Tool Wear of Aluminum-Chromium 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. A diffusion alloyed powder or a completely alloyed powder is usually used as an alloyed powder for the sintered steel. The compressibility of the diffusion alloyed powder is better than that of the completely alloyed powder. 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 [1]. 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 (cBN) seems to be an effective tool material because it has good heat resistance and wear resistance [2]. However, in milling, a major tool failure of cBN readily occurs by fracture because cBN 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 wear-resistance 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 the hardened steel [3] or the sintered steel, there are few studies on tool wear in the cutting of the 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. However, the effectiveness of the aluminum-chromium coating film is unclear when cutting hardened sintered steel.

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

The main results obtained are as follows:

1) 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.
2) Because the (Al,Cr)N coating film exhibited both higher hardness and higher oxidation temperature, the wear progress of the (Al,Cr)N coated cemented carbide became slower.
3) In addition, because the cutting temperature becomes lower due to the lower coefficient of friction of the (Al,Cr)N coating film, the wear progress of the (Al,Cr)N coated cemented carbide became slower.
4) In cutting hardened sintered steel with a (Al,Cr)N coated cemented carbide tool, there was little influence of the cutting speed on the tool wear within the range of the cutting speed from 0.50 m/s to 1.00 m/s.

As mentioned above, it was clear that the (Al,Cr)N coated cemented carbide is an effective tool material in cutting hardened sintered steel.

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Tool Wear of (Ti,W,Si)N-Coated WC-Ni-Based Cemented Carbide in Cutting Hardened Steel

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Cemented carbides, which are made with sintered WC particles using cobalt (Co), nickel (Ni), etc. powder as the binder material, are sintered alloys. WC-Co-based cemented carbide is widely used when cemented carbide is used as a cutting tool material. On the other hand, WC-Ni-based cemented carbide is hardly used for the cutting of other than non-ferromagnetic materials. This is the reason that WC-Ni-based cemented carbide is hardly used as a cutting tool material. In the case of the same WC particle size, the toughness of WC-Ni-based cemented carbide is higher than that of WC-Co-based cemented carbide. However, the hardness of WC-Ni-based cemented carbide is lower than that of WC-Co-based cemented carbide. Furthermore, in order to increase the hardness of cemented carbide, increasing the WC particle content is an effective method. However, in the case of WC-Ni-based cemented carbide, when the WC content increases and the Ni content decreases, bores readily occur in the cemented carbide and the strength of the cemented carbide thus decreases. This is also the reason for WC-Ni-based cemented carbide not being used as a cutting tool material.

On the other hand, Ni and Co are rare metals. In 2006¸ the reserve/production ratio (= reserves/world mine production) of Ni and Co was 41 years and 134 years, respectively. However, in 2011, the reserve/production ratio of Ni and Co is 44 years and 77 years, respectively. That is, in the last five years, the reserve/production ratio of Ni has increased slightly 1.1-fold, whereas the reserve/production ratio of Co has sharply decreased by a factor of 0.57. It is considered that much of the total demand for Co is for the lithium-ion secondary battery; consumption of the lithium-ion secondary battery will decrease while consumption of Co will increase in the future. Therefore, it is possible to switch from a Co to an Ni binder of cemented carbide, and the amount of Co, which is a rare metal, can be reduced. In addition, although price fluctuations are seen, the price per unit mass of Ni is about half that of Co.

From the above, it is considered that WC-Ni-based cemented carbide, which is hardly used as a cutting tool material, is an effective cutting tool material in terms of reduction of rare metals. WC-Co-based cemented carbide is coated in hard materials such as TiN, etc. in order to improve its wear resistance when used as a cutting tool material. Therefore, it is considered that the hardness of WC-Ni-based cemented carbide rises and wear resistance is improved by coating the WC-Ni-based cemented carbide with a hard material.

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

In this study, WC-Ni-based cemented carbide with different Ni contents was used as the substrate. The hardened steel was turned by a (Ti,W,Si)N-coated WC-Ni-based cemented carbide tool, and the tool wear was experimentally investigated. The results showed little difference between the wear progress of the (Ti,W,Si)N-coated WC-Ni-based cemented carbide tool and that of the (Ti,W,Si)N-coated WC-Co-based cemented carbide tool; it is clear that WC-Ni-based cemented carbide can be used as a substrate for (Ti,W,Si)N-coated cemented carbide tools.

The following results were obtained:

1) For the (Ti,W,Si)N-coated WC-Ni-based cemented carbide, the hardness of the coating film was not much different from the content of the binding material, Ni, and the adhesion strength increased with a decrease in Ni content.
2) There is little difference between the wear progress of the (Ti,W,Si)N-coated WC-7%Ni-based cemented carbide tool and that of the (Ti,W,Si)N-coated WC-6%Co-based cemented carbide tool.

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Phase Diagram Including a Negative Pressure Region for a Thermotropic Liquid Crystal in a 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-(methoxy phenyl)-trans-4-propyl-cyclohexane-1- carboxylate (Merck Co. D301), 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 +50 MPa 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 Berthelot system imposes two constraints about two volumes and their changes; the inner volume of the tube Vt and its change dVt must be equal to those of the sample Vs and dVs, respectively. The constraints causes a fact that slopes of pressure increases with temperature ones depend on what phases of the liquid crystal exist in the tube.

The main results are as follows: a phase diagram including a negative pressure region to ca. -5 MPa for a thermotropic liquid crystal, namely 4-(methoxy phenyl)-trans-4-propyl-cyclohexane-1-carboxylate, was depicted with the Berthelot method of a metal tube using a commercial pressure transducer. Two co-existing lines, namely Kr-N and I-N lines, were obtained, but were not intersected within the magnitude of negative pressure. Higher negative pressures, ca -40 MPa, had to been achieved to observe tri-critical point. Techniques to generate such magnitude of negative pressures are desirable and seem to be more useful as tools for drawing the diagrams for any liquids including thermotropic liquid crystals.

Design condition of a sustainable two-layer circular tube with energy absorbing capacity

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Recently, there have been a lot of earthquakes in Japan. Therefore, we should immediately develop a seismic technology for saving our lives from the earthquakes. It has already developed a seismic isolation device using seismic isolation rubber for tower buildings and others [1, 2]. However, almost all detached houses do not have seismic isolation devices attached, because the seismic isolation devices are expensive. Therefore, it is necessary to develop a low-cost seismic isolation device.

We conducted research in order to create and test a composite material for the low-cost seismic isolation device. The composite material is composed of metal square lattice filled with low rigidity material [3]. As a result, it was able to clarify that the composite material has energy absorbing capacity. However, the composite material had little energy absorbing capacity when sustainability was considered [4]. In this research, we changed to two-layer circular tubes from metal square lattice to improve sustainability.

We created a new energy absorbing device which uses a two-layer circular tube as a unit. The device is put between a foundation and pillar by using connecting pin in a detached house. Seismic energy is transmitted from the foundation to the pillar through the connecting pin and the tubes. The tube does not depend on the load direction. Moreover, if hysteresis is produced in the two-layer circular tube under lateral compression load, we think that the two-layer circular tube can have energy absorbing capacity. Therefore, we think that the device has high energy absorbing capacity. Friction should exist between outer layer and inner layer in order to occur hysteresis. Also, we should reveal a force of elastic limit to have sustainability. In this paper, we clarify contact condition between outer layer and inner layer in elastic region. We consider that the energy absorbing capacity changes depending on the size and the number of the tubes. In order to design the device, we should reveal properties of the tube. Therefore, we research the most basic properties of the tube under lateral compression load. In this paper, outer layer is made of stainless steel and inner layer is made of acrylic plastic.

We used a single circular tube for considering a contact condition of the tube under a lateral compression load. We think a relation between the y axial deformation amount δ_y and yield stress σ_a using single circular tube and mechanics of materials to deform in elastic region. We derive allowable y axial deformation amount δ_{ya} and allowable load P_a of the tube in elastic region. Furthermore, we think that the inner layer contacts with the outer layer all over the circumference if the inner layer contacts with the outer layer on x axis and y axis from the start.

The single circular tube model, which was used in the consideration, do not consider friction. Therefore, we used Finite Element Analysis to consider effects of friction. The constraint displacement was set so that the y axial deformation amount of the tube became 0.100mm. This deformation amount was allowable y axial deformation amount of the two-layer circular tube and was calculated by using the single circular tube model. As the result, we found that the maximum Von Mises stress in stainless steel at angle θ=-90°. Furthermore, the maximum Von Mises stress by using FEA is larger than the maximum bending stress calculated by using the single circular tube model. The x axial deformation amount of two-layer circular tube simulated by FEA was smaller than the x axial deformation amount calculated by the single circular tube model. One of the reasons is frictional influence. We consider that friction occurs between outer layer and inner layer near y axis. It was thought that the x axial deformation amount became small since the resistance i.e. total reaction force becomes large in consideration of frictional influence. Therefore we need to modify the contact condition by using a single circular tube model using results of FEA.

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