Tool Wear of Aluminum/Chromium/Tungsten/Silicon-Based-Coated Solid Carbide Thread Milling Cutters in Thread Tapping of Chromium-Molybdenum Steel

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When tapping with taper pipe thread taps with a straight flute, the thickness of chips increases with the increase in tapping processing, these chips become clogged 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 of 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.

An aluminum/chromium-based coating film, namely (Al,Cr)N coating film, has recently been developed. An aluminum/chromium-based coated tool was evaluated through the machining of sintered steel, and showed greatly improved performance [4]. It was clarified that the (Al,Cr)N-coated cemented carbide is an effective tool material for cutting hardened sintered steel [5]. To improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, the cathode material of an aluminum/chromium/tungsten target was used in adding tungsten (W) to the cathode material of the aluminum/chromium target [6]-[8]. Furthermore, to improve the tool life in cutting hardened steel, the cathode material of an aluminum/chromium/tungsten/silicon target was used in adding silicon (Si) to the cathode material of the aluminum/chromium/tungsten target [9]. In this report, the new (Al60, Cr25, W15)(C, N) coating film has both high hardness and good adhesive strength, and can be used as a tool material in cutting hardened steel.

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 (ISO 34CrMo4, AISI 4137) was helical milled with two physical vapor deposition (PVD)-coated cemented carbide end thread milling cutters in order to determine effective tool materials for tapping chromium-molybdenum steel. The coating films used were (Ti,W)N/(Ti,W,Si)N and commercial (Ti,Al)N coating films. The inner layer of the (Ti,W)N/(Ti,W,Si,Al)N coating system is (Ti,W)N coating film, and the outer layer is (Ti,W,Si,Al)N coating film. In order to identify an effective tool material for thread tapping of chromium-molybdenum steel, tool wear was experimentally investigated.

The main results obtained are as follows:

(1) The critical scratch load measured value by the scratch tester of the (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N) coating film was over 130 N.
(2) In thread tapping of chromium-molybdenum steel at a cutting speed of 1.00 m/s, the tool wear width of the (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N)-coated tool was smaller than that of the (Al,Cr)N-coated tool.
(3) It was possible for the (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N)-coated thread milling cutter to perform stable tapping for a long period.

The above results clarify that the (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N) coating film, which is a new type of coating film, has both high hardness and good adhesive strength, and can be used as a coating film for WC-Co cemented carbide cutting tools. Moreover, the new (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N) coating film can be used as a tool material in thread tapping of chromium-molybdenum steel.

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Tool Wear of Sintered Cubic Boron Nitride Compact in Cutting Hardened Steel with High-Pressure Coolant Supplied

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Hardened steel is used for dies and molds, and is quenched and tempered to improve its mechanical properties and wear resistance. For dimensional accuracy, hardened steel is machined by the metal removal process. High-speed cutting is an effective method of improving productivity. As, the cutting temperature rises very high in high-speed cutting, the tool materials require both good wear-resistance and heat-resistance, and the cutting parts must be cooled for efficacy and efficiency.

Polycrystalline cubic boron nitride compact (cBN) seems to be an effective tool material because it has better features as a tool material such as hardness, heat-resistance, etc. There are many studies on the tool wear of cBN tools [1, 2, 3, 4]. However, the cutting performance of cBN tools depends on the content of both the cBN grain and the binding phase [5], the binding phase [6]. Therefore, an effective binding phase, etc. for cBN tools should be selected for cutting hardened steel.

High-pressure coolant cutting is effective for reducing the cutting temperature. For this reason, many studies on high-pressure coolant cutting have recently been carried out.

Itakura et al. [7] reported that high speed cutting of Inconel 718 was attempted at increased cutting fluid flow rate by injecting fluid at a high pressure to the cutting edge. As a result, as the injection speed of the cutting fluid went up, the cutting temperature was reduced and flank wear was reduced. Thus, high-pressure coolant cutting is considered effective for reducing tool wear [8, 9, 10]. Further, the improvement of chip control, particularly chip breaking performance, is also expected by the high-pressure coolant supplied [11].

However, the influences of both the cutting speed and the coolant pressure on merchantability in high-speed cutting hardened steel with high-pressure coolant supplied have not been reported.

In this study, hardened steel was turned with high-pressure coolant supplied, the chip configurations, the tool wear and the surface roughness were experimentally investigated. The hardened steel used was an ASTM D2 cold-worked die steel (60HRC).

The results are as follows:

(1) In turning with high-pressure coolant supplied, the effectiveness of chip breaking performance was improved. In this case, the chip length was shorter with the increase of the coolant pressure, and the chip length was longer with the increase of the cutting speed.

(2) In the case of a cutting speed of 10.00 m/s, large wear on the flank face was observed in dry cutting. It was possible to suppress the tool wear on the flank face with high-pressure coolant supplied.

(3) In the high-pressure coolant cutting method of hardened steel with a cBN tool at a cutting speed of 10.00 m/s, the cBN grain size of 5.0 μm, 45 cBN grain/55 binding phase and main element of the binder phase of TiCN-Al was an effective tool material. And, the surface roughness by cutting with this cBN tool was almost constant up to a cutting distance of 1080 m.

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Cutting Performance of Electroplated Diamond Drill with V-Shaped Groove and through Coolant Hole in Drilling Cemented Carbide

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Cemented carbides have been developed as a material for cutting tools. They was first demonstrated at the Spring Fair at Leipzig in 1927, cutting cast-iron and 12% manganese steel at 2-3 times the normally accepted cutting speeds [1]. Due to the excellent mechanical properties of cemented carbides, such as compressive strength, hardness and toughness they are used for wear resistant material [2], such as drawing dies, molds, rolling rolls etc., in addition to the cutting tool. Cemented carbides are generally machined to improve the dimensional accuracy after sintering. Owing to the high material hardness, machining is generally performed with diamond grinding wheels [3]. Resin-bonded diamond wheels are usually used for grinding various cemented tungsten carbides [4].

For machining difficult-to-cut materials, such as tungsten carbide, micro-electrical discharge machining (EDM) is one of the most effective methods for making holes because the hardness is not a dominant parameter in EDM [5]. However, as die sinking EDM requires the use and subsequent production of tool electrodes, machining time is longer and costs higher than cutting methods such as milling by a machining center [6]. The method with a diamond drill is considered one of the most effective methods for making holes. There have been many studies on drilling ceramics by diamond drills [7-9]. However, few studies on drilling cemented carbides have been reported.

Cutting Performance of Electroplated Diamond Drill with V-Shaped Groove and Through Coolant Hole in Drilling Cemented Carbide

In this study, cemented carbides were holed by electroplated diamond drills with a through coolant hole. Two types of drills with different flute shape, namely with a V-groove and without a V-groove, were used. Furthermore, two types of cemented carbides with different hardness were used, too.

The following results were obtained:

(1) None of the drilled holes showed noticeable burrs or corner dullness.
(2) The main tool failure of the electroplated diamond drill was the flaking of the diamond layer on the drill tip.
(3) The addition of the V-groove on the drill tip extended the tool life by 1.7 times.
(4) Both the drilled hole's diameter of the entrance side and that of the outlet side decreased with the increase of the drilled hole length.
(5) The tool life of the electroplated diamond drill was dependent on the hardness of the cemented carbide.

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Tool Wear of Aluminum/Chromium/Tungsten/Silicon-Based-Coated End Mill Cutters in Milling Hardened Steel

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Hardened steels used for dies or molds are widely cut as a substitute for grinding. Polycrystalline cubic boron nitride (cBN) compact tools are used for cutting hardened steels, due to their high hardness and high thermal conductivity. However, in milling, major tool failure of cBN readily occurs by fracture because cBN has poor fracture toughness. Coated cemented carbide is an effective tool material for milling hardened steels because it has good fracture toughness and wear resistance. The physical vapor deposition (PVD) method is widely applied to cutting tools because it enables the application of coatings at relatively low treatment temperature and high adhesion of the deposition to the substrate. In this case, titanium based films (e.g. TiN, (Ti,Al)N) are generally used as the coating film [e.g. 1, 2].

An aluminum/chromium-based coating film, namely (Al,Cr)N coating film, has recently been developed. An aluminum/chromium-based coated tool was evaluated through the machining of sintered steel, and showed greatly improved performance [3]. It was clarified that the (Al,Cr)N coated cemented carbide is an effective tool material for cutting hardened sintered steel [4]. To improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, the cathode material of an aluminum/chromium/tungsten target was used in adding tungsten (W) to the cathode material of the aluminum/chromium target [5,6]. Furthermore, to improve the wear-resistance of the cutting tool, the cathode material of an aluminum/chromium/tungsten/silicon target has been developed in adding silicon (Si) to the cathode material of the aluminum/chromium /tungsten target. However, it is not clear whether aluminum/chromium/tungsten/silicon-based-coating films are effective tool materials for milling hardened steel.

In this study, hardened steel was milled with three PVD-coated cemented carbide end mill cutters in order to clarify effective tool materials for milling hardened steel (AISI D2, 60HRC) at the cutting speed of 2.5 m/s. The coating films used were two types of aluminum/chromium/tungsten/silicon-based-coating films and (Ti,Al)N-coating film. The tool wear of three PVD-coated end mill cutters was experimentally investigated in milling hardened steel.

The main results obtained are as follows:

(1) In milling hardened steel at a cutting speed of 2.5 m/s, Type II coating film was the best coating material among the three types of coated film. The Type I coating film was superior to the (Ti,Al)N-coating film.

(2) The critical scratch load of both Type I and Type II of over 130 N was larger than that of the (Ti,Al)N-coating film of 65 N.

(3) The multi-layered structure is expected to improve the tool life.

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Tool Wear of Multi-layer AlCrWN/AlCrWSiN-Coated Cemented Carbide in Cutting Hardened Sintered Steel

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An aluminum-chromium based coating film has been developed. Comparing the performance of AlCrN coated tool inserts with that of TiN coated ones, the former can achieve approximately 33% more depth of cut and can attain higher cutting speed due to better thermal resistance of the coated inserts [1]. In milling, the tool life of the end mills with the TiAlN coating is much lower as compared to the cutting tools with the AlCrN coatings [2-3]. As a result, the wear progress of the AlCrN coated cemented carbide tool was slower than that of the TiN or the TiAlN coated cemented carbide tool. However, the results of our study indicate that the critical scratch load, which is the value measured by the scratch test, of the AlCrN 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 AlCrN coating film, cathode material of an Al-Cr-W target was used in adding tungsten (W) to the cathode material of the Al-Cr target [4]. The AL-Cr-W based coating film has both high hardness and good adhesive strength, and can be used as a coating film of WC-Co cemented carbide cutting tools [4]. Furthermore, the addition of W reduces friction [5-6].

The addition of Si to TiN coatings transforms the [111] oriented columnar structure into a dense finely grained structure, and thin films of Ti-Si-N have been deposited by physical vapor deposition to improve the wear resistance of TiN coatings [7]. Cutting experiments have shown that the TiAlSiN coated end mill with Si content of 4.78 at.% had the least flank wear, the milling distance of which was improved about 20% more than the TiAlN coated end mill. Furthermore, the hardness of the AlCrSiWN coating film is higher than that of the AlCrN at temperatures below 700 degrees Celsius, and the addition of Si leads to grain refinement and significantly affects the phase composition and the mechanical properties owing to the formation of amorphous Si3N4 and .

Many multi-layer coating materials to improve the tool life have been developed. The wear progress of the multilayered AlCrWCN/AlCrWSiCN-coated tool was slower than that of the monolayer AlCrWSiCN-coated tool in cutting hardened steel at a feed rate of 0.2 mm/rev. However, the tool wear of the multi-layer AlCrWN/AlCrWSiN-coated tool has not been clarified. The characteristics of the multi-layer AlCrWN/AlCrWSiN-coated coating film have also not been clarified.

In this study, in order to clarify the effectiveness of the multi-layer AlCrWN/AlCrWSiN-coated cemented carbide tool, the wear progress was investigated in cutting hardened sintered steel using the three types of coated tools. Namely, Tool I had the dual-layer (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N)-coating film, Tool II had the multi-layer (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N)-coating film and Tool III had the multi-layer (Al60,Cr25,W15)N/(Al53,Cr23,W14,Si10)N-coating film.

The following results were obtained:

(1) The main tool failure of the three types of coated tools was the flank wear within the maximum value of the flank wear width of 0.2 mm.
(2) The critical scratch load of the three types of coated tools was 130 N or more.
(3) The micro-hardness of Tool III 3000 HV0.25N was highest among the three types of coated tools.
(4) The mean value of the friction coefficient of the (Al53,Cr23,W14,Si10)N coating film, 0.21, was approximately half that of the (Al53,Cr23,W14,Si10)(C,N) coating film, 0.41.
(5) In the case of the higher cutting speed, the wear progress of the multi-layer coating system was slower than that of the dual-layer coating system.
(6) In the case of cutting hardened sintered steel using the multi-layer coated tool, the wear progress of the Type III coated tool was slower than that of the Type II coated tool.

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