Tool Wear of Polycrystalline Cubic Boron Nitride Compact Tools in Cutting Hardened Steel

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In recent years, many difficult-to-cut materials such as hardened steels, sintered steels, cast irons, etc., are widely used. One of these difficult-to-cut materials, hardened steels, are quenched and tempered to improve their mechanical properties and wear resistance. For dimensional accuracy, hardened steels are required to be machined by the metal removal process. As these steels are required to be machined under high efficiency to improve productivity, it is necessary that the tool materials have good wear resistance. Polycrystalline cubic boron nitride compact (cBN) seems to be an effective tool material because it has better features as a tool material such as good heat resistance, high hardness, etc. So, concerning the cutting of hardened steel, there are many studies on the tool wear of cBN tools [1, 2]. However the cutting performance of cBN tools depends on the binding material, etc. [3, 4, 5]. Therefore, an effective binding material, etc. for cBN tools should be selected for the cutting of hardened steel. Furthermore, in a cBN tool, the cutting edge is often formed by chamfering plus honing so as to improve both the strength of the cutting edge and the chipping resistance. And the shape of the chamfered and honed cutting edge, namely the chamfer width and chamfer angle, influences the tool wear.

In this study, in order to identify an effective cBN tool for the cutting of hardened steel, the influences of both the cBN content and the cBN particle size on tool wear at various cutting speeds was experimentally investigated. The hardened steel used was an ASTM D2 cold-worked die steel (JIS SKD11, 60HRC).

The hardened steel was turned with three kinds of cBN tools, which had different contents ratios, different cBN particle sizes, and different binding materials. Furthermore, three kinds of chamfered and honed cutting edges were also used. This will contribute to improvement of productivity in the case of cutting hardened steels.

The main results obtained are as follows:

(1) In the case of the cBN tool with a cBN particle size of 5.0 μm, the tool life of the cBN tool with a cBN content of 75% was longer than that of the cBN tool with a cBN content of 45% at low cutting speed. However, at high cutting speed, the tool life of the cBN tool with a cBN content of 75% became shorter.

(2) The tool life of the cBN tool with both a cBN content of 55% and a cBN particle size of 0.5 μm was the longest.

(3) The tool wear of cBN tools decreased with a decrease in chamfer width.

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Surface Modification of Aluminum Alloy using Plasma Based Ion Implantation and Deposition

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Aluminum alloy has a high strength-to-weight ratio, good corrosion resistance and easy recyclability. In finish cutting at a small feed rate, it has a negative influence on the cutting operation because of continuous chips. Usually, Pb and Bi are added in order to break the continuous chips. The chips become brittle because Pb or Bi, which have a low melting point, are dissolved by the cutting heat, and the chips are broken easily. Therefore, free-machining aluminum alloys such as 6262 aluminum alloy, containing 0.4～0.7mass percent Pb and Bi, are widely used. However, the use of Pb will be prohibited to avoid environmental damage, and it is necessary to improve the chip breakability without adding Pb. In order to clarify the influence of the Si contents added to the 6061 aluminum alloy on the chip control performance, aluminum alloys that have different Si contents, namely 2 mass%, 4 mass%, 6 mass% Si, were drilled with a high speed steel drill. A previous study reported that Si addition increases the chip breaking performance [1]. Moreover, it was reported that Si addition increases the chip breaking performance in the case of turning with a high speed steel tool, too[2].

Aluminum alloys are used for mechanical parts, but the alloys have poor wear-resistance. To increase their wear resistance, a hard coating is applied to the surface of the alloys. Diamond-like carbon (DLC) is applied in surface modification technology due to its superior mechanical characteristics such as wear and abrasion resistance, low friction, high hardness, anti-reflectiveness, etc. In order to improve the wear resistance of 6061 aluminum alloy, a new surface modification method was presented [5]. In this method, the inner layer of anodic oxide coating, the intermediate layer of CrN layer and the outer layer of DLC layer was used. Moreover, this method is indicated for DLC coating of aluminum alloys having different Si contents. However, in this method, it is necessary to reduce production costs. In addition, adhesion between the substrate and the DLC is slightly inferior.

In this study, in order to clarify an effective surface modification to improve the wear resistance of aluminum alloys, a new coatings-substrate system was developed. This new coating-substrate system consists of nitriding pretreatment of the substrate, the intermediate layer of the silicon-based film and the outer layer of the DLC film using plasma based ion implantation and deposition (PBIID). The DLC film was deposited on three kinds of aluminum alloys that have the different Si contents, by this coatings-system. In order to determine the influence of the Si contents on the mechanical properties of the DLC film, SEM observation of the cross section of the coating layer, the adhesion and the wear resistance of the coating layers were experimentally investigated.

As a result, the increase of the Si contents showed no negative influence upon the mechanical properties of the DLC film.

The main results obtained are as follows:

(1) In the case of the DLC un-coated aluminum alloys, rapid progress of the friction coefficient in the case of the 10-N load was found at the short sliding distance.

(2) The hardness of the DLC film was not decreased with the increase of Si contents. And the increase of Si contents did not have a negative influence upon the hardness of the DLC film.

(3) The frictional coefficient of the Al-4%Si alloy was the smallest, the frictional coefficient of the DLC film was decreased with the increase of Si contents, and it was effective for improvement of the frictional coefficient to increase Si contents.

As mentioned above, it is clear that the new coating-substrate system is effective for improving the adhesion between the substrate of the aluminum alloy and the DLC film. Moreover, the increase of the Si contents does not have a negative influence upon the mechanical properties of the DLC film, rather, the increase of Si contents was effective for decreasing the frictional coefficient.

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Tool Wear of Diamond-like Carbon-coated High-speed Steel with a Cr-based interlayer in Cutting of Aluminum Alloys

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As 6061 aluminum alloy has both a high strength-to-weight ratio and good corrosion resistance, it is used for automobile parts or motorbike parts. In finish cutting at a low feed rate, it has a negative influence on the cutting operation because of continuous chips. Usually, Pb and Bi are added in order to break these continuous chips. The chips become brittle because Pb or Bi, which has a low melting point, is dissolved by the cutting heat, and the chips are easily broken. Therefore, free-machining aluminum alloys such as 6262 aluminum alloy, containing 0.4～0.7 mass percent Pb and Bi, are widely used. However, from the standpoint of environmental protection, it is necessary to improve chip breakability without adding Pb. In order to clarify the influence of Si content added to 6061 aluminum alloy on chip control performance, aluminum alloys having different Si contents were drilled by a high-speed steel drill. As a result, it was found that Si addition increases chip breaking performance [1]. Next, 6061 aluminum alloy-based Al-Si alloys, which have different Si contents, were cut with a high-speed steel tool. The tool wear was investigated experimentally. The tool wear increased with an increase in Si content [2]. There are various methods of surface modification technology for giving wear resistance to the surface of a material. In surface modification technology, hard materials such as ceramics are coated onto the surface of another material. Diamond-like carbon (DLC) is coated onto the surface of high-speed steel tools to improve their wear resistance. So, aluminum alloys were turned by a DLC-coated cutting tool, and tool wear was investigated experimentally. As a result, in cutting Al-2%Si alloy, the wear progress of the DLC-coated tool is slower than that of the uncoated tool, and the effect of wear resistance of the diamond-like carbon is recognized. However, in cutting Al-4%Si alloy, there is little difference in the wear progress between the DLC-coated tool and the uncoated tool [3]. The multilayer coating system is designed to have both good substrate adhesion of the inner coating film and superior wear resistance of the outer coating film. However, in the concept of the design of a multilayer coating system, not much information is available in the open literature on "suitable" constituent materials to be chosen as the inner layer, intermediate layer(s), and outer layer [4]. Therefore, a Cr-based interlayer, namely (Al,Cr)N, was developed as an intermediate layer and it is effective for improving the wear resistance of DLC-coated tools.

In this study, in order to clarify the influence of a diamond-like carbon (DLC) coating layer with a Cr-based interlayer, namely (Al,Cr)N, on cutting performance, aluminum alloys having different Si contents were turned. The substrate of the tool material was high-speed steel (1.4%C). Tool wear and surface roughness were experimentally investigated.

The following results were obtained:

(1) In cutting two kinds of Al-Si alloys, namely Al-2%Si alloy and Al-4%Si alloy, the wear progress of the DLC/(Al,Cr)N-coated tool was slower than that of the DLC-coated tool. Therefore, the (Al,Cr)N interlayer was effective for decreasing the tool wear of the DLC-coated tool.

(2) The wear progress of the two kinds of the DLC-coated tools in cutting of Al-4%Si alloy was faster than that in cutting of Al-2%Si alloy.

(3) In cutting of Al-2%Si alloy with a (Al,Cr)N/DLC-coated tool, the surface roughness was almost constant in the range of a cutting distance from 0.1 km to 9.5 km.

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Properties of TaN Coating Film Deposited on WC-Co-based Cemented Carbide using Magnetron Sputter Ion Plating

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Various methods of surface modification technology are available for yielding high function characteristics such as wear-resistance, lower or higher friction coefficient, corrosion-resistance and thermal-resistance on the surface of the material. Generally, the coating of a hard material like ceramic on the surface of a material is a popular surface modification technology. The physical vapor deposition (PVD) method, which is one of the coating technologies, is widely used because it can be coated at a lower treatment temperature of 470K – 870K [1].

In cutting, e.g. turning, milling, drilling and tapping, coated cemented carbide tools, which have good fracture toughness and wear resistance, seem to be effective tool materials. In this case, the titanium based films (e.g. TiN, (Ti,Al)N) are generally used as the coating film [e.g. 2, 3].

On the other hand, in cutting carbon steel with WC(tungsten carbide)-Co cemented carbide tools at high cutting speed, the wear resistance (in particular crater-wear-resistance) can be improved by adding TiC and TaC to WC-Co cemented carbide [4]. The thermal stability of TiC and TaC is better than that of WC at high temperature, the affinity with Fe of TiC and TaC is lower than that of WC, and the oxidation resistance (anti-oxidation) of TiC and TaC is higher than that of WC. Furthermore, the strength of WC-Co cemented carbide at room temperature is decreased by adding TiC and TaC to WC-Co cemented carbide; however, both the strength at high temperature and the creep-resistance of WC-Co cemented carbide can be improved by adding TiC and TaC to WC-Co cemented carbide [5].

On this account, in cutting carbon steel with WC-Co cemented carbide tools, adding TiC and TaC to WC-Co cemented carbide is effective for improvement of the wear resistance of WC-Co cemented carbide [4]. Therefore, the titanium based films are generally used widely as the coating films. However, the tantalum based films (e.g. TaN, TaC) are not applied as the coating film for cutting tools because the melting point of TaC is higher than that of TiC. Moreover, it is unclear whether TaN coating film can be used as a coating film of WC-Co cemented carbide cutting tools.

In this study, in order to clarify the effectiveness of tantalum (TaN) coating film, TaN coating film was formed on the surface of the substrate which was a cemented carbide ISO K10 by the magnetron sputter ion plating process, and the thickness, the hardness and the scratch strength (critical load measured by scratch tester) of TaN coating film were measured. The hardened steel ASTM D2 (JIS SKD11) was turned with two types of PVD coated cemented carbide tools, namely TaN and (Ti,Al)N coated cemented carbide tools. The tool wear of the TaN coated cemented carbide tool was experimentally investigated and compared with that of the (Ti,Al)N coated tool. The substrate base metal of the coated carbide tools is cemented carbides ISO K10.

The following results were obtained:

(1) Droplets on the surface of the TaN coating film, which has the K10 substrate, were negligible.

(2) The micro-hardness of TaN coating film 2510HV was higher than that of TiN coating film 2090HV, and there was little difference in hardness between the TaN 2510HV and (Ti,Al)N 2710HV.

(3) The critical scratch load of TaN coating film over 130N was higher than that of TiN coating film 68N or (Ti,Al)N coating film 73N.

(4) In cutting the hardened steel using TaN and (Ti,Al)N coated tools, the wear progress of the TaN coated carbide tool was almost equivalent to that of the (Ti,Al)N coated carbide tool.

The above results clarify that the TaN 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 of WC-Co cemented carbide cutting tools.

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Phase diagram of thermotropic liquid crystal including negative pressure region generated in metal Berthelot tube

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Phase diagrams including absolute negative pressure regions of thermotropic liquid crystals give useful information on science and technology. For example, when the liquid crystals sealed in cells of liquid crystal displays are cooled, the liquid crystals may experience negative pressures and may occur phase transitions from nematic (N) to isotropic (I) or crystalline phases (Kr), causing the display performance to deteriorate. From a view of physical chemistry, there are reports insisting that critical points of I-N transitions for thermotropic liquid crystals are hidden in the negative pressure regions which may be experimentally reached.

Unfortunately, it has been difficult to perform experiments under negative pressures because liquids subjected to negative pressures enter meta-stable and 'super-expanded' states, so that appearances of vapor phases, that is, cavitation phenomena, readily occur via heterogeneous nucleation, and liquids' pressures become saturated vapor ones.

An experimental method suitable for measuring properties of liquids under negative pressures is the Berthelot method. It has been used to stretch liquids under static conditions by subjecting liquids in containers to quasi-isochoric changes. Container materials are glasses, quartz, metals, and so on. Of these materials, metals are excellent as pressure vessels to facilitate the properties for any liquids, namely water, flammable organics and so on, though maximum negative pressures in metal are lower than those in others.

Since pressure dependencies of soft materials are strong, investigations of them under negative pressures are interesting. Thus, authors have developed the Berthelot method using a metal tube. Recently negative pressures to ca. -20 MPa for liquids have been obtained in a small-sized Berthelot tube. Studies on liquids under negative pressures have been facilitated.

In this work, a phase diagram of a thermotropic liquid crystal, 4-(4'-propylcycrohexyle)benzonitrile (PCH-3, Merck Co.), was depicted to negative pressure region on a pressure-temperature (P-T) plane. Phase transition in thermotropic liquid crystals under negative pressure was investigated by using an elaborated Berthelot method.

The Berthelot tube using a pressure transducer consists of a screw, a pressure transducer of strain gauges (Kyowa Elec. Inst. Co., PHL-A), a socket, a ball for sealing a sample liquid crystal (AKS Co.; 5/16 inch diameter), two o-rings, and a cup. The linearity of voltages as a function of pressures of the pressure transducer was assured up to +50MPa in a temperature range -196 to 200°C. The temperature dependence of its linear coefficient was approximately 0.02 %/°C. The coefficient was used to measure not only positive pressures, but also negative pressures. A validity of the application was supported by suppliers. The sample which had not been in a solid phase, was poured into the chamber on the top of the transducer, and was sealed with the ball by compressing it against a sharp edge at the opening of the chamber using the screw.

The main results are as follows: phase diagram including negative pressure region to -10 MPa for a thermotropic liquid crystal, PCH-3, was depicted by the Berthelot method using a pressure transducer. The coexisting curve was obtained under negative pressures. The tube is useful as a tool for drawing the diagram for any thermotropic liquid crystal. The polymorphism of the crystalline phase of PCH-3 was newly discovered.

回転型連理返りの工作

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Making of “Renrigaeri-doll” Having Ability of Rotation

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小学校高学年を対象とした公開講座にて，からくり人形「回転型連理返り」の工作を行った．からくり人形は環境に優しい省エネ技術として工場などの生産現場で注目されている．参加者アンケート調査の結果，19名中17名からアンケートの回答を得，すべて満足であった．以下，工作の概要と改良点について報告する．

連理返りは，筒2本で連結された人形2体を階段の上下段に置くと筒内を移動できる水銀の重さにより，上段の人形が下段の人形を飛び越え階段を降りていく，というからくりである．人形が動作するのは，人形腕部を回転中心とした水銀の重さによるモーメントが生じるためである．

人形の飛越方法には，人形がその姿勢を保持したまま飛越する無回転型と，人形同士が糸で繋がれ一回転して飛越する回転型の2通りあり，講座では回転型の方がダイナミックな動作をするため，回転型を取り上げた．

工作にあたっては身近で安価な材料を用いることにし，筒はストローで，人形はバルサ材や竹ひごで作った。また本来の連理返りでは筒内に水銀が使用され，筒中央部に水銀移動を遅らせる隔板がある．これは着地を安定させるためのものである．工作では水銀は有毒なため使用できない．そこで市販の金属球を用いて，隔板と同様の動作をさせるための工夫点として筒端から一定長さの数箇所に切れ込みを入れ球の降下を遅くし人形着地後に降下するようにした．こうしないと着地前に球が降下し着地が安定しなかった．

講座で工作した結果として，人形の着地成功率が7〜8割程度であったことと，人形が数段降りたとき筒端が階段の角に当たり人形が止まる現象が見受けられた．

着地失敗の原因は，回転中心と糸を取り付けるフックを結ぶ角度が大きかったことである．回転型連理返りにおける人形の軌跡は，下段人形の回転中心―下段人形のフック－上段人形のフック－上段人形の回転中心－下段人形の回転中心，からなる両クランク機構をなしており，持ち上げられた上段人形が移動しながらあるところで倒立し，その後，着地するまでの間に自重によって正立する。フックの角度が大きいと倒立するまでの移動距離が長くなる．その結果，着地までの距離が短くなって正立できずに失敗する．よって着地成功率を高めるにはフックの角度を小さくすれば良く，実際に動作確認を行ったところ着地は安定した．

人形が数段降りて筒端が階段に当たったのは，2体の人形間の幅と高さが，階段のそれらと比べて短かったためである．もし人形間の幅と高さが階段のそれらに一致していれば人形の動作に伴う筒端の描く軌跡は，人形が何段降りても階段の角と接触せず筒が階段の角に当たることはない．

これに対し，人形間の幅と高さのいずれか一方でも階段のそれらより短い場合は，階段の角と人形の爪先との間にわずかな差が生じ，人形が数段降りたとき筒端が接触し筒が当たる．

人形間の幅と高さは計算によって求めることができる．これらは，筒の形状で決まる初期角度，筒を傾斜させ人形が回転し始める回転角度，回転中心間の距離の3つから求められる．実際に工作した連理返りから計算した幅と高さは，階段の幅と高さに比べると短くなっており筒端が当たった．なお，人形および階段の幅と高さを完全に一致させることは工作精度上，また人形の跳ね返りの影響もあり困難であった．そこで階段を2分割し，差が小さくなるよう間隔を調整した結果，筒端が当たらず人形は最下段まで動いた．

回転型連理返りの工作を小学生高学年の公開講座にて実施し，参加者全員が満足する結果を得，さらに動作向上のための改良を行った．試作当初は容易に動作するものと思っていたが，なかなか動作せず動作原理および試作の重要性を再認識できた．今後の課題としては無回転型の連理返りにも挑戦したい．