Properties of TaWN and TaN/TaWN Coating Film Deposited on WC-Co-Based Cemented Carbide using Magnetron Sputter Ion Plating

Tadahiro WADA

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INTRODUCTION

Many difficult-to-cut materials are widely used. For dimensional accuracy, these difficult-to-cut materials are required to be machined by the metal removal process (Tadahiro Wada et al., 2017). It is necessary that the tool materials have good wear-resistance. Polycrystalline cubic boron nitride compact (c-BN) seems to be an effective tool material (Tadahiro Wada et al., 2017).

However, in turning at a high feed or a large depth of cut, a major tool failure of c-BN occurs by fracture. Coated tools seem to be effective tool materials (Tadahiro Wada et al., 2014). Titanium based films have been widely used as coating films (e.g., K. Sakagami et al., 1998, H. Nakagawa et al., 2002). R.Westergard, M. Bromark, M. Larsson, P. Hedenqvist, S. Hogmark, 1997, reported that tantalum nitride coatings were deposited onto high-speed steel using reactive DC magnetron sputtering. And, the coating abrasive wear resistance was assessed by dimple grinding, the abrasive wear rates of the tantalum nitride coatings were small compared with the wear rate of the TiN coating. Maria Nordin et al., 1999, reported that the highest abrasive wear resistance was found for single layered TaN and the lowest for TiN, too. The TaN has both high hardness and good adhesive strength, and can be used as a coating film of cutting tools (Tadahiro Wada et al., 2011). And, in cutting the hardened steel using TaN and (Ti, Al)N coated tools, the wear rate of the TaN coated tool was almost equivalent to that of the (Ti, Al)N coated tool (Tadahiro Wada et al., 2011). M. Nordin et al., 2000, reported that in milling AISI 316 stainless steel the tool life of the TaN coated tool was longer than that of the TiN coated tool.

Adding Si (silicon), V (vanadium), C (carbon), etc. to the coating film is effective for improving the performance of the coating film and improving the cutting performance. M. Kathrein et al., 2005, reported the remarkable influence of additional elements on the properties of Ti1−xAlxN based coatings. And, alloying with elements such as V, Ta, and B resulted in a significantly increased lifetime in various cutting applications. Yun Chena et al., 2016, reported that AlCrSiCN is harder than AlCrN.

It is considered that the TaWN coating film in which W (tungsten) is added to the TaN coating film is effective for improving the adhesion with WC, which is the main component of the substrate. However, no study has reported on the coating film performance and cutting performance of TaWN coating film with W added to TaN coating film.

The performance of the coating film and improving the cutting performance can be extended by the use of a multi-layer coating system (Maria Nordin et al., 1999, M. Nordin et al., 2000, M. Kathrein et al., 2005, Yun Chena et al., 2016, J.H. Hsieh et al., 1998, A.A. Vereschaka et al., 2014, Tsao Chung-Chen et al., 2002, M. Nouari et al., 2006, Q. Yang et al., 2015). However, it is unclear whether TaN/TaWN coating film can be used as a coating film of WC-Co cemented carbide cutting tools in cutting hardened steel.

In this study, the thickness, hardness and scratch strength of TaWN and TaN/TaWN coated tools were measured. The substrate used was a cemented carbide ISO K10. The work piece used was a hardened steel AISI D2. This work piece was turned with the TaWN and the TaN/TaWN coated tools. The tool wear of the TaWN and TaN/TaWN coated tools was investigated. Furthermore, the TaN coated tool was also used.

CONCLUSIONS

In this study, the thickness, hardness and scratch strength of TaWN and TaN/TaWN coated tools were measured. The substrate used was a cemented carbide ISO K10. The work piece used was a hardened steel AISI D2. This work piece was turned with the TaWN and the TaN/TaWN coated tools. The tool wear of the TaWN and TaN/TaWN coated tools was investigated. Furthermore, the TaN coated tool was also used.

(1) Droplets on the surface of both the TaWN and TaN/TaWN coating films were negligible.
(2) The hardness of the TaWN and TaN/TaWN was 2340 $HV_{0.25N}$ and 2630 $HV_{0.25N}$, respectively.
(3) The critical load of both the TaWN and TaN/TaWN coated tools was over 130 N.
(4) The friction coefficient of the TaN/TaWN and TaN was 0.44 and 0.53, respectively.
(5) The wear rate of the TaN/TaWN coated tool was slower than that of the TaN or TaWN coated tool.

REFERENCES

Vereschaka, A.A., Grigoriev, S.N., Vereschaka, A.S., Popov, A.Yu. and Batako, A. D., (2014). Nano-scale multilayered composite coatings for cutting tools operating under heavy cutting conditions, Procedia CIRP, 14, 239-244. https://doi.org/10.1016/j.procir.2014.03.070

Nakagawa, H., Hirogaki, T. et al. (2002). Study On Tool Life In End-Milling Of Hardened Steel, in Proc. 6th Int. Conf. on Progress of Machining Technology, 81-86.

Hsieh, J.H., Liang, C., Yu, C.H., Wu., W. (1998). Deposition and characterization of TiAlN and multi-layered TiN/TiAlN coatings using unbalanced magnetron sputtering, Surface and Coatings Technology, Vol. 108-109, 132-137. https://doi.org/10.1016/S0257-8972(98)00684-7

Sakagami, K., Yongming, G. and Yamamoto, T., (1998). Effects of Substrate and PVD-Coated Layers on Flank Notch wear of Carbide Tool in Stainless Steel Cutting, in Proc. 4th Int. Conf. on Progress of Cutting and Grinding, 38-42.

Kathrein, M., Michotte, C., Penoy, M., Polcik, P., Mitterer, C. (2005). Multifunctional multi-component PVD coatings for cutting tools, Surface & Coatings Technology, 200, 1867-1871. https://doi.org/10.1016/j.surfcoat.2005.08.105

Nordin, M., Sundstrom, R., Selinder, T.I., Hogmark. S. (2000). Wear and failure mechanisms of multilayered PVD TiN/TaN coated tools when milling austenitic stainless steel, Surface and Coatings Technology, Vol. 133-134, 240-246. https://doi.org/10.1016/S0257-8972(00)00933-6

Nouari, M., Ginting, A. (2006). Wear characteristics and performance of multi-layer CVD-coated alloyed carbide tool in dry end milling of titanium alloy, Surface & Coatings Technology, 200, 5663-5676. https://doi.org/10.1016/j.surfcoat.2005.07.063

Maria Nordin, Mats Larsson, Sture Hogmark. (1999). Wear resistance of multilayered PVD TiN/TaN on HSS, Surface and Coatings Technology, Vol. 120-121, 528-534. https://doi.org/10.1016/S0257-8972(99)00493-4

Q. Yang, R.McKellar. (2015). Nanolayered CrAlTiN and multilayered CrAlTiN-AlTiN coatings for solid particle erosion protection, Tribology International, 83, 12-20. https://doi.org/10.1016/j.triboint.2014.11.002

R.Westergard, M. Bromark, M. Larsson, P. Hedenqvist, S. Hogmark. (1997). Mechanical and tribological characterization of DC magnetron sputtered tantalum nitride thin films, Surface and Coatings Technology, 97(1), 779-784. https://doi.org/10.1016/S0257-8972(97)00338-1

Tadahiro Wada, Koji Iwamoto, Keizo Tsukamoto and Kazuki Hiro. (2011). Properties of TaN Coating Film Deposited on WC-Co-based Cemented Carbide using Magnetron Sputter Ion Plating, Applied Mechanics and Materials, 87, 186-190.

Tadahiro Wada, Mitsunori Ozaki, Hiroyuki Hanyu, and Kinya Kawase. (2014). Tool Wear of Aluminum-Chromium Based Coated Cemented Carbide in Cutting Hardened Sintered Steel, International Journal of Engineering and Technology, 6(3), 223-226. https://doi.org/10.7763/IJET.2014.V6.701

Tadahiro Wada, Hiroyuki Hanyu. (2017). Tool wear of (Ti,Al)N-coated polycrystalline cubic boron nitride compact in cutting of hardened steel, IOP Conference Series: Materials Science and Engineering. https://doi.org/10.1088/1757-899X/264/1/012017

Tsao Chung-Chen, Hocheng Hong. (2002). Comparison of the tool life of tungsten carbides coated by multi-layer TiCN and TiAlCN for end mills using the Taguchi method, Journal of Materials Processing Technology, 123(1), 1-4. https://doi.org/10.1016/S0924-0136(01)01152-9

Yun Chena, Hao Du, Ming Chen, Jun Yang, Ji Xiong, Haibo Zhao. (2016). Structure and wear behavior of AlCrSiN-based coatings, Applied Surface Science, 370, 176-183. https://doi.org/10.1016/j.apsusc.2015.12.027

Tool Wear of Aluminum/Chromium/Tungsten-Based Coated Cemented Carbide in Cutting Alloy Steel

Tadahiro WADA

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INTRODUCTION

Ti1-xAlxN and Cr1-xAlxN alloys are among the most widely used physical and chemical vapor deposited hard coating materials due to their outstanding functional properties [1]. In order to improve the properties of the CrAlN-coating film, there is a method of forming a multilayered coating film [2, 3]. In another method, the properties of the CrAlN-coating film can be easily improved by adding silicon (Si)[4-9] to the target. Adding tungsten (W) to the film other than silicon is also affective for improving the properties of the CrAlN-coating film [10-14]. That is, in order to improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, cathode material of an (Al,Cr,W)-target was used in adding tungsten to the cathode material of the (Al,Cr)-target [10]. In cutting hardened sintered steel, tool wear was experimentally investigated [10, 11]. Moreover, in cutting Sintered Steel [12] and hardened steel [13], tool wear was experimentally investigated. As a result, it was found that adding the tungsten composition to the (Al,Cr)-target has a considerable effect on the wear resistance of the cutting tool. However, the wear progress of the (Al,Cr,W)-based coated cemented carbide in cutting alloy steel have not been clarified.

In this study, to clarify of the effectiveness of the (Al,Cr,W) -coating film for cutting alloy steel, the tool wear was experimentally investigated.

CONCLUSIONS

In this study, to clarify of the effectiveness of the (Al,Cr,W) -coating film for cutting alloy steel, the tool wear was experimentally investigated.

The following results were obtained:

(1) The wear progress of coated cemented carbide tool deposited using the (Al,Cr,W)-target was slower than that of the coated cemented carbide tool deposited using the (Al,Cr)-target.

(2) The wear progress of the (Al64, Cr28,W8)N-coated tool was slower than that of the (Al60, Cr25,W15)N-coated tool.

(3) In the case of the coated cemented carbide tool deposited using the (Al64,Cr28,W8)-target, although the adhesiveness of the (Al64,Cr28,W8)(C,N)-coated tool by adding carbon to the (Al64,Cr28,W8)N-coating film became higher, the wear progress of the (Al64,Cr28,W8)(C,N)-coated tool became faster than that of the (Al64,Cr28,W8)N-coated tool.

(4) As compared to the wear progress of the (Al64,Cr28,W8) C-coated and that of the (Al64,Cr28,W8)(C,N)-coated tool, the wear progress of the (Al64,Cr28,W8)C coated tool was slightly slower. For this reason, it was considered that although the micro-hardness of the (Al64,Cr28,W8)C-coating film was lower than that of the (Al64,Cr28,W8)(C,N)-coating film, the average value of the friction coefficient of the (Al64, Cr28,W8)N coating film, 0.26, was about half of that of the (Al64, Cr28,W8)(C,N) coating film, 0.53.

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REFERENCES

[1] M. Bartosik, D. Holec, D. Apel, M. Klaus, C. Genzel, J. Keckes, M. Arndt, P. Polcik, C.M. Koller, P.H. Mayrhofer, "Thermal expansion of Ti-Al-N and Cr-Al-N coatings", Scripta Materialia, Volume 127, pp. 182-185, 2017.
[2] T. Teppernegg, C. Czettl, C. Michotte, C. Mitterer, "Arc evaporated Ti-Al-N/Cr-Al-N multilayer coating systems for cutting applications", International Journal of Refractory Metals & Hard Materials, 72, pp. 83–88, 2018.
[3] Yin-Yu Chang, Shi-Yao Weng, Chun-Hsiao Chen, Fu-Xing Fu, "High temperature oxidation and cutting performance of AlCrN, TiVN and multilayered AlCrN/TiVN hard coatings", Surface & Coatings Technology, 332, pp. 494–503, 2017.
[4] Mohan Chen,Wanglin Chen, Fei Cai, Shihong Zhang, QiminWang, "Structural evolution and electrochemical behaviors of multilayer Al-Cr-Si-N coatings", Surface & Coatings Technology, 296, pp. 33–39, 2016.
[5] In-Wook Park, Dong Shik Kang, John J. Moore, Sik Chol Kwon, Jong Joo Rha, Kwang Ho Kim, "Microstructures, mechanical properties, and tribological behaviors of Cr–Al–N, Cr–Si–N, and Cr–Al–Si–N coatings by a hybrid coating system hard coatings", Surface & Coatings Technology, 201, pp. 5223–5227, 2007.
[6] Tomas Polcar, Albano Cavaleiro, "High-temperature tribological properties of CrAlN, CrAlSiN and AlCrSiN coatings", Surface & Coatings Technology, 206, pp. 1244–1251, 2011.
[7] Yuwei Ye, Zhiyong Liu, Wei Liu, Dawei Zhang, Yongxin Wang, Haichao Zhao, Liping Wang, Xiaogang Li, "Bias design of amorphous/nanocrystalline Cr–Al–Si–N films for remarkable anti-corrosion and anti-wear performances in seawater", Tribology International, 121, pp. 410–419, 2018.
[8] Chang B. Liu, Wang Pei, Feng Huang, Li Chen, "Improved mechanical and thermal properties of CrAlN coatings by Si solid solution", Vacuum 125, pp. 180-184, 2016.
[9] Shihong Zhang, Lei Wang, Qimin Wang, Mingxi Li, "A superhard CrAlSiN superlattice coating deposited by multi-arc ion plating: I. Microstructure and mechanical properties", Surface & Coatings Technology, 214, pp. 160–167, 2013.
[10] Tadahiro Wada, and Hiroyuki 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.
[11] Tadahiro Wada, Hiroyuki 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 (IJMMME) Volume 3, Issue 2, pp. 56-60, 2015. (ISSN 2320–4060 (Online))
[12] Tadahiro Wada, Hiroyuki 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, 2015.
[13] Tadahiro Wada, Hiroyuki 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.

Wear Mechanism of Multi-layer AlCrWN/AlCrWSiN Coatings on Cemented Carbide Tool Prepared by Arc Ion Plating in Dry Cutting of Sintered Steel

Tadahiro WADA and Hiroyuki HANYU*

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INTRODUCTION

A machine part having a complicated shape can be accurately mass-produced by powder metallurgy, while a sintered material can be produced because it has a large degree of freedom in terms of material design. For dimensional accuracy, it is often necessary for sintered steel machine parts to be machined by a mass production metal removal process. The tool life in cutting sintered steel is shorter than that in cutting molten steel such as carbon steel. Moreover, as sintered machine parts are often cut at high cutting speed for mass-production, the tool materials must have effective wear resistance. An aluminium-chromium based coating film has been developed. Comparing the performance of AlCrN coated tool inserts with that of TiN coated ones, the former can achieve approximately 33% more depth of cut and can attain higher cutting speed due to better thermal resistance of the coated inserts [1]. However, the results of our study indicate that the critical scratch load, which was the value measured by the scratch test, of the AlCrN coating film was 77 N and the micro-hardness was 2760 $HV_{0.25N}$. Therefore, in order to improve both the scratch strength and the micro-hardness of the AlCrN coating film, cathode material of an Al-Cr-W target was used in adding tungsten (W) to the cathode material of the Al-Cr target. As a result, the scratch strength and the micro-hardness of the AlCrWN coating film increased to 81 N and 3110 $HV_{0.25N}$, respectively [2]. To improve the properties of the coating film, the cathode material of an Al-Cr-W-Si target was used [3-5]. For example, Yu-ping Feng et al. reported that the hardness of AlCrSiWN coating film is higher than that of AlCrN at temperatures below 700 degrees Celsius [3]. Many multi-layer coating materials to improve tool life have been developed [6-10]. The wear progress of the multi-layered AlCrWCN/AlCrWSiCN-coated tool was slower than that of the mono-layer AlCrWSiCN-coated tool in cutting hardened steel [11] or in milling hardened steel [12]. However, the properties of the multi-layer AlCrWN/AlCrWSiN-coated coating film have not been elucidated, and the tool wear of the multi-layer AlCrWN/AlCrWSiN-coated tool has not been clarified in cutting sintered steel.

In this study, to clarify the effectiveness of the multi-layer AlCrWN/AlCrWSiN-coated cemented carbide tool, the wear progress was investigated in cutting sintered steel using three types of coated tools.

CONCLUSION

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

The following results were obtained:

(1) The main tool failure of the three types of coated tools was flank wear within the maximum value of the flank wear width of 0.2 mm.
(2) The wear progress of Type III, which was the multi-layer coating system, was the slowest in cutting sintered steel.

* OSG Corporation

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REFERENCES

[1] Yueh-Jaw Lin, Ashutosh Agrawal, Yunmei Fang: Wear progressions and tool life enhancement with AlCrN coated inserts in high-speed dry and wet steel lathing, Wear, Volume 264, Issues 3-4, pp. 226-234 (2008)
[2] Tadahiro Wada, Hiroyuki 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)
[3] Yu-ping Feng, Li Zhang, Rong-xian Ke, Qing-lei Wan, ZheWanga, Zhi-hong Lu: Thermal stability and oxidation behavior of AlTiN, AlCrN and AlCrSiWN coatings, Int. Journal of Refractory Metals and Hard Materials, Vol. 43 March, pp. 241-249 (2014)
[4] Shihong Zhang, Lei Wang, Qimin Wang, Mingxi Li: A superhard CrAlSiN superlattice coating deposited by multi-arc ion plating: I. Microstructure and mechanical properties, Surface & Coatings Technology, 214, pp. 160-167(2013)
[5] Lihui Zhu, Mingmei Hu, Wangyang Ni, Yixiong Liu: High temperature oxidation behavior of Ti0.5Al0.5N coating and Ti0.5Al0.4Si0.1N coating, Vacuum, 86, pp. 1795-1799 (2012)
[6] J.H. Hsieh, C. Liang, C.H. Yu, W. Wu: Deposition and characterization of TiAlN and multi-layered TiN/TiAlN coatings using unbalanced magnetron sputtering, Surface and Coatings Technology, 108-109, pp. 132-137 (1998)
[7] A.A. Vereschaka, S.N. Grigoriev, A.S. Vereschaka, A.Yu. Popov and A. D. Batako: Nano-scale multilayered composite coatings for cutting tools operating under heavy cutting conditions, Procedia CIRP, 14, pp. 239-244 (2014)
[8] Tsao Chung-Chen, Hocheng Hong: Comparison of the tool life of tungsten carbides coated by multi-layer TiCN and TiAlCN for end mills using the Taguchi method, Journal of Materials Processing Technology, Volume 123, Issue 1, pp. 1-4 (2002)
[9] M. Nouari, A. Ginting: Wear characteristics and performance of multi-layer CVD-coated alloyed carbide tool in dry end milling of titanium alloy, Surface & Coatings Technology, 200, pp. 5663- 5676 (2006)
[10] Q. Yang, R.McKellar: Nanolayered CrAlTiN and multilayered CrAlTiN–AlTiN coatings for solid particle erosion protection, Tribolo.gy International, 83, pp. 12-20 (2015)
[11] Tadahiro Wada, Hiroyuki 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)
[12] Tadahiro Wada, Hiroyuki Hanyu: Tool Wear of Aluminum/Chromium/Tungsten/Silicon-based coated End Mill Cutters in Milling Hardened Steel, Proceedings of 3rd International Conference on Mechanical Properties of Materials (ICMPM 2016), December 14-17, Venice, Italy (PM008) (2016)

Tool Wear of Poly Crystalline Diamond in Cutting WC-Co Cemented Carbide with High-Pressure Coolant Supplied

Tadahiro WADA

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INTRODUCTION

WC-Co hard metals or cemented carbides are used in applications where wear resistance is important [1]. For example, they are widely used for a variety of machining, cutting, drilling, and other applications [2] due to their very high hardness and excellent resistance to shock and wear [3].Sintered WC-Co components have to be machined in order to meet the demands of good surface quality and precision [4]. To achieve hard metal parts finishing, replacement of electro-discharge machining (EDM) and diamond wheel grinding is required. In fact, both are time consuming techniques, the former being very expensive due to the electrode cost, while the latter suffers from reduced lifespan of the tools, and the wheels requiring frequent dressing and sharpening [5]. Polycrystalline diamond (PCD) cutting WC-Co cemented carbide is described in the catalog of several cutting tool makers [6]. Katsuko Harano et al. [7] reported that in turning WC-7% mass Co cemented carbide (grain size: 2 µm) with the PCD tool, whose average grain size was 5 µm, under the condition of a cutting speed of 0.33 m/s, a depth of cut of 0.05 mm and a feed rate of 0.1 mm/rev, the flank wear width is about 0.22 mm after cutting to 280 m. Therefore, when cutting cemented carbide at a high cutting speed, due to elevation of the cutting temperature, the tool life is remarkably shortened. For this reason, the recommended cutting speed is 0.17- 0.33 m/s in cutting cemented carbide with a PCD tool [6]. On the other hand, a high-pressure coolant cutting which supplies cutting fluid to the rake face and the flank face is an effective way to lower the cutting temperature [8]-[12]. However, the influences of the cutting speed on the tool wear in higher speed cutting of WC-Co cemented carbide with high-pressure coolant supplied have not been reported.

In order to identify an effective PCD tool for the high-speed cutting of WC-16 mass% Co cemented carbide, the influences of the diamond content and the diamond particle size on the tool wear were experimentally investigated. As the WC-16 mass% Co cemented carbide was turned with high-pressure coolant supplied, the tool wear was experimentally investigated.

CONCLUSIONS

To identify an effective PCD tool for the high-speed cutting of WC-16 mass% Co cemented carbide, the influences of the diamond content and the diamond particle size on the tool wear were experimentally investigated. As the WC-16 mass% Co cemented carbide was turned with high-pressure coolant supplied, the tool wear was experimentally investigated.

The following results were obtained:

(1) In turning WC-16 mass% Co cemented carbide with the PCD tool, the wear progress slowed down considerably by using the high-pressure coolant supplied method.
(2) 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.
(3) In the case of the cutting of the high-pressure coolant supplied by the PCD tool, which has a large diamond particle size, WC-16 mass% Co cemented carbide could be cut at the higher cutting speed of 1.167 m/s.

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REFERENCES

[1] J.C.P. Zunega, M.G.Gee, R.J.K.Wood, J.Walker, Scratch testing of WC/Co hardmetals, Tribology International, 54, (2012), pp. 77-86.
[2] Hwan-Cheol Kim, In-Jin Shon, Jin-Kook Yoon, Jung-Mann Doh, Consolidation of ultra fine WC and WC–Co hard materials by pulsed current activated sintering and its mechanical properties, International Journal of Refractory Metals & Hard Materials, 25, (2007), pp. 46-52.
[3] R.A. Mahdavinejad, A. Mahdavinejad, ED machining of WC–Co, Journal of Materials Processing Technology, 162-163, (2005), pp. 637-643.
[4] Wolfgang Hintze, Stefan Steinbach, Claudia Susemihl, FalkoKähler, HPC-milling of WC-Co cemented carbides with PCD, International Journal of Refractory Metals & Hard Materials, 72, (2018), pp. 126-134.
[5] M. Belmonte, P. Ferro, A.J.S. Fernandes, F.M. Costa, J. Sacramento, R.F. Silva, Wear resistant CVD diamond tools for turning of sintered hardmetals, Diamond and Related Materials, 12, (2003), pp. 738-743.
[6] e. g., Tungaloy Corporation, catalog of cutting tool, (2013-2014), p. 3-20.
[7] KatsukoHarano, Takeshi Satoh, Hitoshi Sumiya and Satoru Kukino, Cutting Performance of Nano-Polycrystalline Diamond, SEI Technical Review, 71, (Oct. 2010), pp. 98-103.
[8] 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.
[9] 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.
[10] 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.
[11] 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.
[12] 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 (ICMAE2017), Prague, Czech Republic, (2017), pp. 50-55.

Tool Wear in Intermittent Cutting of AISI 304 Stainless Steel by Thermally-Sprayed Coatings

Tadahiro WADA

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INTRODUCTION

Engineering processes can be used to modify the surface properties of metallic materials in different types of industries. Thermal spraying is a technique commonly used for obtaining the metal matrix and deposited coatings due to easy process ability, reasonable material costs and good mechanical properties [1]. To increase the wear, erosion, and corrosion resistance of tribologically-stressed functional surfaces, the use of thermally-sprayed coatings is increasing [2]. Many studies on thermal spraying have been reported [3-8].

Ni-based materials alloyed with Cr or/and Al such as NiCr, NiAl or NiCrAlY are frequently employed as coatings to protect components against high-temperature corrosion [8]. A thermally-sprayed coating such as NiCrBSi made by adding Cr, B, Si to a Ni-based thermally-sprayed coating, presents a high bonding strength and excellent resistance to adhesive and abrasive wear at elevated temperatures. So, typical applications are, for example, piston rings or rollers in steel making [3].

WC-Co coating is widely used for wear resistance applications. The addition of Cr to WC-Co improves binding of the metallic matrix with the WC grains and provides a better wear-resistant coating [9]. Stellite-21, WC-Co-Cr and Cr3C2-NiCr coating powders were deposited on high tensile steel being used for tiller blades by the pulsed detonation spraying technique and the wear behavior of these coatings was evaluated by the pin-on-disc mechanism at an ambient temperature under dry conditions in accordance with the ASTM G-99 standard [10]. As a result, it was observed that the WC-Co-Cr coating on high tensile steel provided higher wear resistance in abrasion in comparison to Cr3C2-NiCr and Stellite-21 [10].

Ball valves are widely used in the processing industry to control the flow rate and flow direction or cut off the flow of the pipeline system [11]. Stainless steel is renowned for its corrosion resistance, and it is widely used for applications such as ball valves in corrosive environments [12]. In order to improve the wear resistance, a thermally-sprayed coating may be applied to the ball of the ball valve in some cases. To improve the dimensional accuracy or surface roughness, it is often necessary for thermally-sprayed machine parts to be machined by the removal process. As a thermally-sprayed coating often shows difficult-to-cut properties, a cutting [13], grinding [2, 9] or honing [14] process is usually employed. Replacement of the grinding process with a cutting process is an effective method of improving the productivity. Cutting is performed intermittently because there is a hole in the ball part. However, there are no studies on intermittent cutting of thermally-sprayed coatings.

In this study, in order to obtain an effective tool material for intermittent cutting of two types of thermally-sprayed coatings, tool wear was investigated experimentally. The Ni-based self-fluxing alloy coating (Ni67,Cr16,B4,Si4,Cu3,Mo3,Fe2.5,C0.5) and the thermally-sprayed (WC-Cr-Ni) cermet coating (W70,Cr19,Ni5,C6) were used as the thermally-sprayed coatings. AISI 304 stainless steel was used as a substrate material of thermally-sprayed coatings. In the case of the intermittent cutting of Ni-based self-fluxing alloy coating, conventional cutting materials, namely CVD-coated cemented carbide and ceramics, were used as cutting materials. In the case of the intermittent cutting of the thermally-sprayed (WC-Cr-Ni) cermet coating, in addition to Si3N4 ceramics, three types of uncoated cBN and a coated cBN were also used as the tool materials. Intermittent cutting of these two types of thermally-sprayed coatings was carried out with various cutting materials.

CONCLUSIONS

In this study, to obtain an effective tool material for the intermittent cutting of two types of the thermally-sprayed coating AISI 304, the tool wear was investigated experimentally.

The results are as follows:

A. In the case of intermittent cutting of Ni-based self-fluxing alloy coating AISI 304:

(1) The Si3N4 ceramics are considered an effective tool material.

(2) There was little difference in the maximum value of flank wear width “VBmax” of the Si3N4 ceramic among 0.50 m/s, 1.00 m/s and 1.67 m/s.

B. In the case of intermittent cutting of thermally-sprayed (WC-Cr-Ni) cermet-coated AISI 304:

(1) The uncoated cBN is considered to be a suitable tool material.

(2) The cBN having the large grain size of cBN and high contents rate was effective for wear resistance.

(3) cBN having excellent hardness and the transverse-rupture strength was effective for wear resistance.

(4) In the case of the cBN C, there was little difference in the VBmax between 0.50 m/s and 1.00 m/s.

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REFERENCES

[1] Chao Zheng, Yonghong Liu, Jie Qin, Cheng Chen, Renjie Ji, “Wear behavior of HVOF sprayed WC coating under water-in-oil fracturing fluid condition”, Tribology International, 115, pp. 28-34, 2017.

[2] Sebastian Goeke, Tobias Brüggemann, and Dirk Biermann, “Development of Machining Processes for the Use of Multilayer High-Performance Coatings”, ISRN Tribology, vol. 2013, 6 pages, 2013.

[3] J. Rodrıguez, A. Martın, R. Fernández, J.E. Fernández, “An experimental study of the wear performance of NiCrBSi thermal spray coatings”, Wear, 255, pp. 950-955, 2003.

[4] G. Bolelli, L.-M. Berger, T. Börner, H. Koivuluoto, L. Lusvarghi, C. Lyphout, N.Markocsan, V. Matikainen, P. Nylén, P. Sassatelli, R. Trache, P. Vuoristo, “Tribology of HVOF- and HVAF-sprayed WC-10Co4Cr hardmetal coatings: A comparative assessment”, Surface and Coatings Technology, 265, pp. 125-144, 2015.

[5] S. Sampath, X.Y. Jiang, J. Matejicek, L. Prchlik, A. Kulkarni, A. Vaidya, “Role of thermal spray processing method on the microstructure”, Materials Science and Engineering A, 364, pp.216-231, 2004.

[6] Davide Fantozzi, Ville Matikainen, Mikko Uusitalo, Heli Koivuluoto, Petri Vuoristo, “Chlorine-induced high temperature corrosion of Inconel 625 sprayed coatings deposited with different thermal spray techniques”, Surface and Coatings Technology, 318, pp. 233-243, 2017.

[7] P. Cavaliere, A. Silvello, N. Cinca, H. Canales, S. Dosta, I. Garcia Cano, J. M. Guilemany, “Microstructural and fatigue behavior of cold sprayed Ni-based superalloys coatings”, Surface and Coatings Technology, 324, pp. 390-402, 2017.

[8] E. Sadeghimeresht, N. Markocsan, M. Huhtakangas, S. Joshi, “Isothermal oxidation of HVAF-sprayed Ni-based chromia, alumina and mixed-oxide scale forming coatings in ambient air”, Surface and Coatings Technology, 316, P. 10-21, 2017.

[9] J.K.N. Murthy, D.S. Rao, B. Venkataraman, “Effect of grinding on the erosion behaviour of a WC-Co-Cr coating deposited by HVOF and detonation gun spray processes”, Wear, 249, pp. 592-600, 2001.

[10] Amardeep S. Kanga, Jasmaninder S. Grewal, Gurmeet S. Cheema, “Effect of thermal spray coatings on wear behavior of high tensile steel applicable for tiller blades (5th International Conference on Materials Processing and Characterization (ICMPC 2016)”, Materials Today: Proceedings 4, pp. 95-103, 2017.

[11] Baoling Cui, Zhe Lin, Zuchao Zhu, Huijie Wang, Guangfei Ma, “Influence of opening and closing process of ball valve on external performance and internal flow characteristics”, Experimental Thermal and Fluid Science, 80, pp. 193-202, 2017.

[12] J. Vetter, T. Michler, H. Steuernagel, Hard coatings on thermochemically pretreated soft steels: application potential for ball valves, Surface and Coatings Technology, 111, pp. 210-219, 1999.

[13] Z.W. Zhong, Z.F. Peng, N. Liu, “Surface roughness characterization of thermally sprayed and precision machined WC-Co and Alloy-625 coatings”, Materials Characterization, 58, pp. 997-1005, 2007.

[14] Dirk Biermann, Sebastian Goeke, Wolfgang Tillmann, Jan Nebel, “Improvement of wear resistant thermally sprayed coatings by micro finishing”, CIRP Annals - Manufacturing Technology, 62, pp. 559-562, 2013.