Türk Doğa ve Fen Dergisi
Turkish Journal of Nature and Science
http://bingol.dergipark.gov.tr/tdfd

# The effect of different cutting parameters on cutting force, tool wear and burr formation in micro milling WCu composite material fabricated via powder metallurgy

Ali Erçetin*[1], Kubilay Aslantaş[2]

**Abstract**

In this study, the wears that occurred on the cutting tool edges as a result of being subjected to micro-milling process of W-30%wtCu composite material produced by sintering at 1000 $^0$C were investigated. A series of micro-milling tests were carried out at a constant cutting depth to determine the effect of different feed rates on tool wear. End-mill tools with a diameter of 0.5 mm and two flutes were used in the micro-milling process. Surface images of composite material after sintering and worn surfaces' images of cutting tools after micro-milling process were obtained by utilizing scanning electron microscopy (SEM). Tool wear was followed from digital screen by measuring cutting forces with dynamometer. Suitable cutting speed and feed rate for micro-milling of W-30%wtCu composite material were established by observing tool wear. The results showed that minimum tool wear had taken place at 35 mm/min feed rate and maximum cutting speed. Amount of burr formation was always increased from 1. slot towards 6. slot in all micro milling processes.

**Keywords:** Micro-milling; tool wear; burr formation; SEM; tungsten-copper

# Toz metalürji ile üretilen WCu kompozit malzemesinin mikro işlenmesinde farklı kesme parametrelerinin kesme kuvveti, takım aşınması ve çapak oluşumuna etkisi

**Özet**

Bu çalışmada 1000 $^0$C de sinterlenerek üretilen WCu 70/30 kompozit malzemesinin mikro frezeleme işlemine tabi tutulması sonucu kesici takım uçlarında meydana gelen aşınmalar incelenmiştir. Takım aşınması üzerinde farklı ilerleme hızlarının etkisini belirlemek için bir dizi mikro frezeleme testleri sabit kesme derinliğinde gerçekleştirilmiştir. Mikro frezeleme işleminde çapı 0.5 mm olan iki ağızlı parmak freze takımlar kullanılmıştır. Taramalı elektron mikroskobu (SEM) kullanılarak WCu kompozit malzemesinin sinterleme işlemi sonrası yüzey görüntüleri ve mikro frezeleme işlemi sonrasında kesici takımların aşınan yüzeylerine ait görüntüler elde edilmiştir. Kesme kuvvetlerinin dinamometre ile ölçülmesiyle de takım aşınması dijital ekrandan takip edilmiştir. Takım aşınmasına bakılarak WCu 70/30 kompozit malzemesinin mikro frezelenmesinde uygun kesme ve ilerleme hızları belirlendi. Sonuçlar gösterdi ki, minimum takım aşınması 35 mm/dk ilerleme hızında ve maksimum kesme hızında meydana gelmiştir. Tüm mikro frezeleme işlemlerinde çapak miktarı 1. kanaldan 6. kanala kadar sürekli artmıştır.

**Anahtar Kelimeler:** Mikro frezeleme; takım aşınması; çapak durumu; SEM; tungsten-bakır

## 1. Introduction

Tungsten-copper (WCu) composite have a hard structure due to good wear resistance, well thermal conductivity [1-3], high hardness and high melting temperature of tungsten [4, 5]. There is high difference between melting temperatures of tungsten (W) and copper (Cu). It is also difficult to combine these two elements via casting process so sintering is the way to fabricate WCu composite materials through powder metallurgy [5, 6]. Moreover, P/M technique can attain a more uniform distribution of particulates in the metal matrix without or with less excessive reactions between matrix and the reinforcement [7-10].

WCu composites are widely used as electrical contact material [11]. Hardness of workpiece, composition and type of cutting tool and tool geometry factors effects wear mechanism [12, 13]. Therefore, determining the machining parameters of workpieces are important to fabricate it in micro sizes. There are several studies about machining WCu composites. The studies have shown that surface roughness and tool wear change up to cutting speed and feed rate in micro-milling [5]. Furthermore, increasing depth has a negative effect on tool life [14]. During micro milling process, cutting forces are smaller compared conventional machining process because of small diameter of micro cutting tool radii, so micro cutting process needs high torque [15]. Micro milling process is similar to conventional milling process, but there are important differences. The

[1]Bingol University, Faculty of Engineering and Architecture, Mechanical Engineering, 12000, Bingol, Turkey
[2]Afyon Kocatepe University, Faculty of Technology, Mechanical Engineering, Afyonkarahisar, Turkey
***Corresponding author E-mail:** aliercetin@bingol.edu.tr

main problem is that micro cutting tool is worn and broken fast, so choosing the cutting parameters is very important [16-20]. If appropriate cutting parameters are not chosen in conventional machining process, cutting tool is damaged or worn in a short time (before tool life) [21]. These are also similar to micro machining process.

There are many studies in literature about fabrication of WCu composites via different manufacturing methods. However, there is little experimental investigation about micro milling them. In this study, tool wear, cutting forces and burr formation were investigated as using constant depth of cut, different cutting speed and feed rate parameters.

## 2. Material and Method

Tungsten and copper powders are mixed as containing %70 W and %30 Cu. Pressing process under 60 MPa was performed in a mould which has 40x8 mm dimensions and rectangle shape. Pressed samples were sintered at 1000 $^oC$ temperatures for 1.5 hours under argon gas atmosphere. After sintering process, microstructure investigations were done with using scanning electron microscope (SEM). Photos before sintering and SEM images after sintering WCu composites are shown in Fig. 1.

For micro-milling tests, a CNC vertical machining center with maximum power of 2.2 kW and maximum spindle speed of 24,000 rev/min was used. The cutting forces (Fx and Fy) were recorded using a Kistler mini-dynamometer type 9119AA1 with a resonance frequency of 6 kHz and a charge amplifier type 5070A. The two components (Fx and Fy) were recorded using a Dynoware software at a sampling frequency of 4.17 kHz. Each cutting force test was performed on fresh cutting tool. After cutting process, wear of cutting tools was investigated with using SEM devices.

Cutting parameters for micro milling processes of WCu composite material are shown in Table 1. After applying first and fourth micro milling process for 45 milimeters length, it was seen that cutting tool noses were worn badly, so second and third cutting process were also performed.

Commercially available, two-flute end-mills (PMT part TS-2-0200-S), include 92%wt WC and 8%wt Co, 508 µm in diameter, were used throughout the study. The micro-tools were delivered uncoated by Performance Micro Tool (PMT). Some characteristic and geometric properties of the cutting tool are given in Table 2. General and SEM images of unused cutting tool are shown in Fig. 2.

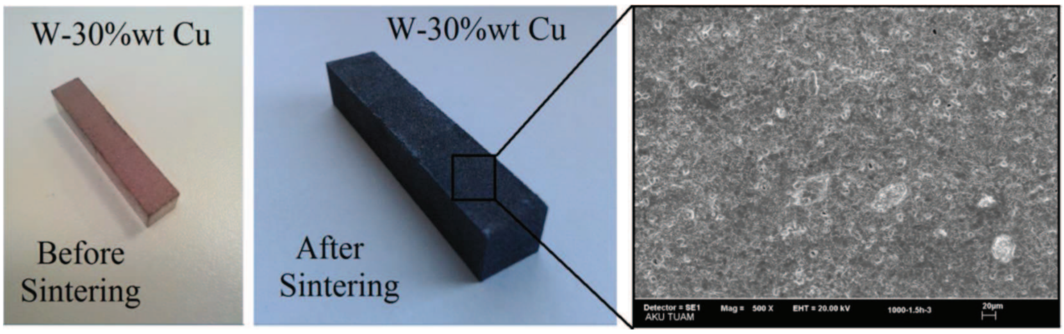


**Figure 1.** General photo and SEM image of WCu composite material.

**Table 1.** Cutting parameters for micro milling process of WCu composite material.

| Processes | Cutting speed (m/min) | Feed rate (mm/min) | Depth of cut (mm) |
|---|---|---|---|
| 1. Cutting Parameter (1.CP) | 31.42 | 50 | 0.1 |
| 2. Cutting Parameter (2.CP) | 31.42 | 35 | 0.1 |
| 3. Cutting Parameter (3.CP) | 15.71 | 25 | 0.1 |
| 4. Cutting Parameter (4.CP) | 15.71 | 50 | 0.1 |

**Table 2.** Geometric and characteristic properties of cutting tool.

| Shaft diameter (mm) | Hardness (HV 0.05) | Tool diameter (µm) | Cutting corner radius (µm) | Flute number | Helix angle ϴ ($^0$) |
|---|---|---|---|---|---|
| 3.2 | 1680 | 500 | 1-1.5 | 2 | 30 |

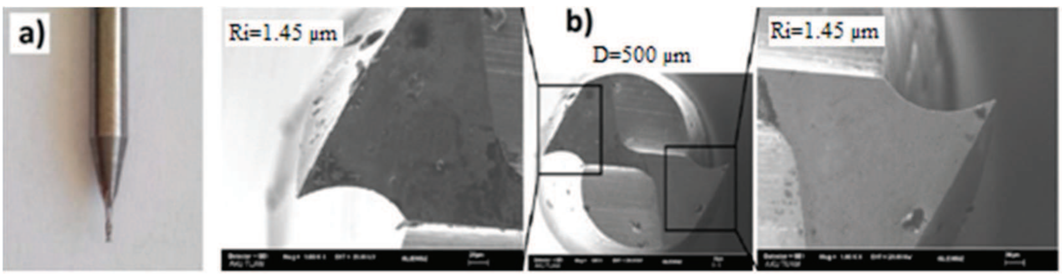


**Figure 2.** Images of unused cutting tool (a) General, (b) SEM image.

## 3. Results and Discussion

### 3.1. Cutting forces

Fig. 3 shows the variation of cutting forces with cutting length for different cutting parameters (1.CP, 2.CP, 3.CP and 4.CP). It is seen that all cutting forces increased by depending on cutting length. In micro-milling process for higher cutting speed and lower feed rate (in fourth cutting parameter, 4. CP), cutting force values are the highest (Fig. 3). It shows that the cutting tool was worn the most in this parameter. It was also seen from the SEM image of tool wear in Fig. 4d. By analyzing the Fig. 3 and Fig. 4 together, in second and third cutting parameters, cutting speed and feed rate are different, but obtained cutting forces and tool wear are close to each other (Fig. 3 and Fig. 4b, 4c). It can be explained that if cutting speed increases with feed rate together in appropriate ratio, cutting tool cut nearly same chip volume. It was understood that cutting force and tool wear increase by decreasing cutting speed or increasing feed rate or both of these.

### 3.2. Tool wear

SEM image of tool wear for 1. CP is shown in Fig. 3a. Tool geometry and BUE formation were intensely seen because of that the feed rate is faster than other cutting parameters. Wear type is abrasive wear (Fig. 4a). By the decreasing only feed rate (2. CP), it was seen that tool geometry is in a better situation than 1.CP (Fig. 4b). In 3. CP, BUE formation was increased and tool geometry is worse with contrasting 2. CP because of that cutting speed was decreased (Fig. 4c). By the choosing lowest cutting speed and highest feed rate from cutting parameters for this study (4. CP), cutting tool geometry was incredibly damaged (Fig. 4d). This deformation effected to increase cutting forces higher than others (Fig. 3).

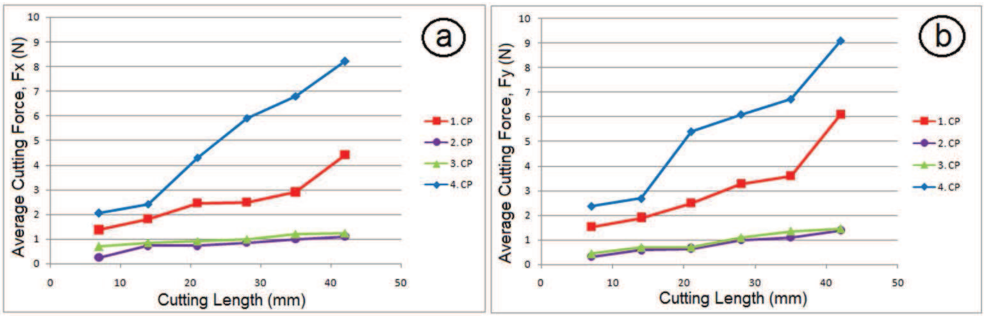


**Figure 3.** Variation of cutting forces with cutting length for different cutting parameters (1.CP, 2.CP, 3.CP, 4.CP).

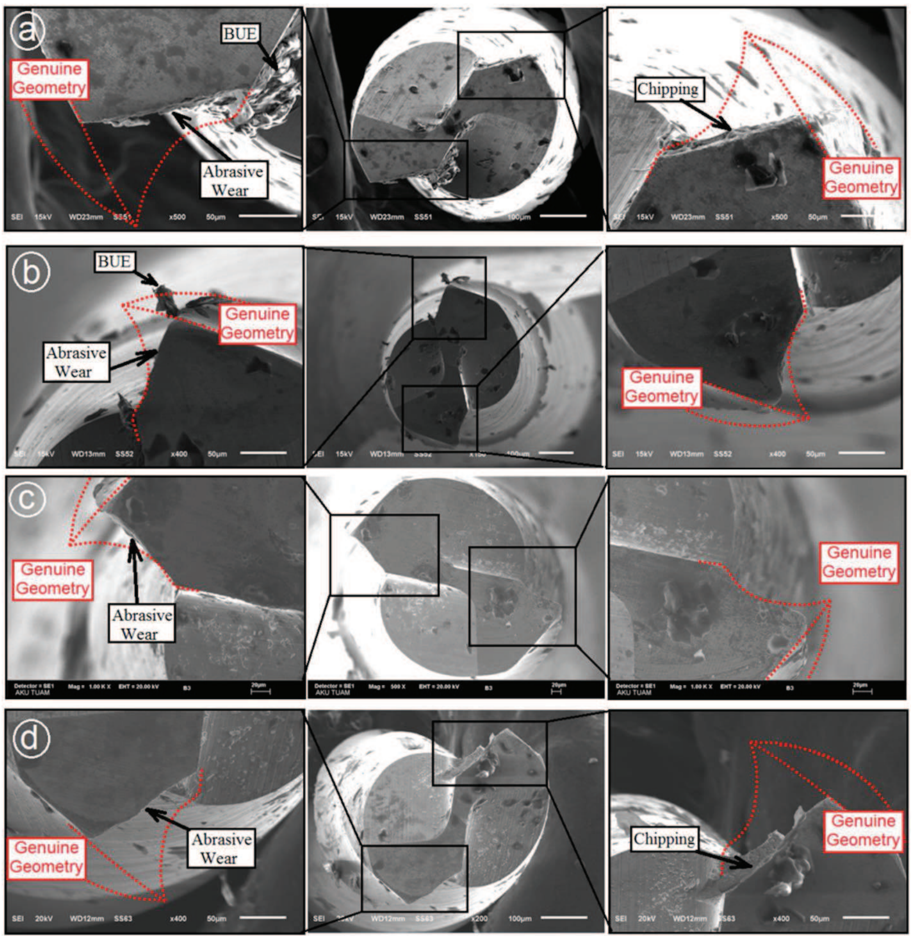


**Figure 4.** SEM images of worn cutting tools for different cutting process, a) 1. CP, b) 2. CP, c) 3. CP, d) 4. CP.

### 3.3. Burr Formation

SEM images of first and last micro slots of WCu composite after micro milling process are shown in Fig. 5. It was seen that there are intensely and widely burr formation on the down milling sides. Amount of burr increases from beginning to end of slots. Cutting tool continues to be abraded with depending on the cutting length. If wear is more, burr formation on sides of slots is more, too. Cutting tool was worn the most in 4. CP (fourth cutting process), so it caused that cutting marks or waves were happened on surface of micro-milled composite (Fig. 5d). Burr distributions of down milling and up milling sides are not on a linear direction.

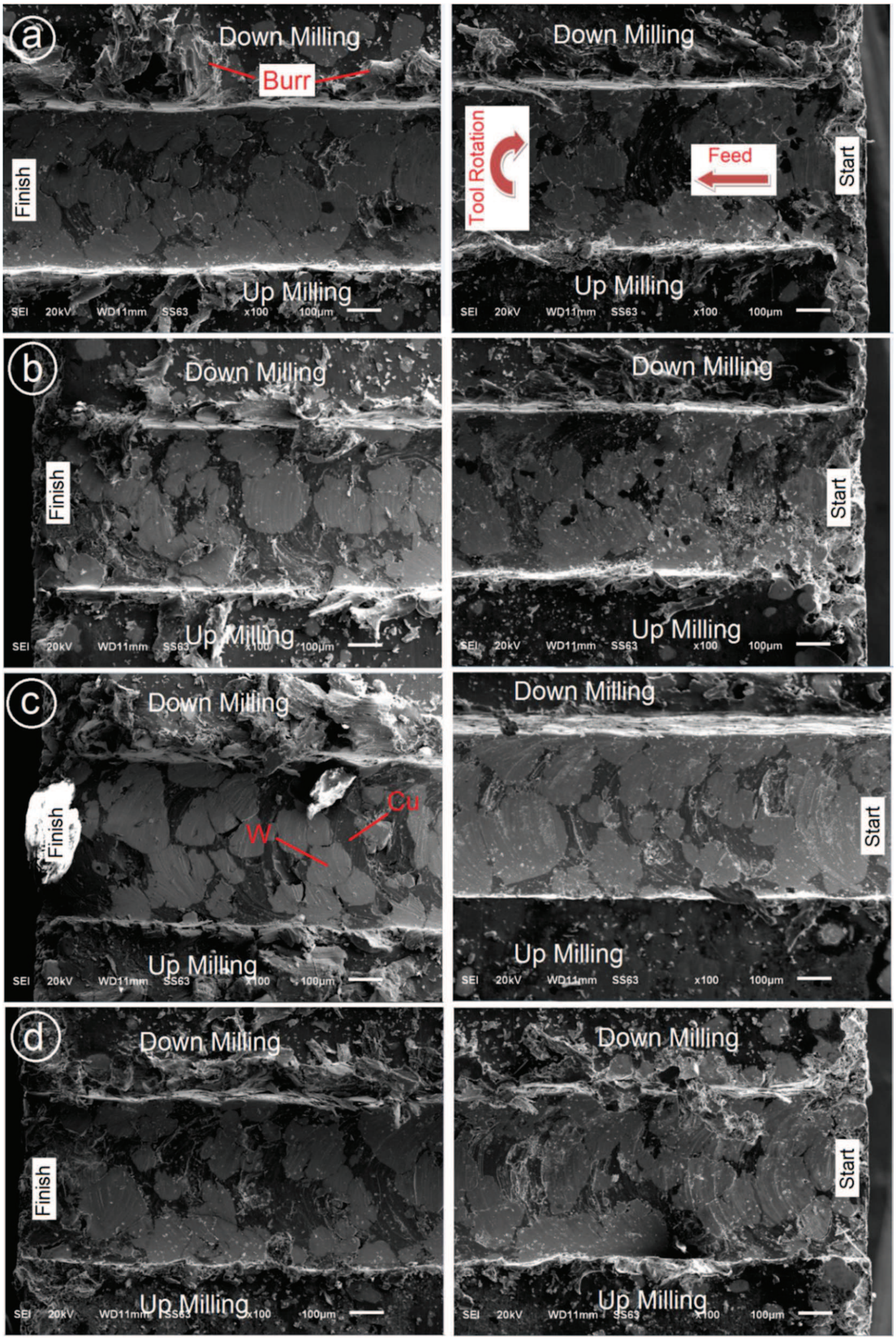


**Figure 5.** SEM images of micro slots of WCu composite after micro milling process.

## 4. Conclusions

This study presents micro milling of W-30%wtCu composite sintered at 1000 $^{o}$C and effect of cutting parameters on tool wear, cutting forces and burr formation. Tool wear is usually abrasive wear. BUE and chippings were occurred on cutting edges. Tool noses were forced more with using low feed rate.

By the increasing feed rate, it was usually seen that BUE formation was happened on cutting tool nose. When the cutting speed increased, heat effected zone at the cutting point was increased too, so it effected the tool wear more. It was also caused radii to increase and effected tool diameter to decrease. It became difficult to cut chip because of increasing tool nose radius. When tool diameter decreased, width of micro slot always narrowed from beginning to end.

## Acknowledgement

This research was supported by grants from the Support Program for Afyon Kocatepe University Scientific and Technological Research Projects, Project No: 14.FEN.BİL.39. SEM images were supported from Bingol University Center Laboratory and Micro-milling process was supported Support Program for Scientific and Technological Research Projects, Project No: 213M572.

## References

[1] Johnson, J.L., German, R.M. Chemically activated liquid phase sintering of tungsten–copper, Powder Metall, 30(1), 91–102, 1994.

[2] Wang, W. Effect of tungsten particle size and copper content on working behaviour of W–Cu alloy electrodes during electro discharge machining, Powder Metall, 40(4), 295-300, 1997.

[3] Li, L., Wong, Y.S., Fuh, J.Y.H., Lu, L. Effect of TiC in copper tungsten electrodes on EDM performance, J Mater Process Technol, 113, 563-567, 2001.

[4] Sepulveda, J.L., Valenzuela, L.A. and Wellman B. Advances Cu/W technology, Metallic Powder Review, PM Special Feature, 24-27, 1998.

[5] Uhlmann, E., Piltz, S. and Schauer, K. Micro milling of sintered tungsten-copper composite materials, Journal of Materials Processing Techology, 167, 402-407, 2005.

[6] Zhang, X.Q., Peng, Y.H. and Ruan, X.Y. Simulation and fracture prediction for sintered materials in upsetting by FEM, J. Mater. Process. Technol., 105, 253–257, 2000.

[7] Merrick, H.F. Effect of heat treatment on the structure and properties of extruded P/M alloy 718, Metallurgical Transactions A, 7(4), 505-514, 1976.

[8] Radavich, J.F., Meyers, D.J., Thermomechanical processing of P/M alloy 718, in: 5th Int. Symp. on Superalloys, Warrendale, PA, 347–356, 1984.

[9] Chua, B.W., Lu, L, Lai, M.O. Influence of SiC particles on mechanical properties of Mg based composite, 1999.

[10] Özgün, Ö., Gülsoy, H.Ö., Yılmaz, R and Fındık, F. Microstructural and mechanical characterization of injection molded 718 superalloy powders, Journal of Alloys and Compounds, 576, 140-153, 2013.

[11] Moon, I.H., Lee, J.S. Activated Sintering of Tungsten-Copper Contact, Materials, Powder Metallurgy, 22(1), 5-7, 2013.

[12] Aslantaş, K., Ucun, İ. and Çiçek, A. Tool life and wear mechanism of coated and uncoated Al2O3/TiCN mixed ceramic tools in turning hardened alloy steel, Wear, (274-275), 442-451, 2012.

[13] Sayit, E., Aslantaş, K. and Çiçek, A. Tool wear mechanism in interrupted cutting conditions, Mater. Manuf. Process, 24, 476-483, 2009.

[14] Son, S.M., Lim, H.S. and Ahn, J.H., Effects of the friction coefficient on the minimum cutting thickness in micro cutting, International Journal of Machine Tools & Manufacture, 45, 529-535, 2005.

[15] Rooks, B., The shrinking sizes in micro manufacturing, Assembly Automation, 244, 352-356, 2004.

[16] Rahman, M., Kumar, A.S. and Prakash, J.R.S. Micro milling of pure copper, J. Mater. Process. Technol., 116(1), 39-43, 2001.

[17] Ucun, I., Aslantas, K. and Bedir, F. An experimental investigation of the effect of coating material on tool wear in micro milling of Inconel 718 super alloy, Wear. 300(1-2), 8-19, 2013.

[18] Ucun, I., Aslantas, K. and Bedir, F. The effect of minimum quantity lubrication and cryogenic pre-cooling on cutting performance in the micro milling of Inconel 718, Proc IMechE B: J. Eng. Manuf., 229(12), 2134-2143, 2015.

[19] Bissacco, G., Hansen, H.N.and Slunsky, J. Modelling the cutting edge radius size effect for force prediction in micro milling, CIRP. Ann-Manuf. Technol., 57(1),113-116, 2008.

[20] Aramcharoen, A., Mativenga, P.T., Yang, S., Cooke, K.E. and Teer, D.G. Evaluation and selection of hard coatings for micro milling of hardened tool steel, Int. J. Mach. Tools. Manuf., 48, 1578-1584, 2008.

[21] Erçetin, A. and Usca, Ü.A. An Experimental Investigation of Effect of Turning AISI 1040 Steel at Low Cutting Speed on Tool Wear and Surface Roughnes, Tr. J. Nature Sci, 5(1), 29-36, 2016.