine boring of high moisture-content wood with cemented carbide bits, high-speed steel bits, and alloy-steel bits was conducted under cathodic protection. We pointed out that tool-wear progression in normal boring (no potential) was mainly controlled by the corrosive wear mechanism [1]. In our second report, tool-life tests of twelve kinds of cemented carbide bits in the machine boring of high moisture-content wood were conducted, and the effect of alloy compositions on the corrosive wear of cemented carbide bits was examined [2]. In addition, the effects of cobalt content, edge hardness, and grain diameters of cemented carbide

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on the edge recession of cemented carbide were clarified. Furthermore, tool-life tests in the machine boring of high moisture-content wood with three kinds of cemented carbide bits and high-speed steel bits were performed with four spindle speeds in the range of 870 - 4050 rpm under the same voltage condition as in the former report. The effect of cutting speed on corrosive wear was examined [3].

In recent years, high wear resistant tools coated with hard thin films such as titanium nitride have been widely used in metal cutting because they have been considered to have a long tool life. However, there are few research reports which examine the characteristics of corrosive wear of coated tools caused by cutting green wood, high moisture content wood, and wood-based materials [4,5].

In this study, both the rake faces and clearance faces of high-speed steel tools were coated with either TiN, TiCN, or CrN, and these three kinds of coated tools, along with uncoated high-speed steel tools, were prepared for the tool-life tests. Each electrical-potential of 0V (normal cutting, no potential), −1kV (cathode voltage), or +1kV (anode voltage) was applied to the tool during cutting. Continuous linear cutting of high moisture-content Douglas-fir (*Psuedotsuga menziesii* Franco) was conducted to examine the characteristics of corrosive wear of coated high-speed steel tools, and was compared with the results for the uncoated tools.

2. EXPERIMENT

2.1 Cutting tools and work material

High-speed steel knives (Japanese Industrial Standard : JIS SKH51) of 25 mm in width, 5 mm in thickness, and 30 degrees in their sharpness angle, were prepared for coating. The shape of the tool is illustrated in Figure 1.

Both the rake faces and clearance faces of the tools were coated with either TiN, TiCN, or CrN by the physical vapor deposition (PVD) method. The thickness of the thin-film for each coated tool was 2 - 3μm. The coating was conducted by NACHI-Fujikoshi Corporation in Japan.

The work material used for the study was high moisture-content Douglas-fir (*Psuedotsuga menziesii* Franco). The average value of moisture content of the work material was 113%, and the values of specific gravity of the material in an air-dried condition, and pH of the work material, were 0.49 and 5.2 respectively. The pH value was measured by the following method: the woody powder of the work material (10 g) was added to the distilled water (100 g), and this water was kept at a constant temperature at 20℃ for 24 hours. The pH value of filtrated water was measured by use of a glass electrode pH meter. After the air-dried work material was cut to the size of 20 mm in width, 100 mm in length, and 50 mm in thickness, the work pieces were soaked in the distilled water for a long period of time to reach a high moisture content condition, and then the edge of the board of the 20 mm×100 mm was cut.

2.2 Experimental method

Cutting tests were carried out on a whirling disc-machine made by reconstructing a disk planer, as shown in Figure 2. In the apparatus, the feed of the cutting tool set on the feed table was set in a perpendicular direction to the rotating face of the disc-machine at a constant speed, by use of a stepping motor. Eight work pieces fixed on the acrylic vices were continuously cut by the cutting tool at a constant cutting depth. The stepping motor was driven by an intelligent driver that transmitted pulses according to data, including operation mode, number of operation pulses, and operation speed, which were preset by a data pack.

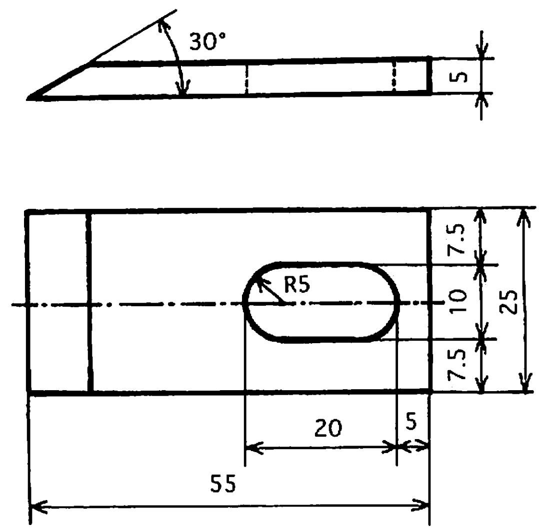

Figure 1. Shape of knife

Figure 3 is a expanded figure which shows part of the cutting in Figure 2. Continuous cutting was performed by insulating tool and work pieces from a mechanical system by use of acrylic plastic plates, and by then pressing a flat spring to the surface of the work pieces. The distance from the point of contact between the flat spring and work pieces to the cutting edge of the tool was 5mm.

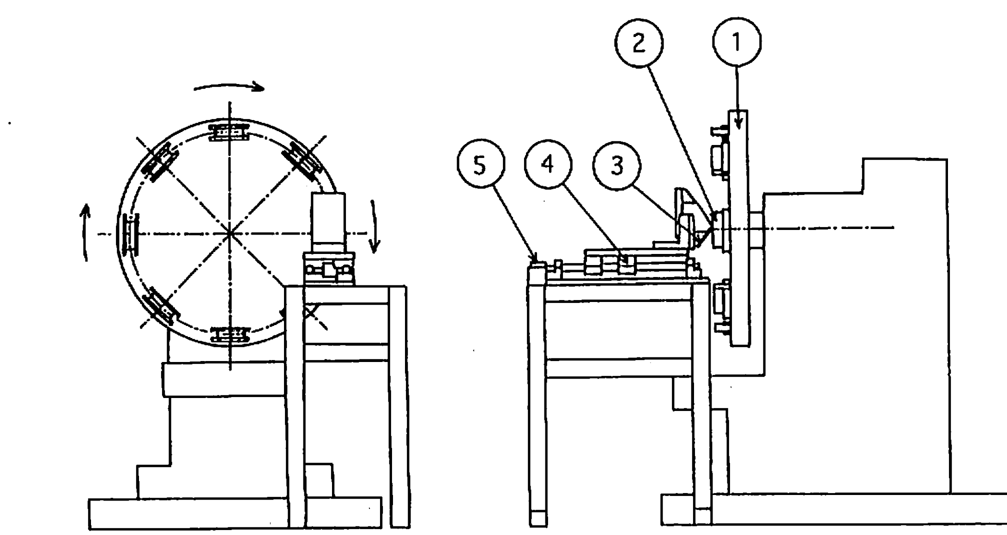

Figure 2. Sketch of testing apparatus
① Whirling disc-machine, ② Work piece, ③ Cutting tool, ④ Feed table, ⑤ Two-phase stepping motor

High moisture-content Douglas-fir was continuously cut until the cutting length became 4.0 km. It was cut with applying an electrical-potential of 0 V (normal cutting), or −1 kV (cathode voltage), or +1 kV (anode voltage) to the tool by use of a direct-current power supply. The cutting conditions were as follows: a cutting speed of 2.3 m/s, a depth of cut of 0.1 mm, a width of cut of 20 mm, a cutting angle of 40 degrees, and a clearance angle of 10 degrees.

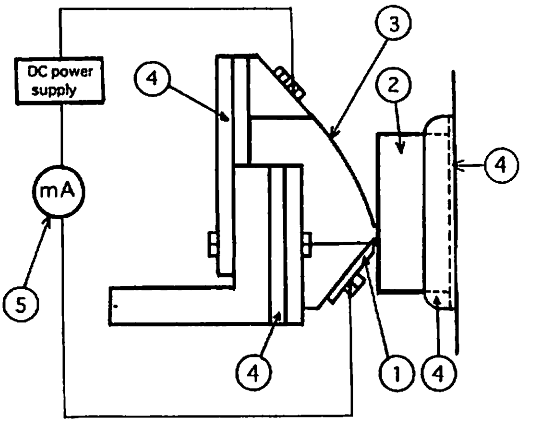

Figure 3. Experiment setup
① Cutting tool, ② Work piece, ③ Metal electrode (flat spring), ④ Acrylic insulator, ⑤ Direct current milliampere meter

2.3 Measuring item and measuring method

In the tool-life tests, the edge recession of the tool and the electric-current flowing during cutting were measured after cutting to a constant cutting length. The worn surfaces of cutting edges on rake faces for all tools were observed with a scanning electron microscope (SEM), without vacuum evaporation processing, after the tests.

The edge recession of the tools was measured on the rake face with a tool microscope. A total of three equally spaced measurements were made along the 20-mm-long cutting edge, and the edge recession of the tool wear was represented by the average value (*Wt*) of these three measurements. The electric-current flowing between the tool and the work piece during cutting was also measured over a constant cutting period by use of a milliampere meter.

3. RESULTS AND DISCUSSION

3.1 SEM observation of worn surfaces of the tools

3.1.1 In normal cutting

The SEM micrographs of the rake faces for all tools in normal cutting applying zero potential after the cutting tests are shown in Figure 4.

From past studies, tool-wear progression is considered to depend on both mechanical action and corrosive action in the cutting of green wood or high moisture-content wood [6-12]. Therefore, tool wear for the uncoated tools progresses quickly due to both actions, and carbide grains, seen as white grains, are observed within a width of about 80 μm from the cutting edge.

However, the delamination of thin film for each coated tool is seen within a width from the cutting edge, due to the two actions as mentioned above, which expose a substrate of the tool. Carbide grains are easily observed because the delamination width for the TiN-coated tool in Figure 4 (a) is about 120 μm, and that for the TiCN-coated tool in Figure 4 (b) is about 80 μm. Carbide grains for the CrN-coated tool can't be clearly seen in Figure 4 (c), because the delamination width is about 10 μm, the smallest among all of the coated tools. This tool is characterized by the crack line visible on its rake face.

3.1.2 In cutting at an electrical-potential of −1 kV (cathode voltage)

The SEM micrographs of the rake faces of all of the tools that had an electrical potential of −1 kV (cathode voltage) applied, are shown after the cutting tests in Figure 5. As is obvious from the worn surface of the uncoated tool in Figure 5 (d), the substrate of the tool was scraped with the remaining carbide grains, because tool wear progression occurs principally by mechanical action with restraining corrosive-wear progression, due to the suppressive effect of cathodic protection. Carbide grains are clearly seen, as compared with those in a normal cutting, with their visible width from the cutting edge expanding about 160 μm. In addition, the substrate of the tool remained like a streak behind the carbide grains.

The delaminations of thin films for TiN-coated tools and TiCN-coated tools occurred by mechanical action within a width of about 10 μm from the cutting edge, and the borderline of delamination was very clear, as shown in Figure 5 (a) and (b). Moreover, the carbide grains can be seen in the vicinity of the cutting edge, as clearly as in normal cutting. As shown in Figure 5 (c), the worn surface of the cutting edge on the CrN-coated tool is different from those on the TiN-coated tool and the TiCN-coated tool. The carbide grains can be clearly seen within a width of about 130 μm from the cutting edge. Delamination of the coated thin film by mechanical action, as seen in both the TiN-coated tool and the TiCN-coated tool, can't be observed. The delamination is characterized by the remaining thin film left in the whole rake face.

3.1.3 In cutting at an electrical-potential of +1 kV (anode voltage)

Figure 6 shows the SEM micrographs of the rake faces for all of the tools that had the electrical-potential of +1 kV applied. With the TiCN-coated tool, the cutting test had to be discontinued when a fracture of the cutting edge, caused by an electric spark, occurred at the cutting length of 3.4 km. Therefore, Figure 6 (b) shows a photograph of the cutting edge which didn't fracture at the cutting length of 3.4 km.

In cutting performed by applying an external electrical-potential of anode voltage to the tool, corrosive-wear progression is considered to be more common, in comparison with normal cutting applying zero potential. As is evident from Figure 6, it is clear that the worn surfaces for all tools were affected by violent corrosive action.

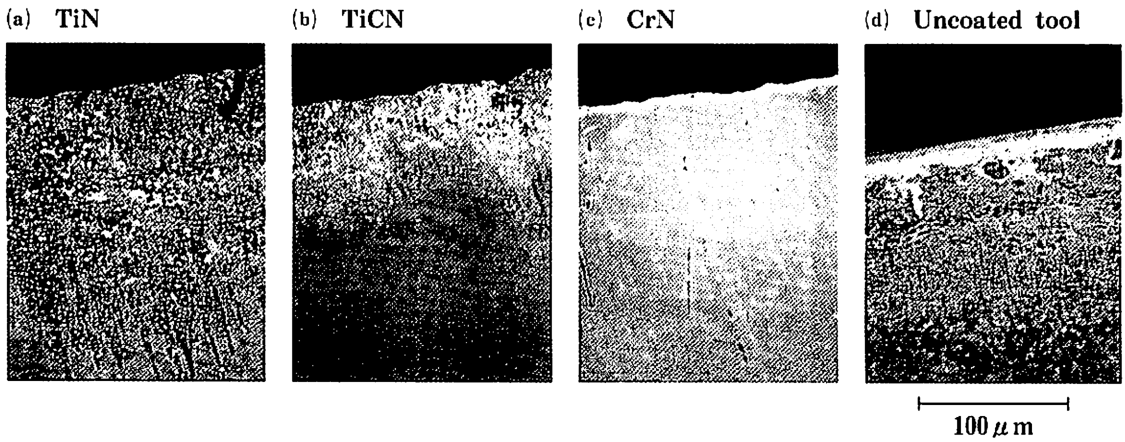

Figure 4. SEM micrographs of the rake faces for all tools in normal cutting applying zero potential

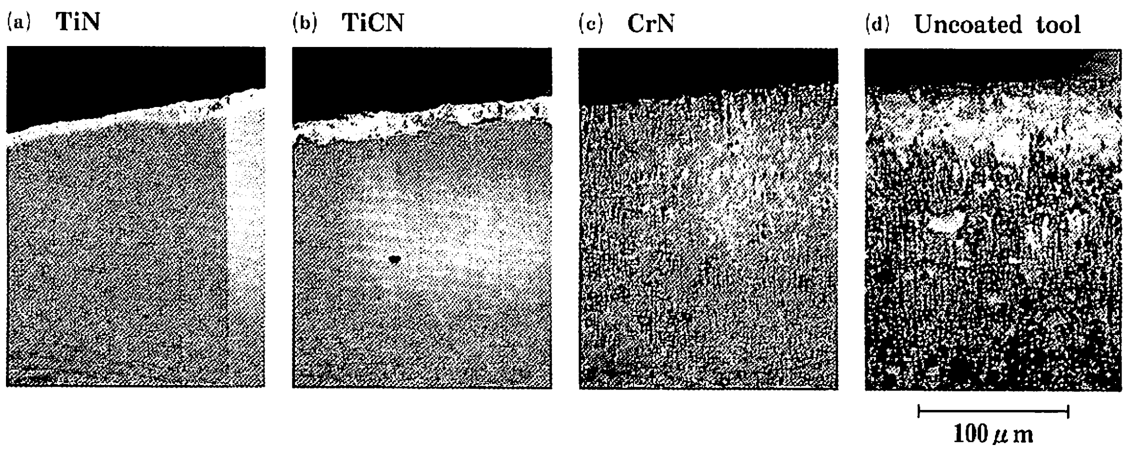

Figure 5. SEM micrographs of the rake faces for all tools in cutting at an electrical-potential of −1 kV (cathode voltage)

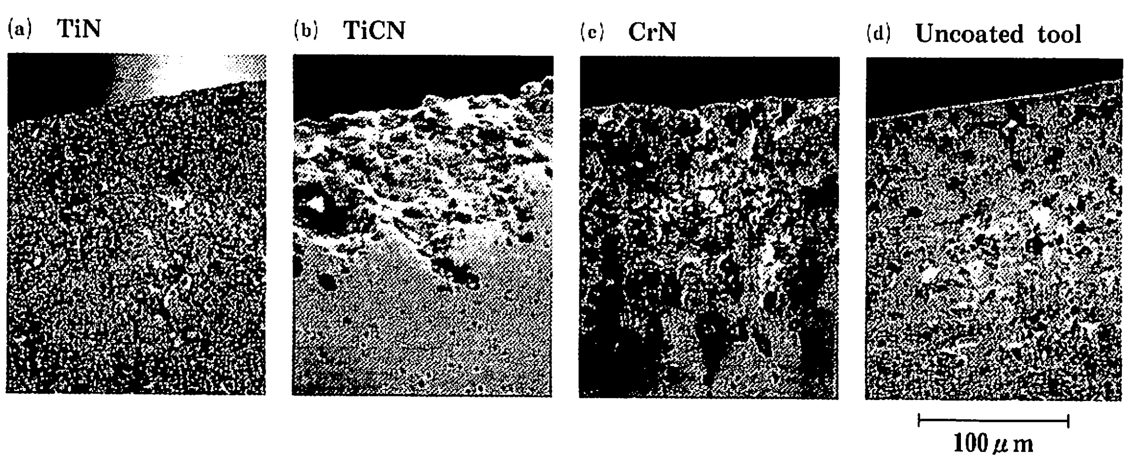

Figure 6. SEM micrographs of the rake faces for all tools in cutting at an electrical-potential of +1 kV (anode voltage)

A lot of big hollows similar to the hollow often seen by preferential removal of the cobalt binder and the release of some of the tungsten carbides of cemented carbide tools in the cutting of high moisture-content wood, performed in early research [2, 6, 7], are seen in the uncoated tool as shown in Figure 6 (d). The delamination width of the coated thin film for the TiN-coated tool was larger than that in the normal cutting. Its width was about 360 μm, and the degree of corrosion of the substrate of the tool was more severe. On the TiCN-coated tool, the worn surface within a width of about 90 μm from the cutting edge was severely damaged by corrosive action, as shown in Figure 6 (b). However, a smooth coated thin film can be observed at 90 μm from the cutting edge on the rake face. For the CrN-coated tool, it is clear that the degree of corrosion of the substrate where delamination of the thin film occurred, is more severe than that for the TiN-coated tool, as shown in Figure 6 (c).

3.2 Tool wear

3.2.1 Progression of tool wear

The progression of tool wear and changes in electric-current flow during cutting where increases in cutting length are performed, are shown for the four kinds of tools in Figure 7 (a)-(d).

From these figures, it can be seen that the edge recessions for all tools increased parabolically for all electrical-potentials. Tool-wear progression under the electrical-potential of −1 kV occurred extremely slowly, because of the suppressive effect of cathodic protection on the corrosive-wear progression. However, when applying an anode voltage of +1 kV to a tool, tool-wear progressions increase because corrosive wear is promoted.

The average value of the electric-current flowing during cutting was from 3.0 to 4.1 mA under +1 kV, and from −2.5 to −3.5 mA under −1 kV for all tools.

3.2.2. Differences in edge recession among the four kinds of tools

Edge recession for the four kinds of tools that had electrical-potential applied at a cutting length of 3.4 km are shown by bar chart in Figure 8.

In normal cutting with zero potential applied, edge recessions for the TiN-coated tool, the TiCN-coated tool, and the uncoated tool showed the same value. The CrN-coated tool showed the smallest value of edge recession. The edge recessions for all tools were larger than the thickness of the coated film. Therefore, after the coated thin film was delaminated by both corrosive action and mechanical action, the substrate of the tool appeared, and its tool-wear progression was promoted. It is clear that the delamination width for the tool coated with a CrN-thin film is the narrowest of all of the coated tools, as seen in the SEM photograph in Figure 4 (c), and that edge recession for the CrN-coated tool is smaller than that for the uncoated tool. We considered the suppressive effect of the CrN coating on the delamination of

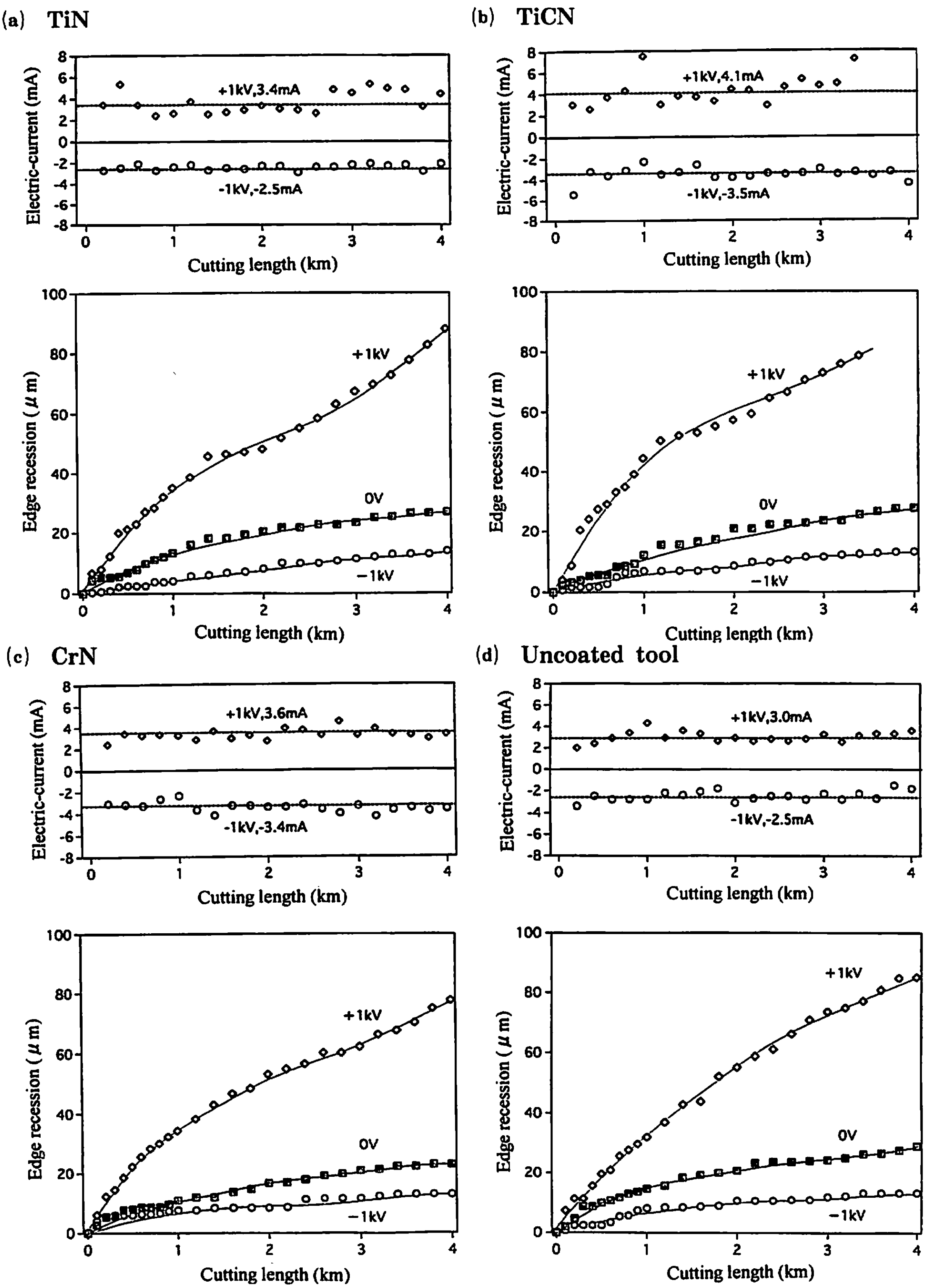

Figure 7. Progression of tool wear and changes in electric-current flow during cutting where increases in cutting length

thin film at the initial stages of cutting, and on the subsequent wear progression of the substrate of the tool, to be the most remarkable.

The amount of tool wear under the cathode voltage of −1 kV was small, due to the effect of cathodic protection for all tools. These values increased by approximately half that in normal cutting, and the difference in these values can hardly be recognized. To obtain maximum control of the corrosion environment under cutting conditions, it is necessary to consider the fact that tool wear progresses by mechanical action. The differences in edge recession among the coated tools were not visible, and edge recessions for the coated tools and the uncoated tools showed the same value. If it can be assumed that the three tools that were coated with a thin film and then delaminated have the same wear progression, then the suppressive effect of coating on tool wear progression by mechanical action, in the initial stages of cutting, can't be recognized.

Edge recessions under the anode voltage of +1 kV showed extremely large values for all tools. These values increased by approximately 3 times over those under zero voltage in normal cutting, and increased by approximately 5.1 - 6.1 times by those under the cathode voltage of −1 kV. Under such an extreme corrosive environment, the TiCN-coated tools showed almost the same edge recession as the uncoated tools, but the edge recessions for the TiN-coated tools and the CrN-coated tools were slightly smaller than that for the uncoated tools.

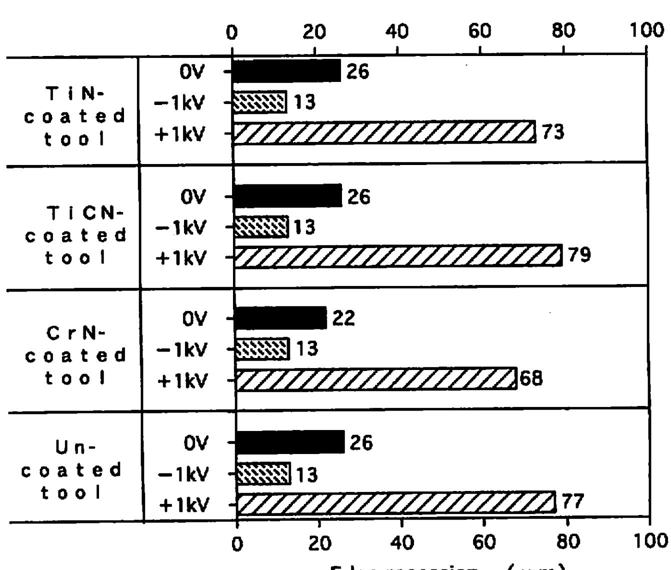

Figure 8. Edge recession for the four kinds of tools for three electrical-potentials at a cutting length of 3.4 km

3.2.3 The ratio of corrosive wear of coated tools in normal cutting

Generally, the wear mechanism of a cutting edge is considered to consist of mechanical wear, corrosive wear, thermal wear, and so on [13-16]. Tool wear in the cutting of high moisture-content wood is caused by both mechanical action and corrosive action, as mentioned above. The ratio of corrosive wear to the total edge recession under 0 V in normal cutting will be examined next.

The cathodic protection method is known as a representative method for suppressing corrosive wear. Tool wear progresses by mechanical action when corrosive wear can be completely suppressed by this method. Figure 9 shows the relationship between these. In Figure 9, edge recessions under the electrical-potential of 0 V in normal cutting and under −1 kV due to mechanical wear are represented by *Wt* and *Wm*, respectively. The value of *Wt*− *Wm*, shown as *Wc*, is edge recession due to corrosive wear. It is possible to regard the value of (*Wc* / *Wt*)×100 to be the ratio of corrosive wear to total edge recession in normal cutting (no electrical-potential).

When calculating the ratio of corrosive wear in edge recession at the final cutting length of 4.0 km for the four kinds of tools, the value for the uncoated tool was about 55%. The value for the TiCN-coated tool was 54%, almost the same value as the uncoated tool. The value for the TiN-coated tool was 48%, and that for the CrN-coated tool was the smallest value at 43%.

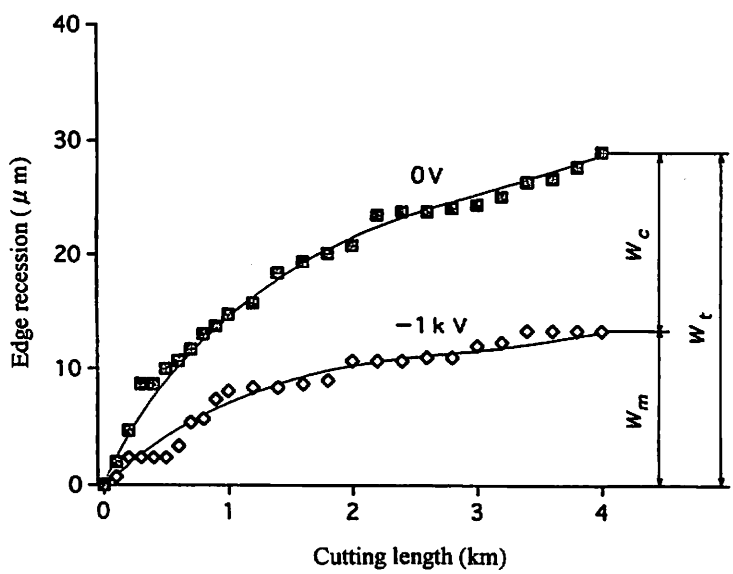

Figure 9. Wear mechanism of a cutting edge in the cutting of high moisture-content wood consists of mechanical wear and corrosive wear. *Wt*, edge recession under electrical-potential of 0V in normal cutting; *Wm*, mechanical wear; *Wc*, corrosive wear (*Wc*= *Wt*− *Wm*)

4. CONCLUSION

Both the rake faces and the clearance faces of high-speed steel tools were coated with either TiN, TiCN, or CrN. Both coated and uncoated tools were prepared for this study. Tool-life tests for the four kinds of tools were conducted by applying three kinds of electrical-potentials, to examine the characteristics of corrosive wear of coated high-speed steel tools. The results obtained are summarized as follows :

From the SEM results, it was observed that delamination of the thin film for each coated tool can be seen within a width from the cutting edge, due to both mechanical action and corrosive action, and exposure of the substrate of the tool in normal cutting occurred at the electrical potential of 0 V. The delamination width for the CrN-coated tool was the smallest among all the coated tools. In the cutting made at the electrical potential of −1 kV, the delamination of coated thin film for the CrN-coated tool film by mechanical action could not be observed. Thin film remained in the whole rake face.

In a normal cutting made at the electrical potential of 0 V, edge recessions for the TiN-coated tool, the TiCN-coated tool, and the uncoated tool were the same value, and the CrN-coated tool had the smallest edge recession. Little edge recession progressed under the cathode voltage of −1 kV, due to the effect of cathodic protection for all tools. These values increased by approximately half of that in normal cutting, and the differences in these values is hardly apparent. The edge recessions of tools under the anode voltage of +1 kV showed extremely large values for all tools. These values increased by approximately 3 times those under zero voltage in normal cuttings, and increased by approximately 5.1 - 6.1 times of those under the cathode voltage of −1 kV. Under such an extremely corrosive environment, the TiCN-coated tool showed almost the same edge recession as the uncoated tool, but the edge recession for the TiN-coated tool and the CrN-coated tool were slightly smaller than that for the uncoated tool.

When calculating the ratio of corrosive wear in the edge recessions at the final cutting length for the four kinds of tools, the value for the uncoated tool was determined to be about 55%. The value for the TiCN-coated tool was 54%, and showed almost the same value as the uncoated tool. The value for the TiN-coated tool was 48%, and that for the CrN-coated tool showed the smallest value at 43%.

Note: A portion of this paper was presented at the 48th annual meeting of the Japan Wood Research Society in Shizuoka, April, 1998.

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コーティング高速度鋼工具の腐食摩耗特性

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和文要約

本研究では，高速度鋼工具のすくい面と逃げ面にTiN，TiCN，またはCrNを被膜した各コーティング高速度鋼工具と無処理工具を用いて，ベイマツ高含水率材の平削り加工を３種類の通電条件下で行い，コーティング高速度鋼工具の腐食摩耗特性を調べた。

工具に直流電圧を与えない０Ｖの通常切削では，工具摩耗量は無処理工具が最も大きく，CrNコーティング工具が最も小さい工具摩耗量を示した。また，－１kVのカソード電圧下での工具摩耗量は，いずれの工具もカソード防食効果によって著しく小さくなり，通常切削の場合の約１／２の値を示し，供試工具による違いはほとんど認められなかった。さらに，＋１kVのアノード電圧下での工具摩耗量は，０Ｖの場合の約３倍，－１kVの場合の5.1～6.1倍の値を示し，TiNコーティング工具とCrNコーティング工具の工具摩耗量は，無処理工具よりも小さくなっていた。通常切削における工具摩耗に占める腐食摩耗の割合を求めると，無処理工具は約55％，TiCNコーティング工具は54％で無処理工具と大差ないが，TiNコーティング工具は48％であり，CrNコーティング工具は43％で最も小さい値を示した。

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