Tool Wear of Titanium/Tungsten/Silicon/Aluminum-based-coated Solid Carbide Thread Milling Cutters in Thread Tapping of Chromium-Molybdenum Steel

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In conventional tapping steels with machine taps, such as the spiral pointed tap, the spiral fluted tap, or the fluteless tap, the emission of chips has a large influence on tool damage of the tap. In particular, when tapping with taper pipe thread taps with a straight flute, the thickness of chips increases with the increase in tapping processing, these chips clog between the thread of the tap and the workpiece, and the thread of the tap very frequently causes tool breakage. It is considered that the helical milling method with thread milling cutters in thread tapping is effective against problems associated with tapping chips. Thread milling is a method for producing a screw thread by a milling operation [1]-[3]. Internal thread milling operation is possible for stable operation because chips are divided and chip clogging can be prevented. However, for internal thread tapping of chromium-molybdenum steel, there are no studies examining how to improve tool damage of pipe thread taps.

On the other hand, in order to improve resistance fractures of the thread milling cutter, cemented carbide, which has good fracture toughness, is often used as the substrate material for the tap. The physical vapor deposition (PVD) method is a widely used coating technology because of its lower treatment temperature, namely 470 K -870 K [4].

Recently, it has become possible to cut hardened steels with (Ti,Al)N-coated cutting tools. However, as machine parts are often cut at higher cutting speeds for mass production, tool materials must have excellent fracture toughness and wear resistance.

A titanium/tungsten-based coating film, namely (Ti,W)N coating film, has been developed. A (Ti,W,Si)N coating film, which is a titanium/tungsten/silicon-based coating film, has also been developed. Furthermore, titanium/tungsten/silicon/aluminum-based coating films, namely (Ti,W,Si,Al)N, (Ti,W,Si,Al)C, and (Ti,W,Si,Al)(C,N) coating films, have been developed. And, compared with commercial (Ti,Al)N, the tool wear width of the (Ti,W)N/(Ti,W,Si,Al)N-coated tool was smaller than that of the (Ti,Al)N-coated tool.

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However, it is not clear whether these coating films are effective tool materials for helical milling with a thread milling cutter.

In this study, chromium-molybdenum steel was helical milled with two physical vapor deposition (PVD)-coated cemented carbide thread milling cutters in order to clarify effective tool materials for tapping chromium-molybdenum steel. The coating films used were (Ti,Al)N and (Ti,W)N/(Ti,W,Si,Al)N coating films. Tool wear was experimentally investigated.

The main results obtained are as follows:

1) In thread tapping of chromium-molybdenum steel at a cutting speed of 0.67 m/s, the tool wear width of the (Ti,W)N/(Ti,W,Si,Al)N-coated tool is smaller than that of the (Ti,Al)N-coated tool.
2) The mean value of the friction coefficient of (Ti,W,Si,Al)N, which is the outer layer of the (Ti,W)N/(Ti,W,Si,Al)N coating system, is 0.564, and that of (Ti,Al)N is 0.817.
3) The (Ti,W)N/(Ti,W,Si,Al)N-coated cemented carbide is an effective tool material for thread tapping of chromium-molybdenum steel.

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Tool Wear of Aluminum/Chromium/Tungsten-based-coated Cemented Carbide in Cutting Hardened Sintered Steel

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A machine part having a complicated shape can be mass-produced accurately by powder metallurgy. After the sintering, the sintered material is quenched and tempered to improve the mechanical properties and wear-resistance. For dimensional accuracy, it is often necessary for the sintered steel machine parts to be machined by the metal removal process. As the sintered machine parts are often cut at high cutting speed for mass-production, the tool materials must have good wear resistance.

The polycrystalline cubic boron nitride compact (c-BN) seems to be an effective tool material because it has good heat resistance and wear resistance. However, in milling, a major tool failure of c-BN readily occurs by fracture because c-BN has poor fracture toughness. Coated cemented carbide tools, which have good fracture toughness and wear resistance, seem to be effective tool materials. TiN, Ti(C,N) and (Ti,Al)N are generally used for the coating film. So, there are many studies on the wearresistance of these coating layers. Although there are some studies on the tool wear characteristics of the PVD coated cemented carbide tools in the cutting of hardened steel or sintered steel, there are few studies on tool wear in the cutting of hardened sintered steel.

An aluminum-chromium based coating film, namely (Al,Cr)N coating film, which exhibits a superior critical scratch load, has been developed. The aluminum-chromium based coated tool was evaluated through the machining of sintered steel, and showed greatly improved performance. So, the effectiveness of the aluminum-chromium coating film is clear when cutting hardened sintered steel.

As a result, it was 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 the (Al,Cr)N coated cemented carbide is an effective tool material in cutting hardened sintered steel. However, it was considered from the results of our study that the critical scratch load, which is the measured value by scratch test, of the (Al,Cr)N coating film is 77 N and the micro-hardness is 2760 HV0.25N. 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 in adding tungsten (W) to the cathode material of the aluminum/chromium target.

In this study, to clarify the effectiveness of aluminum/chromium/tungsten coating film for cutting hardened sintered steel, tool wear was experimentally investigated. The hardened sintered steel was turned with the aluminum/chromium/tungsten-based coated tool according to the physical vapor deposition (PVD) method. Moreover, the tool wear of the aluminum/chromium/tungsten-based coated tool was compared with that of the (Al,Cr)N and (Ti,Al)N coated tools.

The following results were obtained:

(1) In cutting hardened sintered steel at the cutting speed of 0.42 m/s using the (Al60,Cr25,W15)N, the (Al60,Cr25,W15)(C,N), the (Al64,Cr28,W8)(C,N), the (Ti,Al)N and (Al,Cr)N coated tools, the wear progress of the (Al64,Cr28,W8)(C,N) coated tool became the slowest among that of the five coated tools.

(2) The wear progress of the (Al60,Cr25,W15)(C,N) coated tool was almost equivalent to that of the (Al64,Cr28,W8)(C,N) coated tool. However, at a high cutting speed of 1.67 m/s, the wear progress of the (Al60,Cr25,W16)(C,N) coated tool was faster than that of the (Al64,Cr28,W8)(C,N) coated tool.

The above results clarify that the (Al64,Cr28,W8)(C,N) coating film, which is a new type of coating film, has both high hardness and good adhesive strength, and can be used for tool material in cutting hardened sintered steel.

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Wear Mechanism of Aluminum/Chromium/Tungsten-based-coated Cemented Carbide Tools in Dry Cutting of Hardened Sintered Steel

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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 showed greatly improved performance [1]. So, the aluminum-chromium coating film is effective when cutting hardened sintered steel [2].

As a result, it was 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 the (Al,Cr)N coated cemented carbide is an effective tool material in cutting hardened sintered steel [2]. However, it was considered from the results of our study that the critical scratch load, which is the measured value by scratch test, of the (Al,Cr)N coating film is 77 N and the micro-hardness is 2760 HV0.25N. 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 in adding tungsten (W) to the cathode material of the aluminum/chromium target [3]. Furthermore, the hardened 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. And, compared with commercial (Al,Cr)N and (Ti,Al)N coated cemented carbide tools, at a low cutting speed of 0.42 m/s, the wear progress of the (Al64,Cr28,W8)(C,N) coated tool became the slowest among that of the five coated tools and the wear progress of the (Al60,Cr25,W15)(C,N) coated tool was almost equivalent to that of the (Al64,Cr28,W8)(C,N) coated tool. At a high cutting speed of 1.67 m/s, the wear progress of the (Al60,Cr25,W16)(C,N) coated tool was faster than that of the (Al64,Cr28,W8)(C,N) coated tool [3]. However, the tool wear mechanism of aluminum/chromium/tungsten-based-coated cemented carbide in cutting hardened sintered steel has not been clarified. And, the characteristics of aluminum/chromium/tungsten-based coating films have not been clarified either.

In this study, to clarify the tool wear mechanism of the aluminum/chromium/tungsten coating film for cutting hardened sintered steel, SEM observation and EDS mapping analysis were carried out on an abraded surface. Furthermore, the characteristics of aluminum/chromium/tungsten-based coating films were investigated.

The following results were obtained:

(1) The main wear mechanism of both the (Al60,Cr25,W15)(C,N) and the (Al64,Cr28,W8)(C,N) coating films was considered to be abrasive wear.

(2) The micro-hardness of the (Al60,Cr25,W15)(C,N) or the (Al64,Cr28,W8)(C,N) coating film was 3080 HV0.25N or 3050 HV0.25N, respectively.

(3) The critical scratch load of both the (Al60,Cr25,W15)(C,N) and the (Al64,Cr28,W8)(C,N) coating films was over 130 N.

(4) The mean value of the friction coefficient of the (Al64,Cr28,W8)(C,N) coating film, 0.53, was smaller than that of the (Al60, Cr25,W15)(C,N) coating film, 0.63.

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