Cutting Performance in Threading Turning and Grooving Turning of Ti-6Al-4V Alloy with a High-Pressure Coolant Supply

Tadahiro WADA

Proceedings of 2019 IEEE 10th International Conference on Mechanical and Aerospace Engineering (ICMAE), pp. 507-512. (Novotel Brussels City Centre, Address : Rue de la Vierge Noire 32, 1000 BRUSSELS BELGIUM)

INTRODUCTION

Titanium alloys have high specific strength (strength/density) and corrosion resistance. Due to dimensional accuracy, titanium alloys are machined using a metal removal process. Titanium alloys have low thermal conductivity and show high chemical reactivity with many cutting tool materials [1]. Therefore, in cutting titanium alloys, as the cutting temperature is higher, and strong adhesion at the interface between the cutting tool and the chip occurs, the tool wear becomes large. The machinability of titanium and its alloys is poor due to the inherent properties of the materials [2]. In cutting Ti-6Al-4V alloy, complex wear mechanisms such as adhesion and diffusion are caused at higher cutting speeds [3]. Therefore, in cutting Ti-6Al-4V alloy, a slower cutting speed is necessary than that in cutting carbon steel.

To improve productivity, a high-speed cutting method is desired. In high-speed cutting, because the cutting temperature increases greatly, the tool materials are required to have both excellent wear resistance and heat resistance. For cooling and reducing tool wear, a wet cutting method is effective.

Due to the increase of the cutting fluid flow rate by injecting fluid at high pressure into the cutting edge, the cutting temperature decreases and the flank wear decreases [4]. High-pressure coolant cutting, which supplies coolant to the cutting part at high pressure, is effective for lowering the cutting temperature and reducing the tool wear [5, 6]. Furthermore, by supplying high-pressure coolant, the chip breakage performance is also improved [7]. For this reason, high-pressure coolant cutting is used for cutting of difficult-to-cut materials such as titanium alloy [8-13] and Inconel [4].

However, in the threading turning and the grooving turning of Ti-6Al-4V alloy with a high-pressure coolant supply the effects of the coolant pressure on the cutting performance have not been reported.

In this study, in threading turning and grooving turning of Ti-6Al-4V alloy with a high-pressure coolant supply, in order to identify an effective PCD tool for the high-speed cutting of Ti-6Al-4V, the effects of the diamond content and the diamond particle size on the tool wear were experimentally investigated. As the Ti-6Al-4V alloy was threading turned and grooving turned with a high-pressure coolant supplied, the chip configurations and the tool wear were experimentally investigated.

Conclusions

In this study, Ti-6Al-4V alloy was threading turned and grooving turned with a pressurized coolant supplied, and the chip configurations and the tool wear were experimentally investigated.

The following results were obtained:

A. Cutting Performance in Threading Turning Titanium Alloy with a Pressurized Coolant Supply

(1) The main tool failure of un-coated ISO K10 cemented carbide was flank wear with a pressurized coolant supply.

(2) Comparing the conventional coolant supply method and the pressurized coolant supply method, the flank wear width of the pressurized coolant supply method was smaller than that of the conventional coolant supply method.

(3) Comparing the coolant pressures in the case of the pressurized coolant supply method, the flank wear width decreased with the increasing of coolant pressure, and the flank wear width “VB” became significantly smaller.

B. Cutting Performance in Grooving Turning Titanium Alloy with a Pressurized Coolant Supply

(1) The high-pressure coolant supply method was effective for improving the chip breakage performance.

(2) In the case of the conventional coolant supply cutting, the fracture of the cutting part was becoming bigger at a cutting distance of 106.2 m. However, with the high-pressure coolant supply cutting, although wear is observed slightly on both sides of the flank face, no major fracture are seen.

Acknowledgments

I am grateful to Mr. Yusuke Morigo, who is a researcher at TOKUPI Corporation (3-167 Otake Yao Osaka, 572-8530, JAPAN) and Mr. Ryo Sakurai, who is a student of the National Institute of Technology (Nara College), for their help in the execution of the turning experiment. I would like to thank TOKUPI Corporation for their support in the thread turning test, which enabled this work to be conducted. I would also like to express my gratitude to Tungaloy Corporation for supplying the threading insert, the external thread turning holder, the grooving insert and the external grooving turning holder

References

[1] A. Jawaida C.H. Che-Haron, A. Abdullah, Tool wear characteristics in turning of titanium alloy Ti-6246, Journal of Materials Processing Technology, 92-93 (1999), pp. 329-334.

[2] E.O. Ezugwu, Z.M. Wang, A.R. Machado, Titanium alloys and their machinability- a review, J. Materials Processing Technology, 68(1997), pp. 262-274.

[3] N. Corduan, T. Hirnbert, G. Poulachon, M. Dessob, M. Lambehn, J. Mgneau, B. Payoux, Wear Mechanisms of New Tool Materials for TiBAI4V High Performance Machining, CIRP Annals- Manufacturing Technology, Vol. 52, Issue 1, 2003, pp. 73-76.

[4] K. ITAKURA, M. KURODA, Y. DOI, H. TSUKAMOTO, Y. ARIURA, High Speed Cutting of Super Heat Resisting Alloy Inconel 718 -On the Finish Cutting with High Pressurized Cutting Fluid-, 66, pp. 1611-1615, 2000 (in Japanese).

[5] Tadahiro Wada, Kazuki Okayama and Yusuke Morigo, Tool Wear of Sintered Cubic Boron Nitride Compact in Cutting Hardened Steel with High-Pressure Coolant Supplied, High Performance and Optimum Design of Structures and Materials II, Vol. 166(2017), pp. 191-200.

[6] E. O. Ezugwu, J. Bonney, Effect of high-pressure coolant supply when machining nickel-base, Inconel 718, alloy with coated carbide tools, Journal of Materials Process Technology, 152-154, pp. 1045-1050, 2004.

[7] E. O. Ezugwu, High speed machining of aero-engine alloys, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 26(1), pp. 1-11, 2004.

[8] Y. Ayed, G. Germain, A. Ammar, B. Furet, Tool wear analysis and improvement of cutting conditions using the high-pressure water-jet assistance when machining the Ti17 titanium alloy, Precision Engineering, 42 (2015) pp. 294-301.

[9] Z.G. Wang, Y.S. Wong, M. Rahman, High-speed milling of titanium alloys using binderless CBN tools, International Journal of Machine Tools and Manufacture, Volume 45, Issue 1, January(2005), pp. 105-114.

[10] Z.G. Wang, M. Rahman, Y.S. Wong, Tool wear characteristics of binderless CBN tools used in high-speed milling of titanium alloys, Wear, Volume 258, Issues 5–6, February (2005), pp. 752-758.

[11] E. O. Ezugwu, R. B. Da Silva, J. Bonney, Á. R. Machado, Evaluation of the performance of CBN tools when turning Ti-6Al-4V alloy with high pressure coolant supplies, International Journal of Machine Tools and Manufacture, 45-9, (2005) pp. 1009-1014.

[12] E.O. Ezugwu, Key improvements in the machining of difficult-to-cut aerospace super alloys, International Journal of Machine Tools & Manufacture, 45 (2005) pp. 1353-1367.

[13] Rosemar B. da Silva, Álisson R. Machado, Emmanuel O. Ezugwu, John Bonney, Wisley F. Sales, Tool life and wear mechanisms in high speed machining of Ti-6Al-4V alloy with PCD tools under various coolant pressures, Journal of Materials Processing Technology, Volume 213, Issue 8, (2013), pp. 1459-1464.

CUTTING PERFORMANCE IN GROOVING TURNING OF SUPER HEAT-RESISTANT ALLOY INCONEL 718 WITH A HIGH-PRESSURE COOLANT SUPPLY

Tadahiro WADA

International Journal of Mechanical and Production Engineering, ISSN(p): 2320-2092, ISSN(e): 2321-2071
Volume- 7, Issue-11, Nov.-2019, http://iraj.in, pp. 42-46.
(Proceedings of ISER 220th International Conference, Bangkok, Thailand, 21st-22nd August 2019)

INTRODUCTION

Hickel-based alloys such as Inconel 718 are difficult to cut due to their outstanding mechanical properties [1]. A major requirement of cutting tool materials used for machining nickel-based alloys is that they must possess adequate hot hardness to withstand elevated temperatures generated under high-speed conditions during machining. Most cutting tool materials lose their hardness at elevated temperatures resulting in weakening of the inter-particle bond strength and consequent acceleration of tool wear [2]. Therefore, in the cutting of a nickel based-alloy, due to the high cutting temperature and strong adhesion generated at the interface between the cutting tool and the chip, the wear of the tool becomes large. Thus, when cutting nickel-based alloys, a slower cutting rate is required than when cutting carbon steel.

High-speed cutting is desirable to improve productivity, however in high-speed cutting the rise in cutting temperature is significant. In particular, when cutting nickel-based alloys the cutting temperature rises rapidly, so the tool material must have both excellent wear resistance and heat resistance. Wet cutting is effective for cooling and cooling of tools.

High-pressure coolant cutting is effective for lowering the cutting temperature and reducing the tool wear [3-6]. By supplying high-pressure coolant into the cutting edge, the cutting temperature decreases and the flank wear decreases [7]. Furthermore, by supplying high-pressure coolant, the chip breakage performance is also improved [4-6]. Therefore, studies on high-pressure coolant cutting of difficult-to-cut materials such as titanium alloy [8-12] and Inconel [7, 13] has been carried out in addition to the above. However, in the grooving turning of nickel-based alloys with a high-pressure coolant supply the effects of the coolant pressure on the cutting performance have not been reported.

In this study, in grooving turning of Inconel 718 with a pressure coolant supply, the chip configurations and the tool wear were experimentally investigated.

CONCLUSION

In this study, Inconel 718 was grooving turned with a pressurized coolant supplied, and the chip configurations and the tool wear were experimentally investigated.

The following results were obtained:

(1) The pressure coolant supply method improved the chip breakage performance.
(2) In the case of low-pressure coolant supply cutting, the mass per chip increased with increasing cutting speed. However, in the case of high-pressure coolant supply cutting, there was no difference in the mass per chip even if the cutting speed was increased.
(3) It seemed that the bending of chips caused by high-pressure fluid has a large influence on chip breakage in high-pressure coolant cutting.
(4) Comparing the cutting of the conventional coolant supply cutting with the cutting of the pressure coolant cutting, the tool wear with the pressure coolant supply was smaller than that with the conventional coolant supply.
(5) Comparing the cutting of the low-pressure coolant supply with the cutting of the high-pressure coolant supply, the tool wear with the high-pressure coolant supply was smaller than that with the low-pressure coolant supply.

ACKNOWLEDGMENT

I am grateful to Mr. Yusuke Morigo, who is a researcher at TOKUPI Corporation (3-167 Otake Yao Osaka, 572-8530, JAPAN) and Mr. Ryo Sakurai, who is a student of the National Institute of Technology (Nara College), for their help in the execution of the turning experiment. I would like to thank TOKUPI Corporation for their support in the thread turning test, which enabled this work to be conducted. I would also like to express my gratitude to Tungaloy Corporation for supplying the grooving insert and the external grooving turning holder.

REFERENCES

[1] N. H. A. Halim, C. H. C. Haron, J. A. Ghani, M. F. Azhar, “Tool wear and chip morphology in high-speed milling of hardened Inconel 718 under dry and cryogenic CO2 conditions,” Wear, vol. 426–427, Part B, pp. 1683-1690, April 2019
[2] E.O.Ezugwu, "Key improvements in the machining of difficult-to-cut aerospace super alloys," International Journal of Machine Tools and Manufacture, vol. 45, Issues 12-13, pp. 1353-1367, October 2005
[3] E. O. Ezugwu, J. Bonney, “Effect of high-pressure coolant supply when machining nickel-base, Inconel 718,” alloy with coated carbide tools, Journal of Materials Process Technology, 152-154, pp. 1045-1050, 2004
[4] Tadahiro Wada, Kazuki Okayama and Yusuke Morigo, “Tool Wear of Sintered Cubic Boron Nitride Compact in Cutting Hardened Steel with High-Pressure Coolant Supplied,” High Performance and Optimum Design of Structures and Materials II, Vol. 166, pp. 191-200, 2017
[5] E. O. Ezugwu, “High speed machining of aero-engine alloys,” Journal of the Brazilian Society of Mechanical Sciences and Engineering, 26(1), pp. 1-11, 2004.
[6] Tadahiro Wada and Kazuki Okayama, "Tool wear of poly crystalline diamond in cutting Ti-6Al-4V alloy with high-pressure coolant supplied", Proceedings of 2017 8th International Conference on Mechanical and Aerospace Engineering (ICMAE), July 2017, Prague, Czech Republic, pp. 50-55 (DOI: 10.1109/ICMAE.2017.8038616)
[7] K. ITAKURA, M. KURODA, Y. DOI, H. TSUKAMOTO, Y. ARIURA, “High Speed Cutting of Super Heat Resisting Alloy Inconel 718 -On the Finish Cutting with High Pressurized Cutting Fluid-,” vol. 66, pp. 1611-1615, 2000 (in Japanese)
[8] Y. Ayed, G. Germain, A. Ammar, B. Furet, “Tool wear analysis and improvement of cutting conditions using the high-pressure water-jet assistance when machining the Ti17 titanium alloy,” Precision Engineering, vol. 42, pp. 294-301, 2015
[9] Z.G. Wang, Y.S. Wong, M. Rahman, “High-speed milling of titanium alloys using binderless CBN tools,” International Journal of Machine Tools and Manufacture, vol. 45, Issue 1, pp. 105-114, January 2005
[10] Z.G. Wang, M. Rahman, Y.S. Wong, “Tool wear characteristics of binderless CBN tools used in high-speed milling of titanium alloys,” Wear, Vol. 258, Issues 5–6, pp. 752-758, February 2005
[11] E. O. Ezugwu, R. B. Da Silva, J. Bonney, Á. R. Machado, “Evaluation of the performance of CBN tools when turning Ti-6Al-4V alloy with high pressure coolant supplies,” International Journal of Machine Tools and Manufacture, 45-9, pp. 1009-1014, 2005
[12] Rosemar B. da Silva, Álisson R. Machado, Emmanuel O. Ezugwu, John Bonney, Wisley F. Sales, “Tool life and wear mechanisms in high speed machining of Ti-6Al-4V alloy with PCD tools under various coolant pressures,” Journal of Materials Processing Technology, vol. 213, Issue 8, pp. 1459-1464, 2013
[13] Tadahiro WADA, Yusuke MORIGO, Hiroaki TANAKA, "Tool Wear of Sintered Cubic Boron Nitride Compact in Cutting High-Nickel Alloy with High-Pressure Coolant Supplied", Journal of the Japan Society of Powder and Powder Metallurgy, vol. 63, Issue 4, pp. 157-165, 2015 (in Japanese)

Wear Mechanism of Multilayer AlCrWN/AlCrWSiN-coatings on Cemented Carbide Tools Prepared by Arc Ion Plating in Dry Cutting of Hardened Sintered Steel

Tadahiro WADA and Hiroyuki HANYU*

MATEC Web of Conferences 303, 06003(2019), https://doi.org/10.1051/matecconf/201930306003,
ICBMM 2019, pp. 110-115.
(Proceedings of 2019 3rd International Conference on Building Materials and Materials Engineering (ICBMM 2019), University of Lisbon, Portugal, September 25-27, 2019 (MATEC Web of Conferences Volume 303 (2019)) (ISSN: 2261-236X)).

INTRODUCTION

Comparing the performances of the AlCrN coated tool and TiN coated tool, the AlCrN coated tool can increase the depth of cut by about 33% [1]. Furthermore due to the better heat resistance of the AlCrN coating film, the tool life of the end mill with the AlCrN coating is longer than that with the TiAlN coating [2-3]. However, our study results show that the critical scratch load of the AlCrN coating film, which is the value measured by the scratch test, is 77 N and the micro-hardness is 2760 HV0.25 N. Therefore, in order to improve both the critical scratch load and micro-hardness of the AlCrN coating film, a cathode material of the Al-Cr-W target with tungsten (W) added to the cathode material of the Al-Cr target was used [4]. The Al-Cr-W based coating film has both high hardness and excellent critical scratch load and can be used sufficiently as a coating film of WC-Co cemented carbide cutting tools [4]. Furthermore, the friction between the face of the cutting tool and the chip decreases when W is added [5-6].

The addition of Si to the TiN coating film converts the [111] -oriented columnar structure to a dense fine grain structure.

Thin films of Ti-Si-N have been deposited by physical vapor deposition to improve the wear resistance of TiN coatings [7]. Cutting experiments showed that the TiAlSiN coated end mill with a Si content of 4.78 atom% had the least flank wear and improved its milling distance by about 20% over the TiAlN coated end mill [8]. Furthermore, at a temperature of 700 ° C or lower, the hardness of the AlCrWSiN film is higher than the hardness of AlCrN [9]. The addition of Si leads to the refinement of crystal grains and greatly influences the phase composition and mechanical properties due to its formation. Amorphous Si3N4 [10-11]. Many multilayer coating films have been developed to improve tool life [12-16].

The rate of wear of the AlCrWN/AlCrWSiN-coated tool, which has the multilayer coating system, was slower than that of the single layer AlCrWSiN coated tool in the cutting of hardened steel at a feed rate of 0.2 mm/rev [17]. In addition, the tool wear of the AlCrWN/AlCrWSiN-coated tool, which has the multilayer coating system, was investigated in the cutting of hardened sintered steel. [18]. Furthermore, the properties of the multilayer AlCrWN/AlCrWSiN-coating film were also clarified [18]. However, the wear mechanism of the multilayer AlCrWN/AlCrWSiN-coated tool has not been clarified in the cutting of hardened sintered steel.

In this study, to clarify the wear mechanism of the multilayer AlCrWN/AlCrWSiN-coated tool in the cutting of hardened sintered steel, the rate of wear in the cutting of hardened sintered steel using three types of coated tools was investigated. The Type I tool had a single layer (Al60, Cr25, W15)N coating film, the Type II tool had a single layer (Al53, Cr23, W14, Si10)N coating film and the Type III tool had a multilayer (Al60, Cr25, W15)N/(Al53, Cr23, W14, Si10) N-coating film. SEM observation and EDS mapping analysis of the abraded surface of the coating film were performed.

Conclusion

In this study, SEM observation and EDS mapping analysis of the abraded surface of the coating film were performed in order to clarify the wear mechanism of the AlCrWN/AlCrWSiN-coating film in the cutting of hardened sintered steel. The Type I tool had a single layer (Al60, Cr25, W15)N coating film, the Type II tool had a single layer (Al53, Cr23, W14, Si10)N coating film and the Type III tool had a multilayer (Al60, Cr25, W15)N/(Al53, Cr23, W14, Si10) N-coating film.

The following results were obtained:

(1) The wear rate of the Type III tool was the slowest.
(2) The area of the worn surface on the rake face "S" and the contact length between the rake face and the chip "D" were measured. Comparing the three types of coated tools, both the "S" and the "D" of the Type I tool were the smallest, and those of the Type II tool were the largest.
(3) The main wear mechanism of the Type II and the Type III tool was abrasive wear. However, the main wear mechanism of the Type I tool was both abrasive wear and adhesion wear.
(4) The critical scratch load of the Type I tool, 81 N, was lower than that of the Type II or the Type III tool, over 130 N.

Therefore, comparing the Type I and Type III tools, due to the wear mechanism of the Type I tool being both abrasive wear and adhesion wear, the wear rate of the Type I tool, which has the lower critical scratch load, was slower.

Acknowledgment

This work was supported by JSPS (Japan Society for the Promotion of Science) KAKENHI Grant Number JP 17K06102 (Grant-in-Aid for Scientific Research (C)).

References

[1] Yueh-Jaw Lin, Ashutosh Agrawal, Yunmei Fang: Wear, 264, issues 3-4, 226-234(2008)
[2] G.S. Fox-Rabinovich, B.D. Beake, J.L. Endrino, S.C. Veldhuis, R. Parkinson, L.S. Shuster, M. S. Migranov: Surface & Coatings Technology, 200, issues 20-21, 5738-5742(2006)
[3] W. Kalss, A. Reiter, V. Derflinger, C. Gey, J.L. Endrino: International Journal of Refractory Metals and Hard Materials, 24, Issue 5, 399-4046(2006)
[4] Tadahiro Wada and Hiroyuki Hanyu: Applied Mechanics and Materials, 798, 377-383(2015)
[5] K. Bobzin, N. Bagcivan, M. Ewering, R.H. Brugnara, S. Theiß: Surface & Coatings Technology, 205, 2887-2892(2011)
[6] Wan-Yu Wu, Chia-Hao Wu, Bo-Hong Xiao, Ting-Xin Yang, Shi-Yi Lin, Ping-Hung Chen, Chi-Lung Chang: Vacuum, 87, 209-212(2013)
[7] M. Diserens, J. Patscheider, F. Levy: Surface & Coatings Technology, 108-109, 241-246(1998)
[8] Donghai Yu, Chengyong Wang, Xiaoling Cheng, Fenglin Zhang: Thin Solid Films, 517, 4950-4955(2009)
[9] Yu-ping Feng, Li Zhang, Rong-xian Ke, Qing-lei Wan, ZheWanga, Zhi-hong Lu: Int. Journal of Refractory Metals and Hard Materials, 43, 241-249(2014)
[10] Shihong Zhang, Lei Wang, Qimin Wang, Mingxi Li: Surface & Coatings Technology, 214, pp. 160-167(2013)
[11] Lihui Zhu, Mingmei Hu, Wangyang Ni, Yixiong Liu: Vacuum, 86, 1795-1799(2012)
[12] J.H. Hsieh, C. Liang, C.H. Yu, W. Wu: Surface and Coatings Technology, 108-109, 132-137(1998)
[13] A.A. Vereschaka, S.N. Grigoriev, A.S. Vereschaka, A.Yu. Popov and A. D. Batako: Procedia CIRP, 14, 239-244(2014)
[14] Tsao Chung-Chen, Hocheng Hong: Journal of Materials Processing Technology, 123, issue 1, 1-4(2002)
[15] M. Nouari, A. Ginting: Surface & Coatings Technology, 200, 5663-5676(2006)
[16] Q. Yang, R.McKellar: Tribology International, 83, 12-20(2015)
[17] Tadahiro Wada and Hiroyuki Hanyu: International Journal of Engineering and Technology, 8, No. 6, 406-409(2016)
[18] Tadahiro Wada: Solid State Phenomena (Material and Manufacturing Technology VIII), 266, 69-75(2017)
[19] Tadahiro Wada, Hiroyuki Hanyu: International Journal of Mining, Metallurgy & Mechanical Engineering (IJMMME), 3, issue 2, 56-60(2015)

---

* OSG Corporation

Chip Breakability in Turning of 7075 Aluminium Alloy with a High-Pressure Coolant Supply

Tadahiro WADA, Takuro YAMAGUCHI and Yusuke MORIGO*

Journal of Physics: Conference Series 1510 (2020) 012009, IOP Publishing, doi:10.1088/1742-6596/1510/1/012009, pp. 1-8.
(Proceedings of 2019 The 10th Asia Conference on Mechanical and Aerospace Engineering, Chulalongkorn University, Bangkok, Thailand, December 26-28, 2019)

INTRODUCTION

Because of its extremely high strength to weight ratio [1], 7075 aluminum alloy is used for highly stressed structural parts including aircraft fittings, gears and shafts and various other commercial aircraft, aerospace and transportation equipment [2]. The machinability of metals is estimated by the cutting force, tool life, surface finish and chip shape. Due to the strength and hardness of aluminum alloys, the cutting force and tool life are relatively unproblematic, and the chip breakability is the most important feature to ensure reliable operation in automated machining [3].

One improvement in chip cracking is the use of free-cutting alloys. Conventionally, Pb is added to aluminum alloys to improve the chip breakability. However, due to the negative impact on the environment, the addition of Pb has been banned in many countries. The addition of Si improves chip breaking performance [4]-[6], but when turning Si-added aluminum alloys with high speed steel tools, tool wear increases with the increase of Si contents [4]-[5], [7]-[8].

On the other hand, supplying coolant to the cutting area at high pressure improves chip breakability performance [9]-[11], and supplying high-pressure coolant to the cutting edge lowers the cutting temperature and reduces flank wear [12]. This method is also effective in reducing tool wear [9]-[11], [13]. Therefore, many studies on high-pressure coolant supply cutting of hard-to-cut materials such as hardened steel [14], titanium alloy [15]-[19], Inconel [12], [20], cemented carbide [21] have been conducted. However, there have been no reports on the effect of the coolant pressure on the chip breakability performance when aluminum alloys are turned with a high-pressure coolant supplied.

In this study, in turning of 7075 aluminum alloy with a high-pressure coolant supply, the chip configurations, the mass and thickness of chip were experimentally investigated.

CONCLUSIONS

In this study, in turning of 7075 aluminum alloy with a high-pressure coolant supply, the chip configurations, the mass of chip and the thickness of chip were experimentally investigated.

The following results were obtained:

(1) In the case of a cutting speed of 5.0 m/s, a feed rate from 0.05 mm/rev to 0.50 mm/rev and a depth of cut from 0.1 mm to 3.0 mm, chips were not broken at a feed rate of 0.15 mm/rev or less in the conventional coolant supply.
In the high-pressure coolant supply, the combination area of feed rate and depth of cut that can be broken chip was wider than in the conventional coolant supply. In the high-pressure coolant supply at a coolant pressure of 7 MPa, there is a combination area of feed rate and depth of cut that can be not broken chip. However, chips were broken in all areas at a coolant pressure of 20 MPa.

(2) In the case of both the high-pressure coolant supply, which has a coolant pressure of 7, 14 or 20 MPa, and the conventional coolant supply, the thickness of chip increased with the increase of the depth of cut. And, the thickness of chip did not change depending on the cutting method, namely the high-pressure coolant supply cutting method and the conventional coolant supply cutting method.

(3) In the case of both the conventional and the high-pressure coolant supply, the thickness of chip decreased with the increase of the cutting speed.

ACKNOWLEDGMENTS

We would like to thank TOKUPI Corporation for their support in the turning test, which enabled this work to be conducted. We would also like to express our gratitude to KYOCERA Corporation for supplying the indexable insert for turning and the external tool holder.

REFERENCES

[1] Dyi-Cheng Chen, Ci-Syong You, Fu-Yuan Gao, “Analysis and experiment of 7075 aluminum alloy tensile test”, Procedia Engineering(11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan), 81(2014), pp. 1252 - 1258.
[2] H.R. Ezatpour, M. Torabi Parizi, S.A. Sajjadi, G.R. Ebrahimi, A. Chaichi, “Microstructure, mechanical analysis and optimal selection of 7075 aluminum alloy based composite reinforced with alumina nanoparticles”, Materials Chemistry and Physics, 178 (2016), pp. 119 - 127.
[3] Masatsugu Kamiya, Takao Yakou, “Role of second-phase particles in chip breakability in aluminum alloys”, International Journal of Machine Tools & Manufacture, 48 (2008), pp. 688 - 697.
[4] T. Wada, K. Hiro, J. Fujiwara, “Machinability of Aluminum Alloys”, International Journal for Manufacturing Science & Technology, Vol. 5, No. 2, (2003/2004), pp. 39 - 45.
[5] Tadahiro Wada, Junsuke Fujiwara, “Surface Modification of Aluminum Alloys”, Aluminium Alloys, Vol.1, pp. 256-262.
[6] Shinji Yoshihara, Masakazu Hirano and Takehiko Eto, “Effect of Si particles on chipping characteristics of Al-Mg-Si alloys during drilling operation”, Journal of Japan Institute of Light Metals, Vol.51, No.4 (2001), pp.238-241 (in Japanese).
[7] Tadahiro Wada, “CUTTING PERFORMANCE OF DIAMOND-LIKE CARBON COATED TOOL IN CUTTING OF ALUMINUM ALLOYS”, Materials Science Forum, Vols. 638-642, (2010), pp. 368-373.
[8] Tadahiro Wada, Jun Nakanishi, Yasuhiro Miki, Makoto Asano, Koji Iwamoto and Hiroyuki Hanyu, “Surface Modification of Aluminum Alloy using Plasma Based Ion Implantation and Deposition”, Advanced Materials Research, Vols. 488-489, (2012), pp. 960-966.
[9] Tadahiro Wada, Kazuki Okayama and Yusuke Morigo, “Tool Wear of Sintered Cubic Boron Nitride Compact in Cutting Hardened Steel with High-Pressure Coolant Supplied,” High Performance and Optimum Design of Structures and Materials II, Vol. 166, pp. 191-200, 2017
[10] E. O. Ezugwu, “High speed machining of aero-engine alloys,” Journal of the Brazilian Society of Mechanical Sciences and Engineering, 26(1), pp. 1-11, 2004.
[11] Tadahiro Wada and Kazuki Okayama, "Tool wear of poly crystalline diamond in cutting Ti-6Al-4V alloy with high-pressure coolant supplied", Proceedings of 2017 8th International Conference on Mechanical and Aerospace Engineering (ICMAE), July 2017, Prague, Czech Republic, pp. 50-55 (DOI: 10.1109/ICMAE.2017.8038616)
[12] K. ITAKURA, M. KURODA, Y. DOI, H. TSUKAMOTO, Y. ARIURA, “High Speed Cutting of Super Heat Resisting Alloy Inconel 718 -On the Finish Cutting with High Pressurized Cutting Fluid-,” vol. 66, pp. 1611-1615, 2000 (in Japanese)
[13] E. O. Ezugwu, J. Bonney, “Effect of high-pressure coolant supply when machining nickel-base, Inconel 718,” alloy with coated carbide tools, Journal of Materials Process Technology, 152-154, pp. 1045-1050, 2004
[14] T. Wada, K. Okayama & Y. Morigo, “Tool wear of sintered cubic boron nitride compact in cutting hardened steel with high-pressure coolant supplied”, High Performance and Optimum Design of Structures and Materials II (WIT Transactions on The Built Environment Vol. 166), (2016), pp. 191-200.
[15] Y. Ayed, G. Germain, A. Ammar, B. Furet, “Tool wear analysis and improvement of cutting conditions using the high-pressure water-jet assistance when machining the Ti17 titanium alloy,” Precision Engineering, vol. 42, pp. 294-301, 2015
[16] Z.G. Wang, Y.S. Wong, M. Rahman, “High-speed milling of titanium alloys using binderless CBN tools,” International Journal of Machine Tools and Manufacture, vol. 45, Issue 1, pp. 105-114, January 2005
[17] Z.G. Wang, M. Rahman, Y.S. Wong, “Tool wear characteristics of binderless CBN tools used in high-speed milling of titanium alloys,” Wear, Vol. 258, Issues 5–6, pp. 752-758, February 2005
[18] E. O. Ezugwu, R. B. Da Silva, J. Bonney, Á. R. Machado, “Evaluation of the performance of CBN tools when turning Ti-6Al-4V alloy with high pressure coolant supplies,” International Journal of Machine Tools and Manufacture, 45-9, pp. 1009-1014, 2005
[19] Rosemar B. da Silva, Álisson R. Machado, Emmanuel O. Ezugwu, John Bonney, Wisley F. Sales, “Tool life and wear mechanisms in high speed machining of Ti-6Al-4V alloy with PCD tools under various coolant pressures,” Journal of Materials Processing Technology, vol. 213, Issue 8, pp. 1459-1464, 2013
[20] Tadahiro WADA, Yusuke MORIGO, Hiroaki TANAKA, "Tool Wear of Sintered Cubic Boron Nitride Compact in Cutting High-Nickel Alloy with High-Pressure Coolant Supplied", Journal of the Japan Society of Powder and Powder Metallurgy, vol. 63, Issue 4, pp. 157-165, 2015 (in Japanese)
[21] TADAHIRO WADA, “TOOL WEAR OF POLY CRYSTALLINE DIAMOND IN CUTTING WC-CO CEMENTED CARBIDE WITH HIGH-PRESSURE COOLANT SUPPLIED”, International Journal of Mechanical and Production Engineering, Vol. 7, Issue-5, (2019), pp. 23-26.
[22] Tadahiro Wada, “CUTTING PERFORMANCE IN GROOVING TURNING OF SUPER HEAT-RESISTANT ALLOY INCONEL 718 WITH A HIGH-PRESSURE COOLANT SUPPLY”, Proceedings of ISER 220th International Conference, Bangkok, Thailand, 21st- 22nd August, 2019, pp. 82-86.

---

* TOKUPI Corporation

Tool Wear of (Al,Cr,W)/(Al,Cr,W,Si)-Based-Coated Cemented Carbide Tools in Cutting of Hardened Steel

Tadahiro WADA, Akiyoshi NITTA and Junsuke FUJIWARA

International Journal of Materials, Mechanics and Manufacturing, Vol. 8, No. 3, June 2020, pp. 64-68.
(Proceedings of 2020 4th International Conference on Green Energy and Applications, March 7-9, 2020, Singapore.)

INTRODUCTION

The hardened steel AISI D2 has high hardness, strength and wear resistance. In cutting hardened steel AISI D2, the tool wear increases. Polycrystalline Cubic Boron Nitride (PCBN) is generally used as the cutting tool material in cutting hardened steel. Linhu Tang et al. investigated the wear performance and mechanisms of the PCBN tool in dry hard turning of AISI D2 hardened steel at various hardness levels (40-60 ± 1 HRC) [1]. 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 cutting tool materials. TiN, Ti(C,N) and (Ti,Al)N are generally used for the coating film [2].

Cr-Al-N is expected to play a very important role in the future of Surface Engineering, manufacturing industry and in preventing wear of critical components in a wide range of applications [3]. When investigating the potentials of newly developed (Cr,Al)N coatings compared to uncoated tools, CrxAlyN coatings with different chromium to aluminum contents were deposited onto indexed carbide inserts. In order to find improved coatings for dry machining operations both tribological and wear tests were performed [4].

The machining performance of AlCrN and AlTiN coated cemented carbide inserts were investigated during end milling of MDN 250 maraging steel. As a result, the AlCrN coating had better wear resistance and machining performance compared to the AlTiN coating [5]. The performance of mono-layered AlCrN and multi-layered AlTiN PVD coatings on mixed alumina inserts were investigated in the turning of hardened AISI 52100 steel. As a result, the AlCrN coating exhibited superior machining behavior at higher cutting speeds indicating the suitability of the coating at elevated machining speeds [6]. Tadahiro Wada et al. reported that an (Al,Cr)N coated cemented carbide is an effective tool material for cutting sintered steel [7] and hardened sintered steel [8].

The incorporation of Si [9], Y [9], W [10], Fe [11], Zr [12] or Ti [13] into (Cr, Al) N was reported. In cutting hardened steel [14] or sintered steel [15], the wear resistance of (Al, Cr, W) N coated tools with W added to (Al, Cr) N coated tools was improved. The wear resistance of (Al, Cr, W)(C,N) coated tools with C added to (Al,Cr,W) N coated tools was improved [14]-[17]. Furthermore, the wear resistance of (Al, Cr, W,Si)N coated tools with Si added to (Al, Cr,W) N coated tools was improved [18].

On the other hand, gradient and multilayered coatings composed of different nitride layers show superior mechanical strength, such as hardness and wear resistance, as compared to mono-layered coatings due to their specific interfaces [19]. For this reason, many studies on multilayer coatings have been conducted [19]-[24].

In addition, many studies dealing with multi-layer (Al,Cr,W)/(Al,Cr,W,Si) coating films handled in this study have been reported [25]-[28]. As a result of comprehensive judgment of the study results of Tadahiro Wada et al., the following two points were clarified. (1) The wear resistance of PVD-coated tools was improved by adding W and Si to (Al, Cr) targets. (2) Multi-layer coating films have better wear resistance than single-layer coating film. However, the effect of components (Al, Cr, W, Si) on tool wear have not been clarified.

In this study, two types of aluminum/chromium/tungsten/silicon target cathode materials with varying constituents were used to improve the wear resistance of coated cutting tools in cutting hardened steel. For comparison, a cathode material of one type of aluminum/chromium/tungsten target was also used. In addition, multi-layer coating materials were used, including combinations of aluminum/chromium/tungsten/silicon based coating films and aluminum/chromium/tungsten based coating films. Using these three types of targets, the hardened steel was cut with a cutting tool in which cemented carbide K10 substrate metal was PVD coated and the tool wear was examined.

Conclusions

In this study, a carbonitride coating film was deposited on a cemented carbide ISO K10 using three different Al-Cr-W-Si targets. The coating film structure consisted of mono-layer film and multi-layer films. The hardened steel ASTM D2 was cut with five types of coated cemented carbide tools. The tool wear of the coated tools was experimentally investigated.

The following results were obtained:

(1) Comparing the wear progress of the (Al53,Cr23,W14,Si10)(C,N)- and (Al58,Cr25,W7,Si10)(C,N)-coated tool, the wear progress of the (Al58,Cr25,W7,Si10)(C,N)-coated tool is slightly slower than that of the (Al53,Cr23,W14,Si10)(C,N)-coated tool.

(2) Comparing the wear progress of the (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N)- and the (Al53,Cr23,W14,Si10)(C,N)/(Al58,Cr25,W7,Si10)(C,N)-coated tool, the wear progress of the (Al53,Cr23,W14,Si10)(C,N)/(Al58,Cr25,W7,Si10)(C,N)-coated tool is slightly slower than that of the (Al60,Cr25,W15)(C,N)/(Al53,Cr23,W14,Si10)(C,N)-coated tool.

Acknowledgment

This work was supported by JSPS (Japan Society for the Promotion of Science) KAKENHI Grant Number JP 17K06102 (Grant-in-Aid for Scientific Research (C)).

References

[1] L. H. Tang, Y. J. Sun, B. D. Li, J. C. Shen, and G. L. Meng, "Wear performance and mechanisms of PCBN tool in dry hard turning of AISI D2 hardened steel," Tribology International, vol. 132, pp. 228-236, 2019.
[2] T. Wada and H. Hanyu, "Tool wear of aluminum/chromium/tungsten-based-coated cemented carbide in cutting hardened sintered steel," Applied Mechanics and Materials, vol. 772, pp. 72-76, 2015.
[3] E. Spain, J.C. Avelar-Batista, M. Letch, J. Housden, and B. Lerga, "Characterisation and applications of Cr-Al-N coatings," Surface & Coatings Technology, vol. 200, pp. 1507-1513, 2005.
[4] H. Scheerer, H. Hoche, E. Broszeit, B. Schramm, E. Abele, and C. Berger, "Effects of the chromium to aluminum content on the tribology in dry machining using (Cr,Al)N coated tools," Surface & Coatings Technology, vol. 200, pp. 203-207, 2005.
[5] V.Varghese, K.Akhil, M. R. Ramesh, and D. Chakradhar, "Investigation on the performance of AlCrN and AlTiN coated cemented carbide inserts during end milling of maraging steel under dry, wet and cryogenic environments," Journal of Manufacturing Processes, vol. 43, pp. 136-144, 2019.
[6] C. S. Kumar and S. K. Patel, "Effect of chip sliding velocity and temperature on the wear behaviour of PVD AlCrN and AlTiN coated mixed alumina cutting tools during turning of hardened steel," Surface & Coatings Technology, vol. 334, pp. 509-525, 2018.
[7] T. Wada, K. Iwamoto, H. Hanyu, and K. Kawase, "Tool wear of (Al,Cr)N coated cemented carbide in cutting sintered steel," Journal of the Japan Society of Powder and Powder Metallurgy, vol. 58, pp. 459-462 , 2011.
[8] T. Wada, M. Ozaki, H. Hanyu, and K. Kawase, "Tool wear of aluminum-chromium based coated cemented carbide in cutting hardened sintered steel," International Journal of Engineering and Technology, vol. 6, no. 3, pp. 223-226, 2014.
[9] H. Hasegawa, K. Ohashi, S. Tsukamoto, T. Sato, and T. Suzuki, "Characterization of quaternary (Cr,Al)N-based films synthesized by the cathodic arc method," Surface & Coatings Technology, vol. 202, pp. 786-789, 2007.
[10] T. wada, "Tool wear of aluminum/chromium/tungsten-basedcoated cemented carbide in cutting alloy steel," International Journal of Advances in Science Engineering and Technology, vol. 6, iss. 4, pp. 79-82, 2018.
[11] M. Mühlbacher, R. Franz, J. Paulitsch, H. Rudigier, P. Polcik, P. H. Mayrhofer, and C. Mitterer, "Influence of Fe impurities on structure and properties of arc-evaporated AlCrN coatings," Surface & Coatings Technology, vol. 215, pp. 96-103, 2013.
[12] W. Z. Lia, Q. Z. Chen, T. Polcar, R. Serra, and A. Cavaleiro, "Influence of Zr alloying on the mechanical properties, thermalstability and oxidation resistance of Cr-Al-N coatings," Applied Surface Science, vol. 317, pp. 269-277, 2014.
[13] R. Forsén, M. P. Johansson, M. Odén, and N. Ghafoor, "Effects of Ti alloying of AlCrN coatings on thermal stability and oxidation resistance," Thin Solid Films, vol. 534, pp. 394-402, 2013.
[14] T. Wada and H. Hanyu, "Tool wear of aluminum/chromium/tungsten-based-coated cemented carbide in cutting hardened steel," Applied Mechanics and Materials, vol. 798, pp 377-383, 2015.
[15] T. Wada and H. Hanyu, "Tool wear of aluminum/chromium/tungsten-based-coated cemented carbide tools in cutting sintered steel," World Academy of Science, Engineering and Technology, International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, vol. 9, no. 8, pp. 826-829, 2015.
[16] T. Wada and H. Hanyu, "Tool wear of aluminum/chromium/tungsten-based-coated cemented carbide in cutting hardened steel," Applied Mechanics and Materials, vol. 772, pp 72-76, 2015.
[17] T. Wada and H. Hanyu, "Wear mechanism of aluminum/chromium/tungsten-based-coated cemented carbide tools in dry cutting of hardened sintered steel," International Journal of Mining, Metallurgy & Mechanical Engineering, vol. 3, issue 2, pp. 56-60, 2015.
[18] T. Wada and H. Hanyu, "Tool wear of aluminum/chromium/tungsten/silicon-based-coated cemented carbide tools in cutting of hardened steel," International Journal of Engineering and Technology, vol. 8, no. 6, pp. 406-409, 2016.
[19] Y.-Y. Chang, S.-Y.Weng, C.-H. Chen, and F.-X. Fu, "High temperature oxidation and cutting performance of AlCrN, TiVN and multilayered AlCrN/TiVN hard coatings," Surface & Coatings Technology, vol. 332, pp. 494-503, 2017.
[20] L. Wang, X. Nie, J. Housden, E. Spain, J. C. Jiang, E. I. Meletis, A. Leyland, and A. Matthews, "Material transfer phenomena and failure mechanisms of a nanostructured Cr-Al-N coating in laboratory wear tests and an industrial punch tool application," Surface & Coatings Technology, vol. 203, pp. 816-821, 2008.
[21] R. Raab, C. M. Koller, S. Kolozsvári, J. Rammd, and P. H. Mayrhofer, "Interfaces in arc evaporated Al-Cr-N/Al-Cr-Omultilayers and their impact on hardness," Surface & Coatings Technology, vol. 324, pp. 236-242, 2017.
[22] R. Raab, C.M. Koller, S. Kolozsvári, J. Ramm, and P. H. Mayrhofer, "Thermal stability of arc evaporated Al-Cr-O and Al-Cr-O/Al-Cr-N multilayer coatings," Surface & Coatings Technology, vol. 352, 2018), pp. 213-221.
[23] Q. Y. Li, S. J. Dong, Q. Cao, W. P. Ye, D. Q. Gong, and X. D. Cheng, "Thermal stability of multi-layered AlCrN/Cr/AlCrN coatings at elevated temperatures for low thermal emissivity applications," Applied Surface Science, vol. 498, p. 143886, 2019.
[24] A. P. Rubshtein, K. Gao, A. B. Vladimirov, S. A. Plotnikov, B. Zhang, and J. Zhang, "Structure, wear and corrosion behaviours of Cr-Al-C and multilayer [Cr-Al-C/a-C]n coatings fabricated by physical vapour deposition and plasma-assisted chemical vapour deposition techniques," Surface & Coatings Technology, vol. 377, p. 124912, 2019.
[25] T. Wada and H. Hanyu, "Tool wear of aluminum/chromium/tungsten/silicon-based-coated end mill cutters in milling hardened steel," Solid State Phenomena, vol. 263, pp. 85-89, 2017.
[26] T. Wada, "Tool wear of multi-layer AlCrWN/AlCrWSiN-coated cemented carbide in cutting hardened sintered steel," Solid State Phenomena, vol. 266, pp. 69-75, 2017.
[27] T. Wada and H. Hanyu, "Wear mechanism of multi-layer AlCrWN/AlCrWSiN coatings on cemented carbide tool prepared by arc ion plating in dry cutting of sintered steel," in Proc. ICBMM 2018, 2019, vol. 278, pp. 1-5.
[28] T. Wada and H. Hanyu, "Wear mechanism of multilayer AlCrWN/AlCrWSiN-coatings on cemented carbide tools prepared by Arc ion plating in dry cutting of hardened sintered steel," in Proc. ICBMM 2019, 2019, vol. 303, pp. 1-6.

---

* Doshisha University