Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi
Dokuz Eylul University Faculty of Engineering Journal of Science and Engineering

Basılı/Printed ISSN: 1302-9304. Elektronik/Online ISSN: 2547-958X

Tool Coating Effect on the Performance in Milling of Al2124 Aluminium Alloy

Al2124 Alüminyum Alaşımının Frezeleme Performansı Üstüne Takım Kaplamasının Etkisi

Emel Kuram [1*]

[1] Gebze Technical University, Faculty of Engineering, Department of Mechanical Engineering, Kocaeli, TURKEY
Sorumlu Yazar / Corresponding Author *: kuram@gtu.edu.tr

Geliş Tarihi / Received: 21.03.2019 *DOI:10.21205/deufmd.2019216307*
Kabul Tarihi / Accepted: 18.04.2019 *Araştırma Makalesi/Research Article*

Atıf şekli/ How to cite: KURAM, E. (2019). Tool Coating Effect on the Performance in Milling of Al2124 Aluminium Alloy. DEUFMD, 21(63), 749-760.

Abstract

This study investigated the effect of various coated carbide inserts and depth of cut on some machining criteria such as surface roughness, tool wear, top burr width and milling forces during milling of Al2124 aluminium alloy. Monolayer TiCN, AlTiN, TiAlN and two layers TiCN + TiN, AlTiN + TiN deposited by physical vapour deposition coated inserts were utilized in the milling experiments. From experimental results, it was concluded that flank wear, milling forces, surface roughness and top burr width increased with the increment in the depth of cut for all coatings. The main wear mechanisms for all coated inserts were found to be adhesive and abrasive wear. As a result, coated inserts with two layers (TiCN + TiN and AlTiN + TiN) and TiCN coated inserts gave better machining performance with respect to AlTiN and TiAlN coated inserts in milling of Al2124 aluminium alloy.

Keywords: *Coating, Milling, Tool wear, Forces, Surface roughness, Burr*

Öz

Bu çalışmada, Al2124 alüminyum alaşımının frezelenmesi sırasında çeşitli kaplamalı karbür kesici uçların ve kesme derinliğinin yüzey pürüzlülüğü, takım aşınması, üst çapak genişliği ve frezeleme kuvvetleri gibi bazı işleme kriterlerine etkisi araştırılmıştır. Frezeleme deneylerinde fiziksel buhar biriktirme ile kaplanmış tek katlı TiCN, AlTiN, TiAlN ve iki katlı TiCN + TiN, AlTiN + TiN uçlar kullanılmıştır. Deneysel sonuçlardan, tüm kaplamalar için talaş derinliğinin artması ile serbest yüzey aşınmasının, frezeleme kuvvetlerinin, yüzey pürüzlülüğünün ve üst çapak genişliğinin arttığı sonucuna varılmıştır. Tüm kaplamalı uçlar için ana aşınma mekanizmaları adhezif ve abrazif aşınmalar olarak bulunmuştur. Sonuç olarak, iki katlı kaplamalı uçlar (TiCN + TiN ve AlTiN + TiN) ve TiCN kaplı uçlar Al2124 alüminyum alaşımının frezelenmesinde AlTiN ve TiAlN kaplı uçlara göre daha iyi işleme performansı sağlamıştır.

Anahtar Kelimeler: *Kaplama, Frezeleme, Takım aşınması, Kuvvetler, Yüzey pürüzlülüğü, Çapak*

1. Introduction

Aluminium 2124 (Al2124) alloy has a high strength and is employed in the aerospace area for manufacturing structural parts [1] and automotive bodies due to its good combination of toughness and strength [2]. Dry machining trend of aluminium and its alloys results in a real challenge during machining of these alloys. Built-up edge (BUE) formation owing to the affinity of aluminium material to the cutting tools is the main problem during machining with uncoated cutting tool [3], which impair the machinability of aluminium and its alloys. Tool coating is essential in order to enhance the resistance for wear of the tool and hence increasing the tool life [4]. Coated tools diminish cutting temperature and forces, improve wear resistance and surface related properties [5], hence improving the machining performance. Some scholars investigated the effect of various coated tools on the machining performance during milling of aluminium and its alloys. Thamban et al. [3] compared the machining performance of diamond coated and uncoated tools in milling of 6061-T6 aluminium material. Luo et al. [6] employed uncoated, TiAlN/VN and TiAlCrYN coated tools in milling of 7010-T7651 aluminium material. Najiha et al. [7] studied the effect of the uncoated, TiAlN coated and TiAlN + TiN coated inserts during end milling with minimum quantity lubrication for 6061-T6 aluminium alloy. Iyappan and Ghosh [8] developed a poly tetra fluoro ethylene (PTFE) coating and its machining performance was compared with MoS_2 coating in milling of pure aluminium (AA1050). From review of literature, it was seen that limited study was performed about the cutting performance of coated tools during milling of aluminium and its alloys and no work about the effect of different coatings during milling of Al2124 was reported. Further research about tool wear behaviour of the coated inserts, cutting force and surface quality in milling of Al2124 was needed. Al2124 is an aluminium-copper alloy. Copper provides hardness and strength properties to aluminium and therefore machinability characteristic of Al2124 is different from other aluminium alloys. Therefore, coated tools are required to withstand high hardness. With aluminium and its alloys being employed in several strategic areas such as automotive and aerospace industries, it is important to perform a study about machining performance under different coated tools. Therefore, in current study five types of coated inserts, namely, monolayer TiCN, AlTiN, TiAlN and two layers TiCN + TiN, AlTiN + TiN, were employed during milling of Al2124 alloy. Cutting performance of coated inserts was determined in terms of surface roughness, force components, tool wear and top burr width. As a conclusion, the proper selection of coating material in the industrial applications could improve the cutting performance by improving productivity and diminishing cutting tool cost with decreasing tool wear.

2. Material and Method

DECKEL MAHO DMU 60 P machining centre was utilized in the experiments. Al2124 with a dimension of 155 × 175 mm was employed as a material of workpiece. Composition of this alloy is indicated in Table 1. As cutting tools, five different coated carbide inserts were chosen (Table 2). Coating materials were monolayer TiCN, TiAlN, AlTiN and two layers TiCN + TiN, AlTiN + TiN, which were deposited by physical vapour deposition (PVD) method on the tungsten carbide substrate (Figure 1). All inserts had similar geometry, which was a rhombic shape with a 0.8 mm nose radius (ISO designation: APKT 1003PDR) (Figure 2). A diameter of 16 mm tool holder fitted with two inserts was used to hold inserts in the tests (Figure 2). Overhang length of cutting tool was constant and was selected as 43 mm in the tests.

Table 1. Chemical composition of Al2124 aluminium alloy (% weight).

Al	Cu	Mg	Mn	Si
92.855	3.765	1.910	0.460	0.340
Fe	Ti	Cr	Zn	
0.280	0.180	0.125	0.085	

Before milling operation, the workpiece was finished by milling in order to provide flatness of the workpiece. Surface roughness of workpiece was measured as 0.9 μm before machining process. Dry milling was carried out with two variable depth of cuts (1 and 2 mm) employing a fixed feed of 0.1 mm/rev and speed of 300 m/min (Table 3). Slot milling was conducted at the dimensions given in Figure 3. Only one slot was milled for all coatings.

Table 2. Coating properties.

Coated Tools	Friction Coefficient	Hardness (HV)
TiCN	0.50 - 0.55	3100
TiCN + TiN	0.40 - 0.45	3300
AlTiN + TiN	0.50 - 0.60	2900
AlTiN	0.60 - 0.70	2800
TiAlN	0.45 - 0.50	3000

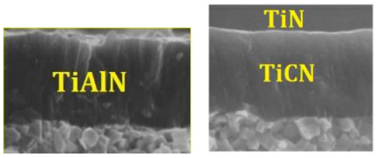


Figure 1. Coating layer [9]

In current work, surface roughness, tool wear, milling forces and top burr width were evaluated in milling of Al2124 aluminium alloy with various coated tools. A Philips XL30 scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) were utilized to determine wear after milling. Both flank and rake faces of two inserts were inspected qualitatively and maximum wear on the flank face was measured to determine the tool wear quantitatively in order to compare the performance of various coating materials. EDX was used in the purpose of determining elemental analysis of worn cutting inserts. Force components were captured online employing a dynamometer (Kistler, type 9257B) attached under the workpiece. In the force analysis, peak-to-valley (P-to-V) values were considered. As a roughness criteria, average surface roughness (R_a) was chosen and R_a was measured along the feed direction with a Mitutoyo Surf Test 301 device. In the measurements, cut-off length and sampling number were chosen as 0.8 mm and 5, respectively. Three measurements at the different location on the surface along the slot were performed and the average of these measurements was considered as final R_a value. An optical microscope (Nikon SMZ800) equipped with a high resolution camera was employed to capture the images of burr in order to measure the top burr width. Maximum top burr width was measured at the magnification of 10× for both down and up milling side of the slots.

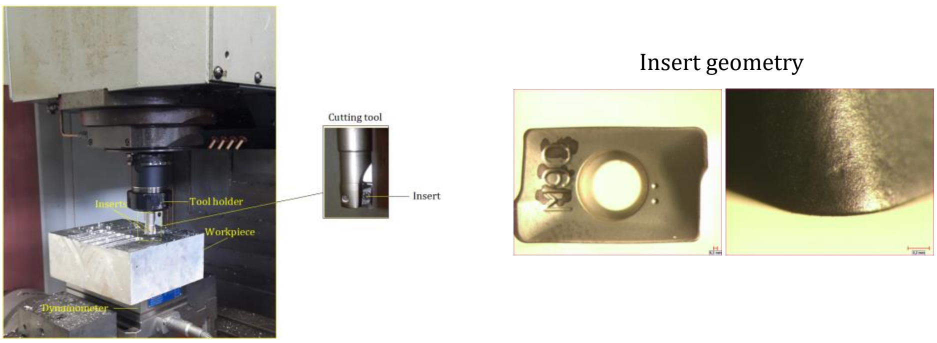


Figure 2. Experimental setup and geometry of insert

Table 3. Experimental conditions.

Coated Tools	Nose Radius (mm)	Slot Length (mm)	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)
TiCN					
TiCN + TiN					
AlTiN + TiN	0.8	70	300	0.1	1 and 2
AlTiN					
TiAlN					

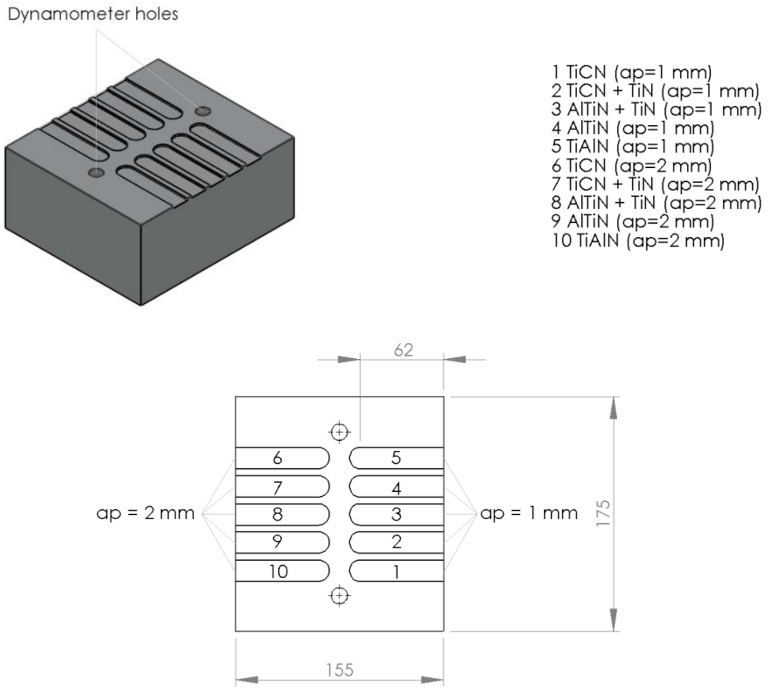


Figure 3. Dimensions of workpiece and machined slots (all units are in mm)

3. Results and Discussions

Flank face images of worn tools taken by SEM for all coated tools are depicted in Figure 4. Adhesion and flank wear were the main tool failure mechanisms and modes for all coated inserts. Adhesion was observed on the cutting inserts because of temperature [10-12]. Higher pressure and temperature between surface and tool face during milling resulted in adhesive wear [13]. Flank wear was owing to the frictional rubbing between flank surface and workpiece material. It was characterized by parallel ridges on flank surface and abrasive grooves [14].

Maximum flank wear values measured from SEM micrographs are depicted in Figure 5 for all coatings. Final flank wear was an average of two inserts. This figure indicated that the maximum flank wear increased with the increment in depth of cut for all coated inserts. It was reported that higher forces, vibration and temperature occurred at higher depth of cut caused higher tool wear [15]. The lowest wear value was obtained after milling with TiCN + TiN coated inserts, followed by AlTiN + TiN coated inserts. High hardness of TiCN + TiN coated insert resulted in the lowest tool wear value. It was known that higher hardness of coatings enhanced the resistance to the mechanical wear. In the literature, lower flank wear value was reported for coated tool with higher hardness [16]. It was also stated that two layers of the coating behaved as a barrier against crack propagation [13]. Two layers gave multifunction to the insert, lower friction with TiN layer [13] and stronger adhesion to the substrate, higher wear resistance with TiCN layer [13,17]. TiCN layer also provided thermal stability to the coated tools [17]. Kulkarni and Sargade [18] reported that the performance of multilayer coated tool was better than the monolayer coating in terms of tool life owing to the increased crack propagation resistance and excellent bonding between substrate and coating. It was also found that TiCN coated insert gave comparable performance with two layers coated inserts (TiCN + TiN) in terms of tool wear value. This was due to the comparable hardness of TiCN (3100 HV) with TiCN + TiN (3300 HV), which improved resistance to the tool wear. Also, it was declared that TiCN coated gave thermal stability to the coated tools [17], resulting lower thermal related tool wear.

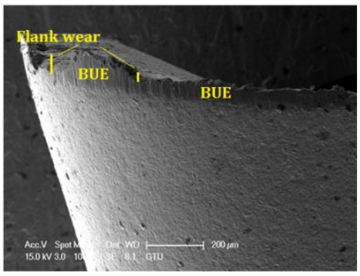
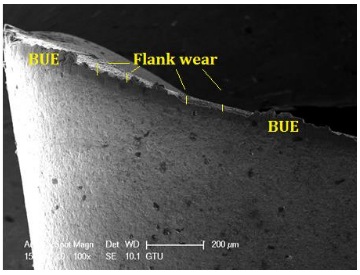
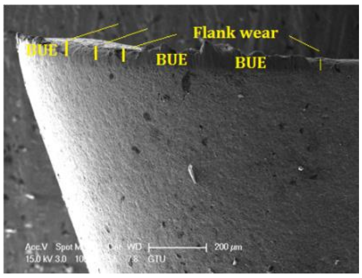
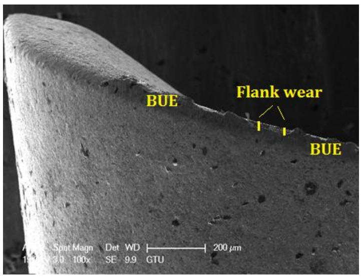
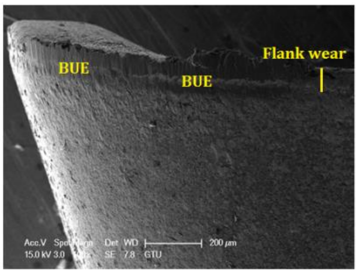
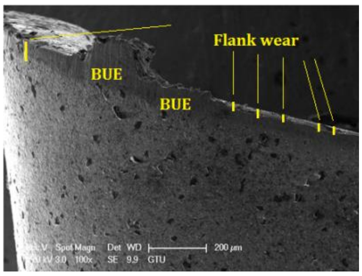
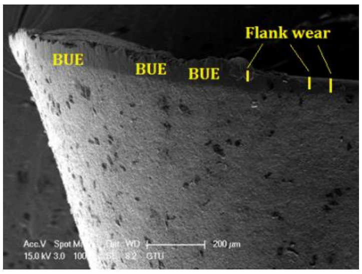
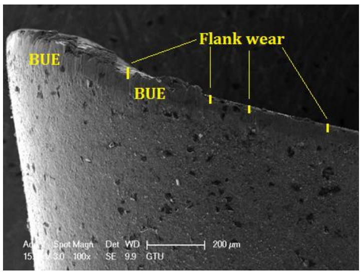
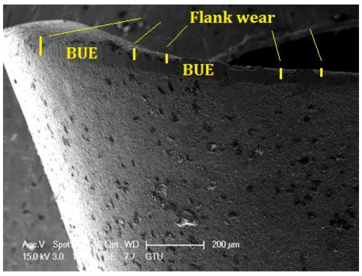
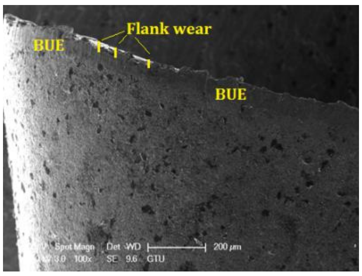
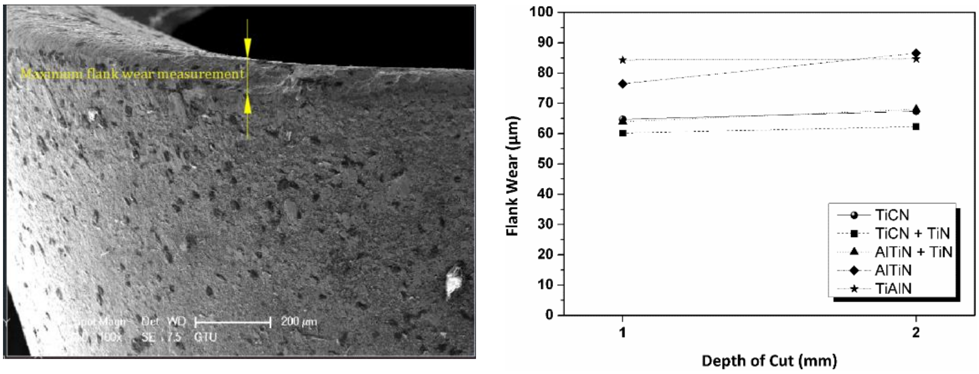
Coating	Depth of Cut = 1 mm	Depth of Cut = 2 mm
TiCN		
TiCN + TiN		
AlTiN + TiN		
AlTiN		
TiAlN		

Figure 4. SEM micrographs of flank face



(a) (b)

Figure 5. (a) Measurement of maximum flank wear; and (b) maximum flank wear as a function of depth of cut for different coated inserts

SEM micrographs of rake face for different coated inserts are depicted in Figure 6. Adhesion of aluminium on the rake face was observed for all type of coated inserts. This was the evidence of occurring a high temperature and stress at the tool-chip contact area, which resulted in the thermal softening of aluminium material. It was declared that owing to high temperature and pressure between the chip and rake face, chips were adhered to cutting edge easily thus, resulted in BUE [19].

In this study, EDX spectra of all coated inserts was taken however only spectra for TiCN coated insert was presented (Figure 7). Presence of Al element, a major constituent of Al2124 alloy, as seen from EDX spectra depicted in Figure 7 (selected area 1 and 2), was an evidence of workpiece material transfer to the rake surface of cutting inserts. This result confirmed adhesion of aluminium on rake face as seen in SEM images of rake face. Softened aluminium material adhered to the rake surfaces of the inserts and this result was owing to the occurrence of pressure at the cutting tool-workpiece interface. Al element come from workpiece material confirming the adhesion mechanism during milling of Al2124 material with coated inserts. It was known that BUE was common during the machining of ductile materials [20] like Al2124. This result was due to the diffusion wear that occurred at the tool–chip interface. At EDX analysis of unworn region (selected area 3), presence of elements such as Ti, C and N was an indication of TiCN coated carbide insert.

Forces in x- and y-directions during milling with different coated inserts are depicted in Figure 8. For all coated inserts, both Fx and Fy forces increased with the increment in depth of cut. Maranhao et al. [21] found similar result to this study. It was stated that when flank wear was more dominant than crater wear, cutting force increased significantly, because of the increment in the sliding friction between workpiece and cutting tool [22]. In this study, flank wear of cutting inserts was found to be higher than that of crater wear. Therefore, with the increasing of depth of cut due to the dominant flank wear, cutting forces increased with depth of cut. Also, during chip removal process the engagement length of the cutting tool was longer at higher depth of cut and thus greater chip load in higher depth of cut resulted in higher force values [23]. In general, TiCN coated insert gave the lowest force values. It was known that higher hardness of coating material resulted in lower cutting forces [24] and this fact might be responsible for the result of lower force in TiCN coated insert. Hosokawa et al. [25] computed cutting force by employing following equation:

$$F = \sqrt{F_x^2 + F_y^2} \quad (1)$$

They concluded that cutting force during milling of Ti6Al4V alloy with TiCN was lower than that with TiAlN coated tool.

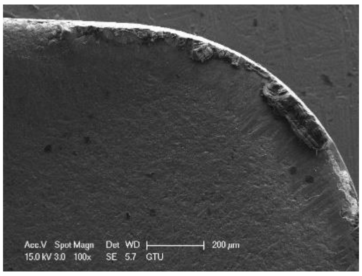
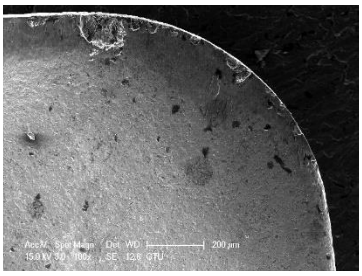
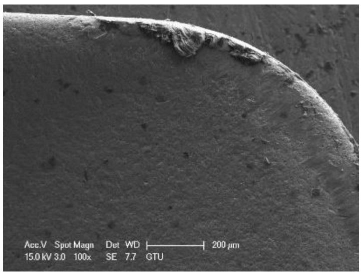
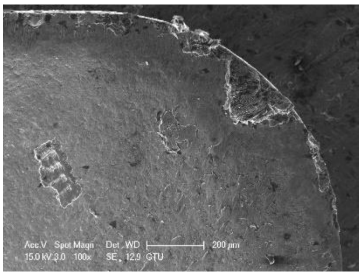
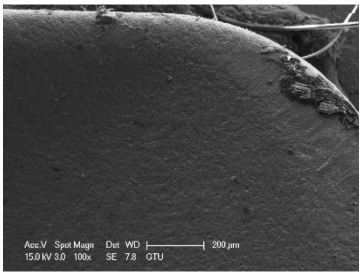
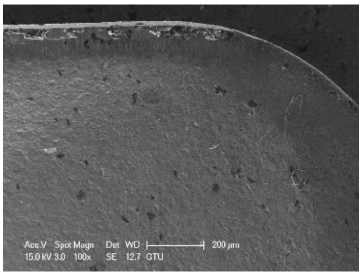
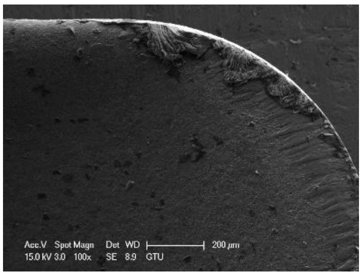
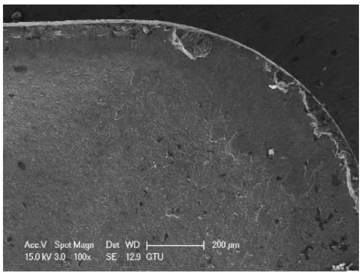
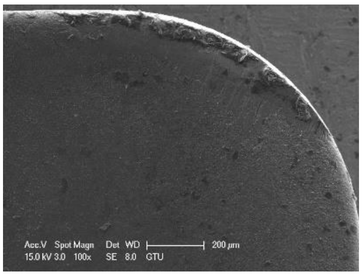
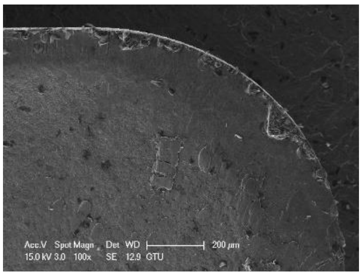
Coating	Depth of Cut = 1 mm	Depth of Cut = 2 mm
TiCN		
TiCN + TiN		
AlTiN + TiN		
AlTiN		
TiAlN		

Figure 6. SEM micrographs of rake face

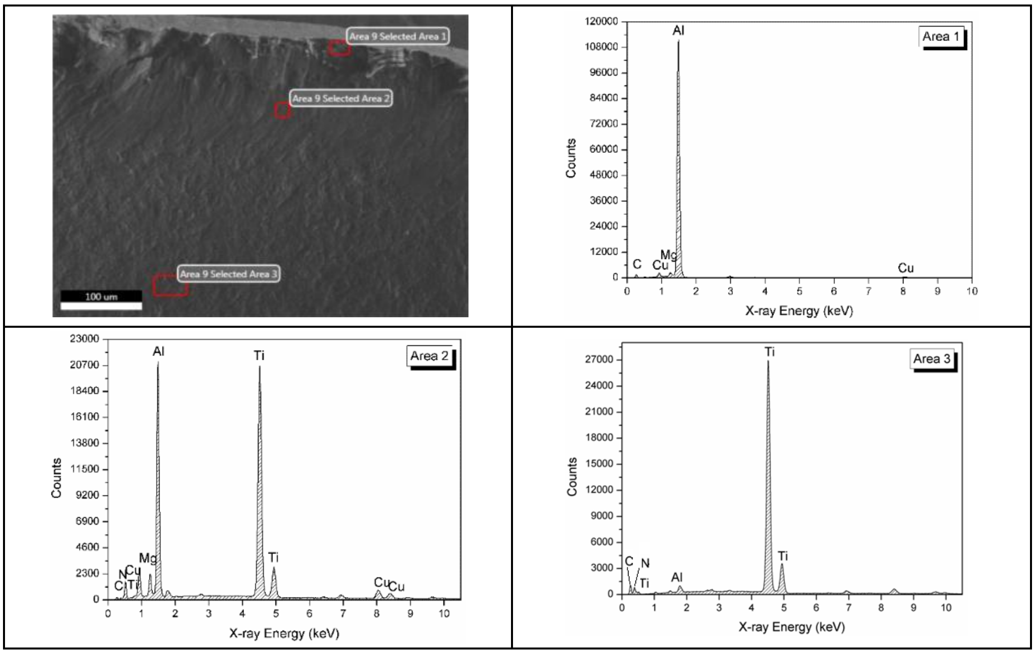
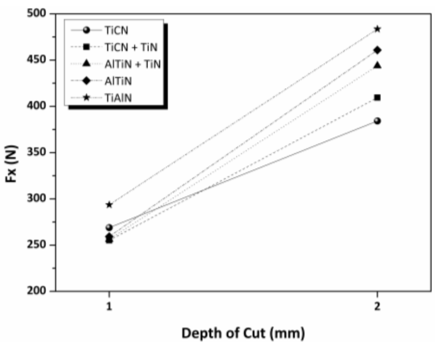
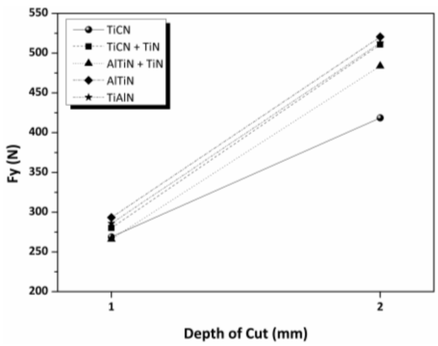


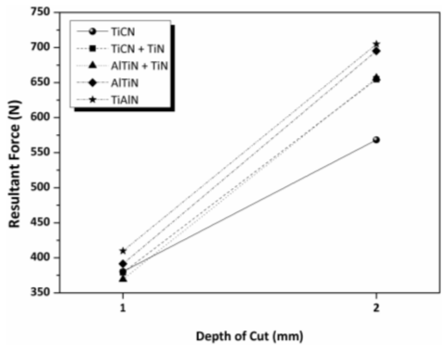
Figure 7. EDX spectra of TiCN coated insert 1 (depth of cut = 1 mm)



(a)



(b)



(c)

Figure 8. (a) Fx; (b) Fy; and (c) resultant force values as a function of depth of cut for different coated inserts

R_a results after milling with different coated inserts are given in Figure 9. For all coated inserts, it was observed this figure that R_a value increased with the increment in depth of cut. The increase in R_a value with depth of cut was also found in other studies [26,27] and this result could be explained by the increasing tool wear rate. The lowest R_a value was achieved with TiCN + TiN coated insert and the highest R_a value was achieved with TiAlN coated insert. The reason why the lowest R_a value was obtained with TiCN + TiN coated insert was that TiCN + TiN coated insert had a lower coefficient of friction than the other coated inserts. Also due to the high hardness of TiCN + TiN coated insert, tool gave less tool wear value and consequently good surface quality was achieved. It was known that higher hardness of coatings enhanced the resistance to the tool wear. Besides, higher hardness induced a lower force during machining, resulting higher surface quality. In the literature, superior workpiece quality achieved with coated tools was explained with relatively high hardness [28]. It was also found that TiCN coated insert gave comparable performance with two layers coated inserts (TiCN + TiN and AlTiN + TiN) in terms of R_a value.

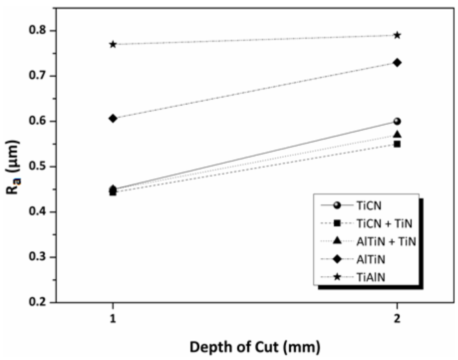


Figure 9. R_a results as a function of depth of cut for different coatings

During slot milling process, the chip was not able to be evacuated continuously hence, it stuck on top side of the machined slot and led to the formation of top burr [29]. In this study, maximum top burr width at both down and up side of slots was measured (Figure 10). Burr width results after milling with different coated inserts are presented in Figure 11. By changing the depth from 1 to 2 mm, top burr width increased for both down and up milling side of the slot. It was declared that higher chip load due to the increasing of depth of cut led to larger burr [23]. The lowest top burr width was obtained after milling with AlTiN + TiN coated inserts at the depth of cut 1 mm. However, when depth of cut was 2 mm, top burr width obtained with AlTiN + TiN coated insert was higher than that with all coated inserts except for TiAlN. This result suggested that the burr behaviour of coated inserts could not be explained solely by the coefficient of friction. Width of top burr was affected by the coefficient of friction, adhesion and heat occurred during the machining operation. Therefore, it was considered that the adhesion tendency of AlTiN + TiN coated insert was lower and this resulted in lower top burr width at the depth of cut of 1 mm.

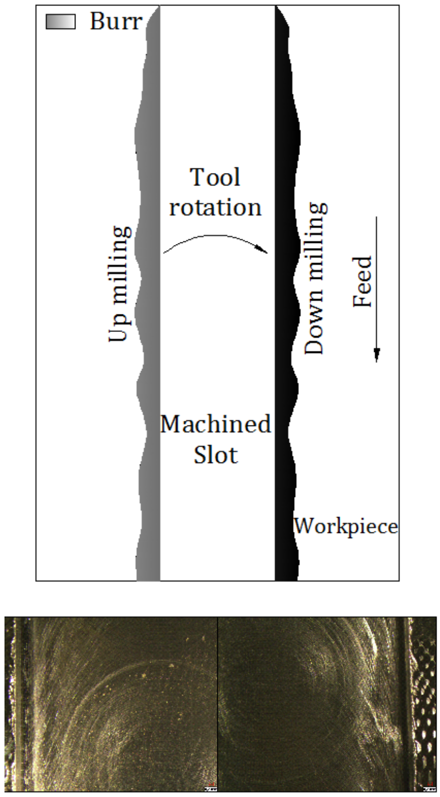
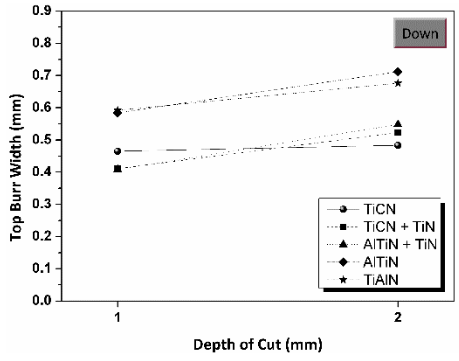
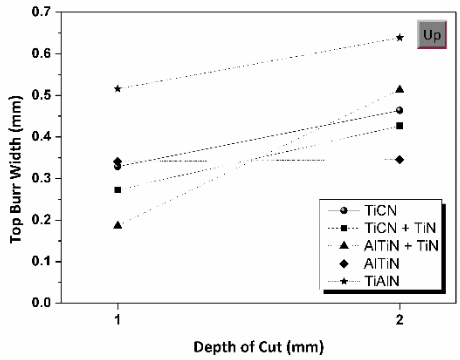


Figure 10. Down and up milling side of machined slot



(a)



(b)

Figure 11. Maximum top burr width for (a) down; and (b) up side as a function of depth of cut for different coated inserts

4. Discussion and Conclusion

This experimental study aimed to determine the performance of various coated inserts during milling of Al2124 aluminium alloy. The experiments were performed with coated inserts, namely, monolayer TiCN, AlTiN, TiAlN and two layers TiCN + TiN, AlTiN + TiN deposited on the tungsten carbide substrate. Tool wear, forces, surface roughness and top burr width were evaluated at different depth of cut values for these coatings. The obtained results were summarized as follow:

1. Main wear mechanisms for all coated inserts were adhesive and abrasive wear during milling of Al2124 aluminium alloy. EDX analysis confirmed the aluminium workpiece material transfer to the coated inserts, which was the indicator of the adhesion mechanism.

2. Flank wear increased with depth of cut for all coated inserts. Coated inserts with two layers (TiCN + TiN and AlTiN + TiN) gave lower flank wear values than coated inserts with monolayer. The lowest wear value was obtained after milling with TiCN + TiN coated inserts due to the higher hardness of TiCN + TiN coated inserts. However, the performance of TiCN coated inserts was comparable to the inserts of coated with two layers in terms of tool wear.

3. For all coated inserts, both Fx and Fy increased with the increment in depth of cut. In general, the lowest force value was obtained during milling with TiCN coated insert.

4. R_a value increased with the increment in depth of cut for all coated inserts. The lowest R_a value was achieved after milling with TiCN + TiN coated insert. The reason why the lowest R_a value was obtained with the TiCN + TiN coated insert was that TiCN + TiN coated insert had a lower coefficient of friction than the other coated inserts. It was also found that the performance of TiCN coated inserts was comparable to the inserts of coated with two layers in terms of R_a.

5. Top burr width increased with increasing depth of cut for both down and up milling side of the slot. The lowest top burr width was obtained after milling with AlTiN + TiN coated inserts.

6. As a conclusion, coated inserts with two layers and TiCN coated inserts gave better machining performance as compared to AlTiN and TiAlN coated inserts during milling of Al2124 aluminium alloy.

Acknowledgment

The author would like to thank to Professor Babur Ozcelik for providing laboratory facilities, Onder Gedik for helping during milling process and Ahmet Nazim for helping during SEM analysis.

References

[1] Sukumaran, K., Ravikumar, K.K., Pillai, S.G.K., Rajan, T.P.D., Ravi, M., Pillai, R.M., Pai, B.C. 2008. Studies on Squeeze Casting of Al 2124 Alloy and 2124-10% SiCp Metal Matrix Composite, Materials Science and Engineering A, Cilt. 490, s. 235-241. DOI: 10.1016/j.msea.2008.01.054

[2] Shaterani, P., Zarei-Hanzaki, A., Fatemi-Varzaneh, S.M., Hassas-Irani, S.B. 2014. The Second Phase Particles and Mechanical Properties of 2124 Aluminum Alloy Processed by Accumulative Back Extrusion, Materials and Design, Cilt. 58, s. 535-542. DOI: 10.1016/j.matdes.2014.01.078

[3] Thamban, I., Abraham, B.C., Kurian, S. 2013. Machining Characteristics Analysis of 6061-T6 Aluminium Alloy with Diamond Coated and Uncoated Tungsten Carbide Tool, International Journal of Latest Research in Science and Technology, Cilt. 2, s. 553-557.

[4] Vannan, R.R.R.M., Moorthy, T.V., Hariharan, P., Prabhu, P. 2016. Effect of Physical Vapour Deposited Bi-Layer (AlCrN+TiAlN) Coating on High Speed Steel Single Point Cutting Tool, Materials and Manufacturing Processes, Cilt. 32, s. 373-376. DOI: 10.1080/10426914.2016.1176178.

[5] Mativenga, P.T., Abukhshim, N.A., Sheikh, M.A., Hon, B.K.K. 2006. An Investigation of Tool Chip Contact Phenomena in High-Speed Turning Using Coated Tools, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Cilt. 220, s. 657-667. DOI: 10.1243/09544054JEM351

[6] Luo, Q., Robinson, G., Pittman, M., Howarth, M., Sim, W.-M., Stalley, M.R., Leitner, H., Ebner, R., Caliskanoglu, D., Hovsepian, P.E. 2005. Performance of Nano-Structured Multilayer PVD Coating TiAlN/VN in Dry High Speed Milling of Aerospace Aluminium 7010-T7651, Surface & Coatings Technology, Cilt. 200, s. 123-127. DOI: 10.1016/j.surfcoat.2005.02.017

[7] Najiha, M.S., Rahman, M.M., Kadirgama, K. 2015. Experimental Investigation and Optimization of Minimum Quantity Lubrication for Machining of AA6061-T6, International Journal of Automotive and Mechanical Engineering, Cilt. 11, s. 2722-2737. DOI: 10.15282/ijame.11.2015.47.0228

[8] Iyappan, S.K., Ghosh, A. 2015. Comparison of Tribological Properties of MoS_2 and Graphite-PTFE Coatings and its Impact on Machining of Aluminium by HSS End Mills, Materials and Manufacturing Processes, Cilt. 30, s. 912-920. DOI: 10.1080/10426914.2014.984212

[9] Wertheim, R. 2001. New Directions in Cutting Tool Materials and Machining Options.

[10] Dogra, M., Sharma, V.S., Sachdeva, A., Suri, N.M. 2012. Finish Hard Turning of Continuous and Interrupted Surfaces with Cubic Boron Nitride (CBN) and Coated Carbide Tools, Materials and Manufacturing Processes, Cilt. 27, s. 523-530. DOI: 10.1080/10426914.2011.593238

[11] Zheng, G., Zhao, J., Cheng, X., Xu, R., Zhao, G. 2016. Experimental Investigation on Sialon Ceramic Inserts for Ultra-High-Speed Milling of Inconel 718, Materials and Manufacturing Processes, Cilt. 31, s. 633-640. DOI: 10.1080/10426914.2015.1019090

[12] Thakur, A., Gangopadhyay, S., Mohanty, A. 2015. Investigation on Some Machinability Aspects of Inconel 825 during Dry Turning, Materials and Manufacturing Processes, Cilt. 30, s. 1026-1034. DOI: 10.1080/10426914.2014.984216

[13] Kong, X., Yang, L., Zhang, H., Zhou, K., Wang, Y. 2015. Cutting Performance and Coated Tool Wear Mechanisms in Laser-Assisted Milling K24 Nickel-Based Superalloy, International Journal of Advanced Manufacturing Technology, Cilt. 77, s. 2151-2163. DOI: 10.1007/s00170-014-6606-9

[14] Mohanty, S., Gangopadhyay, S., Thakur, A. 2016. On Applicability of Multilayer Coated Tool in Dry Machining of Aerospace Grade Stainless Steel, Materials and Manufacturing Processes, Cilt. 31, s. 869-879. DOI: 10.1080/10426914.2015.1070413

[15] Abdullah, R.I.R., Redzuwan, B.I., Aziz, M.S.A., Kasim, M.S. 2017. Comparative Study of Tool Wear in Milling Titanium Alloy (Ti-6Al-4V) Using PVD and CVD Coated Cutting Tool, Industrial Lubrication and Tribology, Cilt. 69, s. 363-370. DOI: 10.1108/ILT-09-2016-0202

[16] Beake, B.D., Ning, L., Gey, Ch., Veldhuis, S.C., Komarov, A., Weaver, A., Khanna, M., Fox-Rabinovich, G.S. 2015. Wear Performance of Different PVD Coatings during Hard Wet End Milling of H13 Tool Steel, Surface & Coatings Technology, Cilt. 279, s. 118-125. DOI: 10.1016/j.surfcoat.2015.08.038

[17] Thakur, D.G., Ramamoorthy, B., Vijayaraghavan, L. 2012. Some Investigations on High Speed Dry Machining of Aerospace Material Inconel 718 Using Multicoated Carbide Inserts, Materials and Manufacturing Processes, Cilt. 27, s. 1066-1072. DOI: 10.1080/10426914.2011.654158

[18] Kulkarni, A.P., Sargade, V.G. 2015. Characterization and Performance of AlTiN, AlTiCrN, TiN/TiAlN PVD Coated Carbide Tools while Turning SS 304, Materials and Manufacturing Processes, Cilt. 30, s. 748-755. DOI: 10.1080/10426914.2014.98421

[19] Wang, C.Y., Xie, Y.X., Qin, Z., Lin, H.S., Yuan, Y.H., Wang, Q.M. 2015. Wear and Breakage of TiAlN- and TiSiN-Coated Carbide Tools during High-Speed Milling of Hardened Steel, Wear, Cilt. 336-337, s. 29-42. DOI: 10.1016/j.wear.2015.04.018

[20] Kuram, E. 2017. Nose Radius and Cutting Speed Effects during Milling of AISI 304 Material, Materials and Manufacturing Processes, Cilt. 32, s. 185-192. DOI: 10.1080/10426914.2016.1198019

[21] Maranhao, C., Davim, J.P., Jackson, M.J. 2011. Physical Thermomechanical Behavior in Machining an Aluminium Alloy (7075-O) Using Polycrystalline Diamond Tool, Materials and Manufacturing Processes, Cilt. 26, s. 1034-1040. DOI: 10.1080/10426914.2010.520794

[22] Dogra, M., Sharma, V.S. 2012. Machinability and Surface Quality Issues in Finish Turning of Hardened Steel with Coated Carbide and CBN Tools, Materials and Manufacturing Processes, Cilt. 27, s. 1110-1117. DOI: 10.1080/10426914.2011.654164

[23] Hassanpour, H., Sadeghi, M.H., Rezaei, H., Rasti, A. 2016. Experimental Study of Cutting Force, Microhardness, Surface Roughness, and Burr Size on Micromilling of Ti6Al4V in Minimum Quantity Lubrication, Materials and Manufacturing Processes, Cilt. 31, s. 1654-1662. DOI: 10.1080/10426914.2015.1117629

[24] Polini, W., Turchetta, S. 2016. Cutting Force, Tool Life and Surface Integrity in Milling of Titanium Alloy Ti-6Al-4V with Coated Carbide Tools, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Cilt. 230, s. 694-700. DOI: 10.1177/0954405414558732

[25] Hosokawa, A., Shimamura, K., Ueda, T. 2012. Cutting Characteristics of PVD-Coated Tools Deposited by Unbalanced Magnetron Sputtering Method, CIRP Annals - Manufacturing Technology, Cilt. 61, s. 95-98. DOI: 10.1016/j.cirp.2012.03.010

[26] Akhtar, W., Sun, J., Chen, W. 2016. Effect of Machining Parameters on Surface Integrity in High Speed Milling of Super Alloy GH4169/Inconel 718, Materials and Manufacturing Processes, Cilt. 31, s. 620-627. DOI: 10.1080/10426914.2014.994769

[27] Priyadarshi, D., Sharma, R.K. 2016. Optimization for Turning of Al-6061-SiC-Gr Hybrid Nanocomposites Using Response Surface Methodologies, Materials

and Manufacturing Processes, Cilt. 31, s. 1342-1350. DOI: 10.1080/10426914.2015.1070427

[28] Siwawut, S., Saikaew, C., Wisitoraat, A., Surinphong, S. 2018. Cutting Performances and Wear Characteristics of WC Inserts Coated with TiAlSiN and CrTiAlSiN by Filtered Cathodic Arc in Dry Face Milling of Cast Iron, The International Journal of Advanced Manufacturing Technology, Cilt. 97, s. 3883-3892. DOI: 10.1007/s00170-018-2200-x

[29] Niknam, S.A. 2013. Burrs Understanding, Modelling and Optimization during Slot Milling of Aluminium Alloys. École de Technologie Supérieure Université du Québec, Ph.D. Thesis, 209s, Montreal.