Study on Ductile-Brittle Transition of Single Crystal Silicon by a Scratching Test Using a Single Diamond Tool

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INTRODUCTION

Single crystal silicon is used in many fields, such as semiconductor circuits and solar batteries [1]. Single crystal silicon can also achieve ductile mode cutting when the cutting depth is less than the critical cutting depth for the ductile-brittle transition point (dc). Earlier studies suggest that many factors influence the ductile-brittle transition such as temperature dependence, crystallographic orientations, tool rake angles and cutting speeds [2]-[5]. In the recent cutting process from a silicon ingot to a silicon wafer used as semiconductor materials, a multi-wire saw with fixed diamond abrasive grains is widely used due to recent increases in wafer size [6] and reductions in wafer thickness. In this study, we conducted scratch tests of single crystal silicon using a single crystal diamond tool. The purpose of this study is to conduct basic studies for improvement of a multi-wire saw, dc was also measured while scratch speeds (Vc) were changed. We examined the relationship between Vc and thrust force (Ft) at that time.

DUCTILE-BRITTLE TRANSITION

The removal modes of brittle materials have two main material removal modes: ductile mode cutting from plastic deformation removals and brittle mode cutting from brittle fracture removals [7]–[8]. There are many conditions for the ductile-brittle transition and many influential factors.

CONCLUSIONS

Single crystal silicon can also achieve ductile mode cutting when the cutting depth is less than the critical cutting depth for the ductile-brittle transition point (dc). In this study, we conducted scratching tests of single crystal silicon using a single diamond tool at scratch speeds of 1.88, 5.65, 17.00 and 22.6 m/s. The purpose of this study is to conduct basic studies for improvement of a multi-wire saw. Also, dc was measured while scratch speeds (Vc) were changed. Moreover, we examined the relationship between Vc and cutting resistances (thrust force) at that time.

The following conclusions were obtained:

1) dc is not dependent on scratch speeds.
2) In plastic flow in ductile mode cutting, scratch marks were observed.
3) dc is about 0.5 μm at room temperature.
4) Thrust force at the ductile-brittle transition decreases by increasing scratch speeds.

REFERENCES

[1] K. Naoe, “Next-generation high-performance single crystals”, Fujikura technical journal, vol. 2, no.123, pp. 116-119, 2012(in Japanese).

[2] N. Morita, Y. Yoshida, E. Kobayashi, N. Nagata, “Study on Brittle-Ductile Transition of Monocrystal Silicon at High Temperature and its Application to Ductile Mode Cutting”, Transactions of the JSME (in Japanese), vol. 64, no.621, pp. 378-383, 1998.

[3] T. Shibata, S. Fujii, E. Makino, M. Ikeda, “Ductile-regime turning mechanism of single-crystal silicon”, Precision Engineering, vol. 18, no. 2-3, pp. 129-137, April-May. 1996.

[4] T.P. Leung, W.B Lee, X.M. Lu, “Diamond turning of silicon substrates in ductile-regime”, Journal of Materials Processing Technology, no. 73, pp. 42-48, 1998.

[5] T. Sugita, K. Ueda, K. Endo, “Possibility of plastic deformation type removal in microcutting of brittle materials”, Journal of the Japan Society for precision Engineering, vol. 52, no. 12, pp. 144-147, 1986(in Japanese).

[6] H. Oishi, K. Asakawa, K. Tsukamoto, Y. Uno, “Effects of Wire Running Speed and work Feed Rate on Multiwire Saw Slicing”, Journal of the Japan Society for precision Engineering, vol. 67, No. 5, pp. 791-796, 2001(in Japanese).

[7] M. Arif, M. Rahman, W. Yoke San, “Analytical model to determine the critical feed per edge for ductile–brittle transition in milling process of brittle materials”, International Journal of Machine Tools and Manufacture, vol. 51, No. 3, pp. 170-181, March. 2011.

[8] P. Feng, C. Zhang, Z. Wu, J. Zhang, “Effect of Scratch Velocity on Deformation Features of C-plane Sapphire during Nanoscratching”, Journal of Mechanical Engineering, vol. 59, No. 6, pp. 367-374, 2013.

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Tool Wear of Poly Crystalline Diamond in Cutting Ti-6Al-4V Alloy with High-Pressure Coolant Supplied

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INTRODUCTION

TITANIUM alloys have high strength, low density, and corrosion resistance. Titanium alloys such as nickel-based types have a very high strength-to-weight ratio, making them very suitable for aircraft engines and airframe manufacture [1]. For dimensional accuracy, titanium alloys are machined using the metal removal process. Titanium and titanium alloys have low thermal conductivity and high chemical reactivity with many cutting tool materials [2]. Hence, on machining, the cutting tools wear very rapidly due to the high cutting temperature and strong adhesion at the tool-chip interface and tool-workpiece material interface [2]. The machinability of titanium and its alloys is considered to be poor owing to several inherent properties of the materials [3]. At the higher cutting speed, the chemical and mechanical properties of Ti-6Al-4V cause complex wear mechanisms such as adhesion and diffusion [4]. Therefore, during the machining of the titanium alloy, it is necessary to maintain a cutting speed lower than that used for carbon steels [5]. On the other hand, high-speed cutting is an effective method for improving productivity. As the cutting temperature rises significantly in high-speed cutting, the tool materials require both good wear-resistance and heat-resistance, and the cutting parts must be cooled to achieve efficacy and efficiency. In this case, sintered cubic boron nitride compact (cBN) or poly crystalline diamond (PCD) are effective tool materials because they have better features such as hardness, heat-resistance, etc. There are many studies on the tool wear of cBN tools [6] or PCD tools [7]. According to Honghua Su et al. [8], in high-speed milling of Ti-6.5Al-2Zr-1Mo-1V (TA15) alloy, the performance and wear mechanism of the tools were investigated. As a result, compared to the PCBN tool, the PCD tool has a much longer tool life, especially at higher cutting speeds. Farhad Nabhani [9] compared the performance of cBN and PCD with that of the coated tungsten carbide tool currently being used to machine titanium aerospace alloy, and tests confirmed that the tool life of PCD is longer than that of other tools. High-pressure coolant cutting is effective for reducing the cutting temperature and many studies on high-pressure coolant cutting have recently been conducted [10]. Itakura et al. [11] reported high speed cutting of Inconel 718 at an increased cutting fluid flow rate by injecting fluid at a high pressure to the cutting edge. As the injection speed of the cutting fluid increased, the cutting temperature was decreased and flank wear was reduced. Thus, high-pressure coolant cutting is considered effective for reducing tool wear [12]. The improvement of chip control, particularly chip breaking performance, is also expected by the high-pressure coolant supplied [13]. Y. Ayed, G. Germain, A. Ammar, and B. Furet et al. [14] reported the experimental results concerning the machinability of the titanium alloy Ti17 with and without high-pressure water jet assistance using uncoated WC/Co tools at cutting speeds of 0.83 m/s to 1.67 m/s. As a result, the optimum water jet pressure was determined, leading to an approximately 9-fold increase in tool life. Compared to conventional lubrication, an increase of about 30% in productivity can be obtained. Z.G. Wang et al. [15] reported milling of Ti-6Al-4V by binderless cubic boron nitride at a maximum cutting speed of 6.7 m/s with high-pressure coolant supplied. Z.G. Wang et al. [16] reported the experimental results concerning the machinability of Ti-6Al-4V alloy with high-pressure coolant supplied using a binderless cubic boron nitride tool at a maximum cutting speed of 5.8 m/s. E. O. Ezugwu et al. [17] evaluated the performance of different cBN tool grades in finish turning of Ti-6Al-4V alloy with high-pressure coolant supplied at high cutting conditions, up to 4.2 m/s. E.O. Ezugwu [18], or Rosemar B. da Silva et al. [19] reported that Ti-6Al-4V can be cut with PCD tools by the high-pressure coolant supplied at much higher cutting speeds, up to 4.2 m/s, conditions that are impossible to obtain under conventional coolant supply. However, the influences of the cutting speed on the tool wear in higher speed cutting of Ti-6Al-4V with high-pressure coolant supplied have not been reported. In this study, in order to identify an effective PCD tool for the high-speed cutting of Ti-6Al-4V, the influences of the diamond content and the diamond particle size on the tool wear were experimentally investigated. As the Ti-6Al-4V was turned with high-pressure coolant supplied, the chip configurations and the tool wear were experimentally investigated.

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CONCLUSIONS

In this study, Ti-6Al-4V was turned with high-pressure coolant supplied, and the chip configurations and the tool wear were experimentally investigated.
The following results were obtained:
(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 in the coolant pressure.
(2) In the case of a cutting speed of 7.50 m/s, large wear on the cutting part was observed at the cutting of conventional-pressure coolant supplied by both the CVD coated tool and the cermet tool.
(3) In the case of the cutting of conventional-pressure coolant supplied by the cBN tool, tool wear of the PCD tool was smaller than that of both the CVD coated tool and the cermet tool.
(4) In a comparison of cutting of the conventional-pressure coolant supplied and cutting of the high-pressure coolant supplied by the cBN tool, the tool wear in cutting with the high-pressure coolant supplied was slightly smaller than that in cutting with the high-pressure coolant supplied.
(5) In a comparison of the cBN tool and the PCD tool in the case of cutting of the high-pressure coolant supplied, the PCD tool could cut to a cutting distance of 4521 m.
(6) In the case of the cutting of the high-pressure coolant supplied by the PCD tool, which has a large diamond particle size, Ti-6Al-4V could be cut at the higher cutting speed of 12.50 m/s.
(7) In the case of the cutting of high-pressure coolant supplied by the PCD tool, the tool wear of the PCD tool decreased with the increase in the diamond particle size.

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Study on Deformation Evaluation of Bracket in Design of Adjustment Hinge

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INTRODUCTION

As for the living environment of our country, barrierfree correspondence is required as represented by an increase in care recipients [1]. In nursing care at home, opening and closing the door by moving the room is indispensable. However, conventional doors for general homes do not take into consideration the opening and closing with the vulnerable ability of the care recipient, and the opening and closing situation while the carer is holding the care recipient. Therefore, it is expected that demand for doors assuming home care in the future will increase. In particular, it is expected that hinges will also be required to adjust opening and closing force and automatic opening and closing functions. When considering realization of added value by hinges, high functionality is required for hinges. Therefore, it is necessary to realize cost reduction and material saving of hinges. Therefore, we aim to realize material saving and cost reduction by using materials with thinner thickness than before. For that purpose, it is necessary to realize the same strength and life as the conventional one with a thin plate thickness. In addition, it is necessary to reduce the number of times of durability tests and prototypes to reduce both development period and cost. In this research, as a high function hinge, think about hinges with adjustment function. It is a hinge that can adjust the distance between the door and the frame in order to avoid interference with the frame of the door after setting the door. In order to realize a more accurate analysis in considering the product life of the hinge, we try to establish an analysis method of the adjustment mechanism.

CONCLUSION

A stress assuming axial force was applied to the female threaded portion of the bracket, and the state of the adjustment mechanism at the time of fixation was analyzed. Although the result of deformation amount is different from experiment, the tendency of deformation is similarity relationship. Therefore, it is considered that a constant evaluation can be made as a stress condition. In the future, we will clarify the deformation of the hinge in the plastic region by nonlinear analysis and clarify the method for setting the condition of more accurate analysis.

REFERENCES

[1] Ministry of Health, Labour and Welfare Health and Welfare Services for the Elderly, http://www.mhlw.go.jp/english/wp/wphw9/
dl/10e.pdf [Accessed August 23, 2016]
[2] Morio FUJIMOTO, Takuji MORIGUCHI and Shinichi ENOKI, "Prediction of Deformation and Damage of a Hinge Adjustment Mechanism by Finite
Element Analysis", JSDE Fall Meeting 2016, (2016), pp.145-146 (in Japanese).
[3] ISO 16047:2005 Fasteners -- Torque/clamp force testing
[4] Bernard J. Hamrock, Bo Jacobson and Steven R. Schmid, Fundamentals of Machine Elements, (1999), pp.672-675.

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INFLUENCE OF NEGATIVE SUBSTRATE BIAS VOLTAGE ON PROPERTIES AND CUTTING PERFORMANCE OF T_AWS_IN COATING FILMS DEPOSITED USING MAGNETRON SPUTTERING ION PLATING

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INTRODUCTION

Many difficult-to-cut materials such as hardened steels, titanium- or nickel-based alloys, etc., are widely used today. For dimensional accuracy, these difficult-to-cut materials have to be machined by the metal removal process. As these difficult-to-cut materials must be machined under high efficiency to improve productivity, the tool materials should be wear resistant. Polycrystalline cubic boron nitride compact (cBN), or poly crystalline diamond (PCD) are effective tool materials because they are heat resistant and hard. However, in cutting, e.g. turning at a high feed or a large cutting depth, milling, drilling and tapping, a major tool failure of cBN or PCD readily occurs by fracture because cBN and PCD have poor fracture toughness. In this case, coated cemented carbide tools, which have good fracture toughness and wear resistance, are effective tool materials. Conventionally, titanium based coating films (e. g. TiN and TiAlN [e.g., 1, 2]) have been widely used as coating films.

Studies on Ta-based coating films as new coating films are also being conducted [3-5]. Furthermore, M. Nordin et al. [6] reported that when milling austenitic stainless steel, a multilayered TiN/TaN coating outperformed single-layered TiN and TaN due to its lower chip/tool interaction, which resulted in a lower comb crack density, and superior toughness. Wada et al. [7] reported that the TaN 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.

Adding Si (silicon), V (vanadium), C (carbon), etc. to the coating film is also effective for improving the performance of the coating film and improving the cutting performance. K. Kutschej et al. [8] reported that the formation of lubricious oxides due to alloying Ti1-xAlxN coatings with V is responsible for the improvement of their tribological properties especially at elevated temperatures. J.W. Nah et al. [9] reported that the chemical state of (Ta,Si)N coating reactively sputtered on a high-speed steel substrate was studied by XRD, AES and XPS. M. Kathrein et al. [10] reported the remarkable influence of additional elements on the properties of Ti1−xAlxN based coatings. Alloying with elements such as V, Ta, and B resulted in a significantly increased lifetime in various cutting applications. Yun Chena et al. [11] reported that AlCrSiCN is harder than AlCrN. Wada et al. [12] reported the coating film performance and cutting performance of the TiWSiN coating film with W added to the TiWN coating film. The results revealed that the TiWSiN coating film in which Si is added to the TiWN coating film is effective for improving the microhardness of the coating film.

The properties of the coating film depend on the negative substrate bias voltage [13-15]. Sung Ryong Choi et al. [15] investigated the influence of substrate bias voltage on deposition behaviors such as the deposition rate, film composition, macro particles and surface roughness for the TiSiN coatings deposited on WC-Co substrates by a hybrid coating system of arc ion plating and sputtering techniques. Also, the hardness and Young's modulus of TiSiN coatings by nanoindentation tests were investigated with the substrate bias voltage. As a result, the micro-indentation hardness largely increased with the increase of the substrate bias voltage, and reached the maximum value of 60 GPa at the substrate bias voltage of -100 V. The micro-indentation hardness and Young's modulus values, however, gradually decreased with the further increase of the substrate bias voltage above -100 V.

There are few studies on the coating film performance and cutting performance of the TaWSiN coating film with Si added to the TaWN coating film. The influence of negative substrate bias voltage on both the mechanical properties and the cutting performance of TaWSiN coating films remains unclear.

To clarify the influence of negative substrate bias voltage on both the mechanical properties of TaWSiN coating films, this study measured the hardness and the scratch strength of the TaWSiN coating film formed by the magnetron sputter ion plating process with different negative substrate bias voltages. The hardened steel AISI D2 was turned with the TaWSiN-coated cemented carbide tools. The tool wear of the TaWSiN-coated cemented carbide was experimentally investigated and compared with that of the TaWN-coated cemented carbide. The substrate base metal of the coated carbide tools is WC-Co cemented carbides ISO K10.

CONCLUSIONS

In this study, we clarified the influence of negative substrate bias voltage on both the mechanical properties and the cutting performance of TaWSiN coating films. The hardness and the scratch strength of TaWSiN coating film formed on the surface of a substrate of WC-Co cemented carbide ISO K10 by the magnetron sputter ion plating process were measured. Next, the hardened steel AISI D2 was turned with the TaWSiN-coated cemented carbide tools. The tool wear of the TaWSiN-coated cemented carbide was experimentally investigated and compared with that of the TaWN-coated cemented carbide.

The following results were obtained:

1. In all cases, the initial cracks were initiated at the edge/corner of the square specimens.The microhardness of the TaWSiN coating film was slightly less hard with the decrease of the negative substrate bias voltage.
2. The critical scratch load of the TaWSiN coating film increased with the decrease of the negative substrate bias voltage.
3. In cutting hardened steel at a cutting speed of 1.00 m/s, the wear progress of all types of TaWSiN-coated tools was lower than that of the TaWN-coated tool.
4. Within the range of most cutting speeds from 0.67 m/s to 1.50 m/s, the tool life of the coated tool deposited using the negative substrate bias voltage of 105 V was the longest among the four types of TaWSiN-coated tools.

The above results clarify that the TaWSiN coating film decreasing the negative substrate bias voltage of 105 V has both high hardness (microhardness of 2690 HV0.25N), and good adhesive strength (critical load of 90N), and can be used as a coating film of WC-Co cemented carbide cutting tools.

Tool wear of (Ti, Al) N-coated polycrystalline cubic boron nitride compact in cutting of hardened steel

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INTRODUCTION

Many difficult-to-cut materials such as hardened steels, titanium and nickel based alloys, etc., are widely used today. For dimensional accuracy, these difficult-to-cut materials are required to be machined by the metal removal process. As these difficult-to-cut materials 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. Therefore, regarding the cutting of hardened steel, which is one of these difficult-to-cut materials, there are many studies on the tool wear [1-3], the cutting force [4]-[5] or the surface roughness [6] of cBN tools. The cutting performance of cBN tools depends on the cBN contents rate [7], and the binding phase [8]. Therefore, an effective binding phase, etc. for cBN tools should be selected for the cutting of hardened steel. On the other hand, coating has long been applied to high speed steel and carbide tools, and more recently, on cBN substrates [9]. Reginaldo T. Coelho et al. reported that in turning a hardened ASTM A29 4340 nickel chromium molybdenum steel (AISI 4340) using three types of coated cBN tool, namely the (Ti,Al)N-nano-coated, (Ti,Al)N-coated and (Al,Cr)N-coated, and uncoated cBN tool, the lowest tool wear happened with the (Ti,Al)N-nano-coated cBN tool followed by the (Ti,Al)N-coated, (Al,Cr)N-coated and uncoated cBN tool [9]. A hardened ASTM 52100 bearing steel (DIN 100Cr6, 62 HRC) was turned by two types of coated cBN tool, namely the (Ti,Al)N- and TiN-coated cBN tool, and uncoated cBN tool. As a result, the experimental results showed that in the case of the lower feed rate of 0.08 mm/rev, there is little difference in tool life between the coated and uncoated cBN. However, in the case of the higher feed rate of 0.15 mm/rev, the tool life of coated cBN is longer than that of the uncoated tool, in particular the tool life of (Ti,Al)N-coated cBN is three times longer than that of the uncoated cBN tool [10]. It was reported that the coated cBN tool demonstrated longer tool life (~20%) than the uncoated tool life at a cutting speed of V<300 m/min, and the difference in tool life between the coated and uncoated CBN tool is negligible when V>300 m/min in high speed turning of Inconel 718 with the uncoated and coated cBN tool [11]. Moreover, it was reported that at a cutting speed of 250 m/min, the coated cBN tools had approximately 20% longer tool life than uncoated cBN, and the gap was rapidly closing with the increase in speed and became negligible at a speed of 350 m/min in turning of Inconel 718 with the uncoated and coated cBN tools [12]. In high turning Inconel 718 with the coated and uncoated cBN tool at a cutting speed of 250 m/min, the coated cBN tool had approximately 20% longer tool life than the uncoated cBN tool [13]. However, R. M'Saoubi et al. reported that the uncoated insert displays a lower flank wear and crater wear width when compared to most of the coated tools, except TiSiN, excepted in cutting hardened steel 16MnCr5 (58-62 HRC) with four typeskinds of coated cBN tools [14]. Furthermore, Fatih Taylan et al. reported that in face milling of hardened 90MnCrV8 tool steel (61 HRC), the tool failure was also investigated [15]. As a resultresults, the damage of the cutting tools over the entire range of cutting conditions was mainly in the form of chipping, the breakage ISO type C (ISO 8688 standard) of the TiN-based-coated cBN was four times greater than that of uncoated cBN. Therefore, TiN-based coated cBN was not useful for hard milling application.

In this study, in order to verify the effectiveness of the (Ti,Al) N-coated cBN, which is formed on the substrate of cBN by the physical vapor deposition (PVD) method, the hardened steel was turned with the (Ti,Al)N-coated cBN tool at a cutting speed of 3.33, 5.00 m/s, a feed rate of 0.3 mm/rev and a depth of cut of 0.1 mm. Furthermore, the uncoated cBN, which was the substrate of the (Ti,Al)Ncoated, was also used.

The hardened steel used was an ASTM D2 cold-worked die steel (60 HRC). The substrate of (Ti,Al)N-coated cBN used was three types of cBN tools, which had a different contents rate and different main binding phases. The tool wear of the cBN tools was experimentally investigated. This investigation will contribute to the improvement of productivity in the case of high feed cutting hardened steels.

CONCLUSIONS

In this study, in order to verify the effectiveness of the (Ti,Al) N-coated cBN, which is formed on the substrate of cBN by the PVD method, the hardened steel was turned with the (Ti,Al) N-coated cBN tool at a cutting speed of 3.33, 5.00 m/s, a feed rate of 0.3 mm/rev and a depth of cut of 0.1 mm. Furthermore, the uncoated cBN, which was the substrate of the (Ti,Al) N-coated, was also used. The tool wear of the cBN tools was experimentally investigated.

The following results were obtained:

(1)The contact area between the rake face and the chip of the (Ti. Al)N-coated cBN tool was smaller than that of the uncoated cBN tool.

(2)The tool wear of the (Ti,Al)N-coated cBN was smaller than that of the uncoated cBN.

(3)The wear progress of the (Ti,Al)N-coated cBN with the main element phase of the TiCN-Al was slower than that of the (Ti,Al)N-coated cBN with the main element phase of the TiN-Al.

(4)In the case of the high cutting speed of 5.00 m/s, the tool wear of the (Ti,Al)N-coated cBN was also smaller than that of the uncoated cBN.

These results clarify that the (Ti,Al)N-coated cBN can be used as a tool material in high feed cutting hardened steel.

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