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

Tadahiro Wada and Hiroyuki Hanyu*

World Academy of Science, Engineering and Technology International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, Vol. 9, No. 8(2015) pp. 826-829.

An aluminum/chromium-based-coating film, namely (Al,Cr)N coating film, has been developed. The aluminum/chromium-based-coated tool was evaluated through the machining of sintered steel, and exhibited markedly improved performance [1]. Therefore, the effectiveness of the aluminum/chromium-coating film is apparent when cutting hardened sintered steel [2].

This result clarified that the wear progress of the (Al,Cr)N coated cemented carbide tool was slower than that of the (Ti,Al)N coated cemented carbide tool, and (Al,Cr)N coated cemented carbide is an effective tool material for cutting hardened sintered steel [2]. However, the results of our study indicate that the critical scratch load, which is the measured value by the scratch test, of the (Al,Cr)N coating film is 77 N and the micro-hardness is 2760 $HV_{0.25N}$. Therefore, in order to improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, cathode material of an aluminum/chromium/tungsten-target was used to add tungsten (W) to the cathode material of the aluminum/chromium-target [3]. The hardened sintered steel was turned with the aluminum/chromium/tungsten-based-coated cemented carbide tool. Compared with commercial (Al,Cr)N and (Ti,Al)N coated cemented carbide tools, the wear progress of the aluminum/chromium/tungsten-based-coated tool was slower than that of the (Al,Cr)N coated tool [3].

Furthermore, the wear progress and the wear mechanism of the aluminum/chromium/tungsten-based-coated tool were investigated [4, 5]. However, the wear progress and the tool wear mechanism of aluminum/chromium/tungsten-based-coated cemented carbide in cutting sintered steel have not been clarified.

In this study, to clarify the wear progress and the tool wear mechanism of the aluminum/chromium/tungsten-based-coated tool for cutting sintered steel, the sintered steel was turned. Scanning Electron Microscope (SEM) observation and Energy Dispersive x-ray Spectroscopy (EDS) mapping analysis were conducted on the abraded surface.

The main results obtained are as follows:

(1) The wear progress of the (Al64,Cr28,W8)(C,N) coated tool was the slowest among that of the five coated tools.

(2) Adding carbon (C) to the aluminum/chromium/tungsten-based-coating film was effective for improving the wear-resistance.

(3) The main wear mechanism of the (Al60,Cr25,W15)N-, the (Al60,Cr25,W15)(C,N)- and the (Al64,Cr28,W8)(C,N)-coating films was abrasive wear.

* OSG Coating Service Co., Ltd.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 24560149 (Grant-in-Aid for Scientific Research (C)).

References

[1] Tadahiro Wada, Koji Iwamoto, Hiroyuki Hanyu and Kinya 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, 2011, pp.459-462 (in Japanese).

[2] Tadahiro Wada, Mitsunori Ozaki, Hiroyuki Hanyu, and Kinya Kawase, "Tool Wear of Aluminum-Chromium Based Coated Cemented Carbide in Cutting Hardened Sintered steel", IACSIT International Journal of Engineering and Technology, Vol. 6, No. 3, 2014, pp.223-226.

[3] Tadahiro Wada and Hiroyuki Hanyu, "Tool Wear of Aluminum/Chromium/Tungsten-based-coated Cemented Carbide in Cutting Hardened Steel", Proceedings of 2014 IMSS International Conference on Future Materials Engineering (ICME 2014), October 27-28, 2014, Paris, France.

[4] Tadahiro Wada and Hiroyuki Hanyu, "Tool Wear of Aluminum/Chromium/Tungsten-based-coated Cemented Carbide in Cutting Hardened Sintered Steel", Proceedings of 2014 International Conference on Power Science and Engineering (ICPSE 2014), December 18 - 20, 2014, Barcelona, Spain.

[5] Tadahiro Wada and Hiroyuki Hanyu, "Wear Mechanism of Aluminum/Chromium/Tungsten-based-coated Cemented Carbide Tools in Dry Cutting of Hardened Sintered Steel", Proceedings of 3rd International Conference on Aerospace, Mechanical, Automotive and Materials Engineering (ICAMME'15), March 29-30, 2015, Singapore.

Tool Wear of Aluminum/Chromium/Tungsten-based-coated Cemented Carbide in Cutting Hardened Steel

Tadahiro WADA and Hiroyuki HANYU*

Applied Mechanics and Materials, Vol. 798 (2015) pp. 377-383.

Hardened steels used for dies or molds are widely cut as a substitution for grinding. Polycrystalline cubic boron nitride compact (cBN) tools are used for cutting hardened steels, due to their higher hardness and higher thermal conductivity. However, in higher feed rate turning or discontinuous cutting, e.g. milling, drilling and tapping, main tool failure of the cBN occurs easily by fracture because the cBN has poor fracture toughness. In these cutting hardened steels, coated cemented carbide tools, which have good fracture toughness and wear resistance, are effective tool materials. The physical vapor deposition (PVD) method, which is a coating technology, is widely applied to cutting tools because the PVD method can be coated at a lower treatment temperature and a higher adhesion of the deposition to the substrate. In this case, titanium based films (e.g. TiN, (Ti,Al)N) are generally used as the coating film [e.g. 1, 2].

An aluminum/chromium-based coating film, namely (Al,Cr)N coating film, has recently been developed. An aluminum/chromium-based coated tool was evaluated through the machining of sintered steel, and showed greatly improved performance [3]. Furthermore, it was clarified that the (Al,Cr)N coated cemented carbide is an effective tool material in cutting hardened sintered steel [4]. However, it was considered from our study that the critical scratch load, which is the measured value by scratch test, of the (Al,Cr)N coating film is 77 N and the micro-hardness is 2760 $HV_{0.25N}$. Therefore, in order to improve both the scratch strength and the micro-hardness of the (Al,Cr)N coating film, cathode material of an aluminum/chromium/tungsten target was used in adding tungsten (W) to the cathode material of the aluminum/chromium target.

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

The following results were obtained:

(1) The micro-hardness of (Al,Cr,W)N or (Al,Cr,W)(C,N), (Al,Cr)N coating film was 3110 $HV_{0.25N}$ or 3080 $HV_{0.25N}$, respectively. And the micro-hardness of two types of Aluminum/Chromium/Tungsten-based coating film were higher than that of both the (Al,Cr)N coating film 2760 $HV_{0.25N}$ and the (Ti,Al)N 2710 $HV_{0.25N}$.

(2) The critical scratch load of (Al,Cr,W)(C,N) coating film 123N was much higher than that of (Al,Cr)N coating film 77N or (Ti,Al)N coating film 73N.

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

The above results clarify that the aluminum/chromium/tungsten-based coating film, which is a new type of coating film, has both high hardness and good adhesive strength, and can be used as a coating film of WC-Co cemented carbide cutting tools.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 24560149 (Grant-in-Aid for Scientific Research (C)).

References

[1] K. Sakagami, G. Yongming and T. Yamamoto: Pro. 4th Int. Conf. on Progress of Cutting and Grinding, (1998), p.38.
[2] H. Nakagawa, T. Hirogaki et al.: Pro. 6th Int. Conf. on Progress of Machining Technology, (2002), p.81.
[3] 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 (in Japanese).
[4] 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.

* OSG Corporation

Tool Wear of Aluminum / Chromium / Tungsten/ Silicon-Based-Coated Cemented Carbide Tools in Cutting of Hardened Steel

Tadahiro WADA and Hiroyuki HANYU*

International Journal of Engineering and Technology, Vol. 8, No. 6(2016) pp. 406-409.

An (Al, Cr)N coated tool was evaluated through the machining of sintered steel, and showed greatly improved performance [1]. And, the (Al, Cr)N coated cemented carbide is an effective tool material in cutting hardened sintered steel [2]. However, the results of our study indicate that the critical scratch load, which is the measured value by the scratch test, of the (A l, Cr) N coating film is 77 N and the micro-hardness is 2760 $HV_{0.25N}$. Therefore, in order to improve both the scratch strength and the micro-hardness of the (Al, Cr)N coating film, the cathode material of an aluminum / chromium / tungsten-target was used in adding tungsten (W) to the cathode material of the aluminum / chromium target [3]. Furthermore, the hardened sintered steel was turned with the aluminum / chromium / tungsten-based-coated cemented carbide tools. Compared with commercially available (Al, Cr)N and (Ti, Al)N coated cemented carbide tools, at a low cutting speed of 0.42 m/s, the wear progress of the aluminum/chromium/tungsten-based-coated tool became the slowest [3].

However, the addition of Si to TiN coatings is reported to transform the [111] oriented columnar structure into a dense finely grained structure, and thin films of Ti-Si-N have been deposited by physical vapor deposition to improve the wear resistance of TiN coatings [4]. The hardness of the Ti0.84Si0.15N1.03 revealed the highest hardness value, around 47 GPa, which is more than double that of common TiN [5]. The Ti1-xSixN system revealed a significant increase in the load values for total failure when compared with that of TiN [6]. However, the (Ti, Al, Si)N forms a two-phase scale as in the (Ti, Al)N, but the oxidation resistance is slightly lower, too [7].

From the viewpoint of film-forming, in Inconel 718 turning, the (Ti, Al)N-multilayer coating showed some performance advantage over the (Ti, Al)N-monolayer at higher speed [8]. Nowadays, most multi-layer coating materials contain a combination of TiN, TiC, Ti(C,N) and Al_2O_3; to improve the tool life, they are deposited in different sequences [9].

In this study, to improve the tool life in cutting hardened steel, the cathode material of an aluminum/chromium/tungsten/silicon-target was used in adding silicon (Si) to the cathode material of the aluminum/chromium/tungsten-target. Multi-layer coating materials containing a combination of aluminum / chromium / tungsten / silicon-based-coating film and aluminum/chromium/tungsten-based-coating film to improve the tool life were also used. Furthermore, the characteristics of aluminum / chromium / tungsten / silicon-based coating films were investigated.

The following results were obtained:

(1) The micro-hardness and the critical scratch load measured value by a scratch tester of the (Al53, Cr23, W14, Si10) (C, N)-coating film was 2990 $HV_{0.25N}$ and over 130 N, respectively.

(2) The mean value of the friction coefficient of the (Al53, Cr23, W14, Si10) (C, N)-coating film was 0.41.

(3) The wear progress of the (Al53, Cr23, W14, Si10) (C, N)-coated tool was slower than that of the (Ti, Al) N- and the (Al60, Cr25, W15) (C, N)-coated tool.

(4) In the case of the feed rate of 0.1 mm/rev, the wear progress of the multilayer coated tool was almost equivalent to that of the monolayer coated tool. However, at a higher feed rate of 0.2 mm/rev, the wear progress of the multilayer coated tool was slower than that of the monolayer coated tool.

The above results clarify that the new type of (Al60, Cr25, W15) (C, N)-coating film has both high hardness and good adhesive strength, and can be used as a tool material in cutting hardened steel.

* OSG Corporation

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 24560149 (Grant-in-Aid for Scientific Research (C)).

References

[1] 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, 2011, pp. 459-462 (in Japanese).

[2] T. Wada, M. Ozaki, H. Hanyu, and K. Kawase, “Tool wear of aluminum-chromium based coated cemented carbide in cutting hardened sintered steel,” IACSIT International Journal of Engineering and Technology, vol. 6, no. 3, 2014, pp. 223-226.

[3] 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 and Mechanical Engineering, vol. 3, no. 2, 2015, pp. 56-60.

[4] M. Diserens, J. Patscheider, and F. Levy, “Improving the properties of titanium nitride by incorporation of silicon,” Surface and Coatings Technology, 1998, pp. 241-246.

[5] F. Vaza, L. Rebouta, S. Ramos, M. F. D. Silva, and J. C. Soares, “Physical, structural and mechanical characterization of Ti1-xSixNy films,” Surface and Coatings Technology, 1998, pp. 236–240.

[6] F. Vaza, L. Rebouta, S. Ramos, M. F. D. Silva, and J. C. Soares, “Characterization of titanium silicon nitride films deposited by PVD,” Vacuum, vol. 52, 1999 , pp. 209-214.

[7] F. Vaza, L. Rebouta, S. Ramos, M. F. D. Silva, and J. C. Soares, “Oxidation resistance of (Ti, Al, Si)N coatings in air,” Surface and Coatings Technology, vol. 98, 1998, pp. 912-917.

[8] H. G Prengel, P. C Jindal, K. H. Wendt, A.T. Santhanam, P. L Hegde, and R. M. Penich, “A new class of high performance PVD coatings for carbide cutting tools,” Surface and Coatings Technology, vol. 139, no. 1, 2001, pp. 25–34.

[9] M. Nouari and A. Ginting, “Wear characteristics and performance of multi-layer CVD-coated alloyed carbide tool in dry end milling of titanium alloy,” Surface and Coatings Technology, vol. 200, no. 18–19, 2006, pp. 5663–5676.

Si Particle Size-controlled Al-17 mass% Si Alloy and Tool Wear in Cutting Al-17 mass% Si Alloy by Polycrystalline Diamond Compact Cutting Tool

Tadahiro WADA

Applied Mechanics and Materials, Vol. 798 (2015) pp. 372-376.

Aluminum alloys are used for automobile and motorbike parts due to their high strength-to-weight ratios and good corrosion resistance. However, as aluminum alloys have poor wear-resistance, silicon (Si) is added to improve the wear-resistance. In particular, hypereutectic Al-Si alloys such as A390 (Al-17 mass% Si) are used in applications that require high resistance to wear and corrosion, good mechanical properties, low thermal expansion and reduced density [1]. As a result, they are used in heavy wear applications, often at elevated or medium temperatures, such as in pistons, cylinder blocks and AC compressors [2]. High silicon aluminum alloys are generally machined to improve the dimensional accuracy. However, the use of hypereutectic Al–Si alloys in engine applications presents other challenges, including poor casting process reliability, and difficulties encountered in machining processes, primarily due to large (100 μm) primary silicon particles [3]. Primary silicon in hypereutectic aluminum- silicon alloys is very hard, imparting improved wear resistance but also decreasing tool life during machining [4].So, in cutting high silicon aluminum alloys with conventional cutting tools, the wear progress becomes faster because of the hard primary Si particles. Therefore, diamond cutting tools such as polycrystalline diamond (PCD) compact cutting tools or chemical vapor deposition (CVD) diamond cutting tools, are usually used to cut high silicon aluminum alloys[5] - [8]. To minimize machining issues while fully utilizing the outstanding wear properties, primary silicon crystals should be controlled to a uniform small size and have a uniform spatial distribution [4]. However, the effect of the primary silicon particle size on tool wear is unclear when cutting Al-17 mass% Si alloys.

In this study, in order to improve the tool wear resistance of polycrystalline diamond compact cutting tools, the Si particle size of an Al-17 mass% Si alloy was changed by adjusting the water-cooling speed. Two different kinds of Si particle size, which were changed by adjusting the water-cooling speed, were used. The Al-17mass%Si alloy was turned with the polycrystalline diamond compact cutting, and the tool wear was experimentally investigated.

The following results were obtained:

(1) The formed Si particle size was from 30 to 70 μm or from 40 to 170 μm.

(2) The mechanical properties of the Al-17 mass% Si alloy did not depend on the Si particle size.

(3) The Si particle size including that in the Al-17 mass% Si alloy had a major influence on the tool wear, and it was possible to reduce the tool wear by increasing the Si particle size including that in the Al-17 mass% Si alloy.

References

[1] Alireza Hekmat-Ardakan, Frank Ajersch, "Thermodynamic evaluation of hypereutectic Al–Si (A390) alloy with addition of Mg", Acta Materialia, 58(2010), pp.3422–3428.

[2] P. Kapranos, D.H. Kirkwood, H.V. Atkinson, J.T. Rheinlander, J.J. Bentzen, P.T. Toft, C.P. Debel, G. Laslaz, L. Maenner, S. Blais, J.M. Rodriguez-Ibabe, L. Lasa, P. Giordano, G. Chiarmetta, A. Giese, "Thixoforming of an automotive part in A390 hypereutectic Al–Si alloy", Journal of Materials Processing Technology, 135(2003), pp. 271–277.

[3] M. Elmadagli, T. Perry, A.T. Alpas,"A parametric study of the relationship between microstructure and wear resistance of Al–Si alloys",Wear, 262(2007), pp. 79–92.

[4] Naglaa Fathy, "Microstructural Evolution of Hyper-Eutectic Al-18% Si Alloy during Semi-Solid Isothermal Heat Treatment", Int'l Journal of Research in Chemical, Metallurgical and Civil Engg. (IJRCMCE), Vol. 1, Issue 1(2014), pp. 5-9.

[5] Yasuhiko OKITA, Satoru KUKINO and Tomohiro FUKAYA, "Development of Highly-Wear-Resistant, High-Strength Polycrystalline Diamond "SUMIDIA DA1000"",SEI TECHNICAL REVIEW, No. 66, (2008), pp. 101- 105.

[6] E.J. Oles, A. Inspektor, C.E. Bauer, "The new diamond-coated carbide cutting tools", Diamond and Related Materials, 5(1996), pp. 617- 624.

[7] K. Harano, T. Satoh, H. Sumiya, "Cutting performance of nano-polycrystalline diamond", Diamond & Related Materials, 24(2012), pp.78- 82.

[8] Humberto Gomez, Delcie Durham, Xingcheng Xiao, Michael Lukitsch, Ping Lu, Kevin Chou, Anil Sachdev, Ashok Kumar, "Adhesion analysis and dry machining performance of CVD diamond coatings deposited on surface modified WC–Co turning inserts", Journal of Materials Processing Technology, 212(2012), pp. 523- 533.

[9] Tadahiro wada, Junsuke Fujiwara and Hideki Koizumi, "Wear Characteristics of Diamond Tool in Cutting of Al-17mass%Si Alloy", Proceedings of The 1st International Conference on Design Engineering and Science (ICDE2005), October 28-31, 2005, Organized by Japan Society for Design Engineering, pp. 181-185.

[10] Kamio A., "Microstrucuture and property of Aluminum", Japan Institute of Light Metal, Tokyo, (1991), pp. 231. (in Japanese).

[11] Minoru Akaishi, Shinobu Yamaoka, Fumihiro Ueda, Tadakazu Ohashi,"Synthesis of polycrystalline diamond compact with magnesium carbonate and its physical properties", Diamond and Related Materials, 5(1996), pp. 2-7.

高圧クーラント供給を用いた高ニッケル合金切削における cBN 焼結体の工具摩耗

和田　任弘，森合　勇介 *，田中　宏明 **

粉体および粉末冶金，第 63 号第 4 号，2016 年 4 月 , pp. 157-165.

ガスタービンや航空機エンジンの部品に採用されている超耐熱合金インコネル 718 は難削材として知られている [1]．超耐熱合金の被削性が悪い原因として，高温強度が大きい，加工硬化が生じやすい，工具材料との親和性が大きい，熱伝導率が低いなどが考えられている [2]．高ニッケル合金切削における工具摩耗を調べた研究は多く行われている [3]．従来から，熱伝導性の悪い被削材を切削する場合，切削速度を低くして，かつ熱伝導性の良好な工具材を使用することが，工具寿命の延長に有効な方法であることは良く知られている．しかも，超硬合金によるインコネルの切削においては超硬合金 K 種などを用いて切りくずを薄く生成させるような切削が好ましいとされてきたが，工具寿命の点から高速度切削で加工することが出来ないため，きわめて低能率の加工条件で加工せざるを得なかった [4]．高速度切削には，耐熱性に優れたセラミックスや cBN 焼結体が有効な工具材種であり，山根ら [5] は，セラミックス工具によるインコネル 718 の高速度切削を行い，工具損傷，特に境界部の損傷についてその発生状況を調べ，境界損傷の抑制法について検討し，インコネル 718 の高速度切削の可能性を探った．新谷ら [4] は，結合材の異なる CBN 工具 3 種を用いてインコネル 718 材を旋削し，CBN 工具の損傷形態を観察することにより適合材種の選定と損耗機構の解明を行った．

さて，超耐熱合金の切削には，高圧の切削油剤をすくい面と逃げ面に供給する高圧クーラント切削法が有効である．猪谷ら [6] は，インコネル 718 の高圧クーラント切削を行い，通常の湿式切削（常圧外部給油）に比べ，切削温度低下に効果があることを示した．さらに，板倉ら [7] は，超硬合金 K20 種工具でインコネル 718 の高圧クーラント切削を行い，切削油剤の流速を速くなるに従って逃げ面摩耗幅が減少することを明らかにした．このように，高圧クーラントを切削部に供給する方法は，工具摩耗抑制に有効である [8-10] と考えられる．さらに，切削部へ高圧クーラントを供給することにより，工具損傷抑制効果のみならず切りくず処理性の向上 [11] も期待される．

以上のことから，高ニッケル合金のように熱伝導性が悪く，凝着摩耗を起こしやすい被削材の高速度仕上げ切削においては，cBN 焼結体工具による高圧クーラント切削が有効であると考えられるが，cBN 焼結体の摩耗特性について体系的に調べた研究は見あたらない．そこで本研究では，cBN 焼結体工具による高ニッケル合金の高速度仕上げ切削を対象とし，有効な cBN 焼結体を見出すことを目的として，cBN 含有量，cBN 粒径，および結合材の異なる 5 種類の cBN 焼結体の工具摩耗を調べた．また，高圧クーラント切削における切りくず形状，および表面粗さについても調べた．

得られた主な結果は，次の通りである．

(1) クーラント圧力を高圧にすることにより，切りくずは短く折断された．このため，高圧クーラント切削は，切りくず処理性，特に切りくず折断性能向上に有効な方法であった．

(2) 高ニッケル合金の仕上げ切削の場合，乾式切削では，逃げ面の切込み境界部に，大きな工具損傷が見られた．これに対し，cBN 含有量 50 ～ 60％の cBN 焼結体による高速度・高圧クーラント切削では，逃げ面の切込み境界部の工具損傷を抑制することができた．

(3) 高ニッケル合金の高圧クーラント切削には，cBN 含有量が 60％で，Al_2O_3-Al の結合材を持つ cBN 焼結体が有効な工具材種であった．

(4) cBN 含有量が 60％で，Al_2O_3-Al の結合材を持つ cBN 焼結体工具による高ニッケル合金の高圧クーラント切削において，クーラント圧力を高圧で切削する場合，切削速度を低速にすると，逃げ面の切込み境界部に大きな工具損傷が生じ，工具寿命が短命になった．

* （株）トクピ製作所

** 大阪電気通信大学

文献

1) K. Itakura, M. Kuroda, H. Omokawa, H. Itani, K. Yamamoto, Y. Ariura, “Wear Mechanism of Coated Cemented Carbide Tool in Cutting of Super Heat Resisting Alloy Inconel ”, Journal of the Japan Society for Precision Engineering, 65 (1999) 976-981.

2) K. Karino: Nansakuzai Sinsozai no Sessakukakou Handobukku, Kogyo Chosakai Publishing Co., Ltd., (2002) 256.

3) S. HANASAKI, J. FUJIWARA, K. SAKAGAMI, Y. HASEGAWA, “Cutting of a High-Nickel Alloy: 1st Report, Mechanism of Flank Groove Wear Formation”, Transactions of the JSME (C), 55 (1989) 780-786.

4) K. Shintani, H. Kato et al., “Cutting Performance of CBN Tools in Machining of Nickel Based Superalloy”, Journal of the Japan Society for Precision Engineering, 58 (1992) 1685-1690.

5) Y. YAMANE, N. AMANO, K. HAYASHI, N. NARUTAKI: “High Speed Machining of Inconel 718 with Ceramic Tools-Suppression of Notch Wear-“, Journal of the Japan Society for Precision Engineering, 59 (1993) 1815-1820.

6) H. Itani, M. Kuroda, T. Egawa, M. Takeuchi, K. Itakura: “High Efficiency Cutting of Difficult-to-Machine Material by High Pressure Injection”, Mitsubishi Heavy Industries, LTD. Technical Review, 35 (1998) 148-151.

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-“, 66 (2000) 1611-1615.

8) 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 (2004) 1045-1050.

9) 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) 1009–1014.

10) E.O Ezugwu, J Bonney,Y Yamane: “An overview of the machinability of aeroengine alloys”, Journal of Materials Processing Technology, 134-2 (2003) 233–253.

11) E. O. Ezugwu: “High speed machining of aero-engine alloys”, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 26-1 (2004) 1-11.