Chapter 2

Experimental Investigation of the Effect of Machining Parameters on the Surface Roughness and the Formation of Built Up Edge (BUE) in the Drilling of Al 5005

Erkan Bahçe and Cihan Ozel

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/56027

1. Introduction

Aluminum is one of the metals, besides iron and steel, which are widely used in many industrial fields such as aviation, navigation and automotive. The most considerable reasons why aluminum is so widely used are: i) it is light, ii) its alloys have higher strength than the construction steel, iii) it has high heat and electrical conductivity. Because of these excellent characteristics, the usage of aluminum as engineering material has an ever-increasing importance in several technological fields [1,2]. Although aluminum is widely used, there are many problems such as tool abrasion, burr formation and poor hole surface quality in drilling process of aluminum and its alloys [2,3]

The surface quality, which is one of these problems, is quite important for the efficient working of machine parts. The structure of a machined surface is one of the most important criteria in terms of quality, and tribological properties of the machined surface are considerably affected from the surface tissue. Generally the surface quality is characterized with surface roughness. Surface roughness is an important factor which must be considered not only in the conventional subjects of tribology such as abrasion, friction and lubrication but also in different fields such as sealing, hydrodynamics, electrical and heat conductivity. Surface roughness is mainly affected during the machining process by cutting parameters such as cutting speed, feed rate and depth of cut [4,5,6]. If these parameters are not chosen convenient, the surface roughness increases. This situation creates a notch effect and results in crack initiation, decrease in fatigue strength and corrosion resistance. So, the characterization and measurement of surface roughness has a great important in the sense of the optimization of machining process [7,8].

In former studies on hole surface quality, Nouari and his colleagues subjected Al 2024-T3 to dry drilling process, and did some optimizations and analysis experimentally for both the dimensional accuracy of the machined surface and longevity of cutting tools [9]. In their study, they used sintered tungsten carbide (STC) cutting tools and high speed stell (HSS) cutting tools, and set the feed rate to 0,04 mm/rev and cutting speed to 25, 65, 165 m/min. They concluded from the experiments that STC cutting tools are more convenient in comparison with HSS cutting tools from the points of tool life, deviation in hole diameter and surface roughness. Lin investigated tool life, surface roughness, tool abrasion and burr formation for the process of the high speed machining of stainless steel material with TiN coated carbide tool [10]. As a result of his researches, he determined that the abrasions in shear edge result from the high feed rate in low cutting speed, and optimum cutting speed for desired burr height and surface roughness was 75 m/min. In addition, he determined that in high speed machining of stainless steels the tool life increased considerably in case of adjusting the feed rate to the values lower than 0,05 mm/rev. Lin and Syhu, studied on the treatment of the tool life and burr formation in the drilling of stainless steel with the drill bits coated by different materials [11]. Kurt et al., investigated the effect of cutting parameters on the drilling temperature, cutting force and surface roughness in the drilling of Al 2024 alloy with DLC coated drill. In their study, they determined that the most effective factors influencing the hole surface quality are feed rate and drill diameter [12]. They observed that the change in feed rate and diameter at high cutting speeds affects the average surface roughness considerably. Dudzinski et al., determined that the tool life was very short in the drilling of Inconel 718; therefore the surface quality gets worse [13]. They determined that the main wear mechanism seen in the cutting tools used was abrasion. In addition, they observed that the chips resulted in the formation of built-up-edge (BUE) by adhering on the cutting tool, and the removal of BUE from the cutting tool repeatedly caused notches. Kılıçkap investigated the roughness of hole surface and the height of the burrs formed at the hole exit in the drilling of Al 7075 material [14]. Also in another research, Kılıçkap, experimentally studied on the effects of cutting speed, feed rate and different cooling techniques on the temperature and the roughness of hole surface in the drilling of Al 7075 [15]. In their study, they observed that the most appropriate cooling technique was oil cooling from the point of good surface roughness. Also, they determined that the roughness increased with the increase of the feed rate, while it decreased with the increase of rotation speed. Hanyu et al. investigated the effects of finely crystallized diamond coating method, which was developed by themselves, on the surface roughness in the dry and semi-dry drilling of Al 7075 alloy [16]. They demonstrated experimentally that finely crystallized diamond coating method yields four times better results in comparison with the conventional diamond coating method. Konig and Grass investigated the effects of cutting parameters on the roughness of hole surface and surface tissue in the drilling of fiber reinforced thermosets [17]. They denoted that the surface roughness increases with increase of the feed rate. In his study, Tosun, optimized the drilling parameters affecting the burr height and surface roughness of DIN 42CrMo4 steel material by considering different drill materials, cutting speeds, drill point angles and feed rates with the help of Grey Relational Analysis (GRA) [18]. Sur et al. studied on the effects of Ti alloy on the surface roughness in the turning of Al 6063 alloy [19]. They observed that the increase of 35 percent in the hardness of the material resulting from the doping of Ti to the material had relatively an inconsiderable effect on the surface roughness of the material in comparison with effects of cutting speed and feed rate. Also, they determined that the increase in the feed rate affected the surface roughness negatively, while the increase in the cutting speed contributed to the treatment of surface roughness positively; however the feed rate had a more dominant effect on the surface roughness in comparison with the cutting speed. Darwish, et al., investigated the effects of cutting speed, feed rate and drill diameter on the hole surface quality, dimensional accuracy and geometric tolerance in soft steel materials [20]. In their study, they observed that cutting speed and feed rate had a great effect on surface quality, and the higher dimensional accuracy was obtained at low cutting speeds and feed rates.

In the studies mentioned above, generally the effects of cutting parameters on the roughness of the hole surface were investigated in the machining process of stainless steel and 2000, 6000 and 7000 series aluminum alloys. However, it has drawn attention that the studies on 5000 series aluminum alloys, which are widely used in many industrial fields such as aviation, navigation and automotive, are not sufficient. In this study, Al 5005 material was drilled on CNC milling machine under dry drilling conditions by considering different machining parameters such as various rotation speeds, feed rates, drill diameters and point angles, and the roughness of hole surface and the formation of BUE on cutting edges were investigated.

2. Experimental method

In this study, Al 5005 was drilled by considering various drilling parameters such as diameter, point angle, feed rate and rotation speed. CNC milling machine (Taksan, TMC 700V) with vertical machining centre was used in the experiments. The spindle power of the machine, rotation speed and feed rate values were taken as 5.5 kW, 50-8000 rev/min and maximum 0.6 mm/rev, respectively. Maximum feed rate values of the work table on X, Y and Z axes were 500, 600 and 450 mm, respectively. Factorial design, in which the effects of mostly different and unrelated factors on a definite characteristic are investigated, was taken into consideration in design process of the experiment. In factorial design, the experimental design is established by processing the variable parameters (or their levels) crossingly [21]. In this study, the experiments were conducted in accordance with 72 different combinations ($2^1.3^2.4^1$) by using 2 levels for the drill diameter, 4 levels for the point angle, 3 levels for the rotation speed and the feed rate. The values of variable parameters in conducted experiment were selected in compliance with the similar studies as shown in Table 1 [9,10,14,18].

In this study, the cutting fluid was not used in order to observe the effect of drill parameters on the roughness of the hole surface [22]. Al 5005 material used in the experiments was in the dimension of 10mmx70mmx400mm, and its chemical properties were given in Table 2. In the drilling process, the space between the axes of each hole on the sample was adjusted to be 20 mm (Figure 1).

Feed Rate (mm/rev)	Rotation Speed (rev/min)	Point Angle (degree)	Drill material and diameter (mm)
0.1, 0.2, 0.3	400, 800, 1200	90, 118, 130,140	HSS, Ø5, Ø10

Table 1. Experimental parameters

Al 5005	Mg	Si	Fe	Cu	Mn	Cr	Zn	Other elements	Al
%	0.5-1.10	0.3	0.3	0.2	0.20	0.10	0.25	0.15	remainder

Table 2. The chemical structure of Al 5005

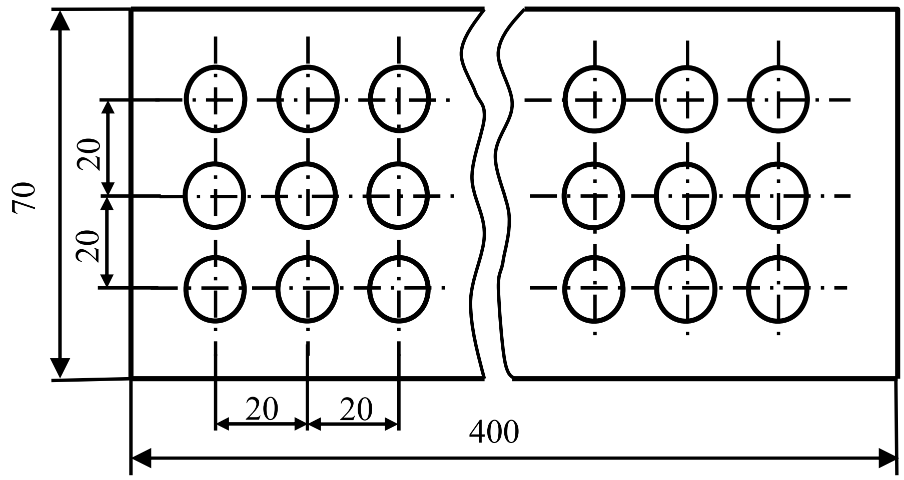


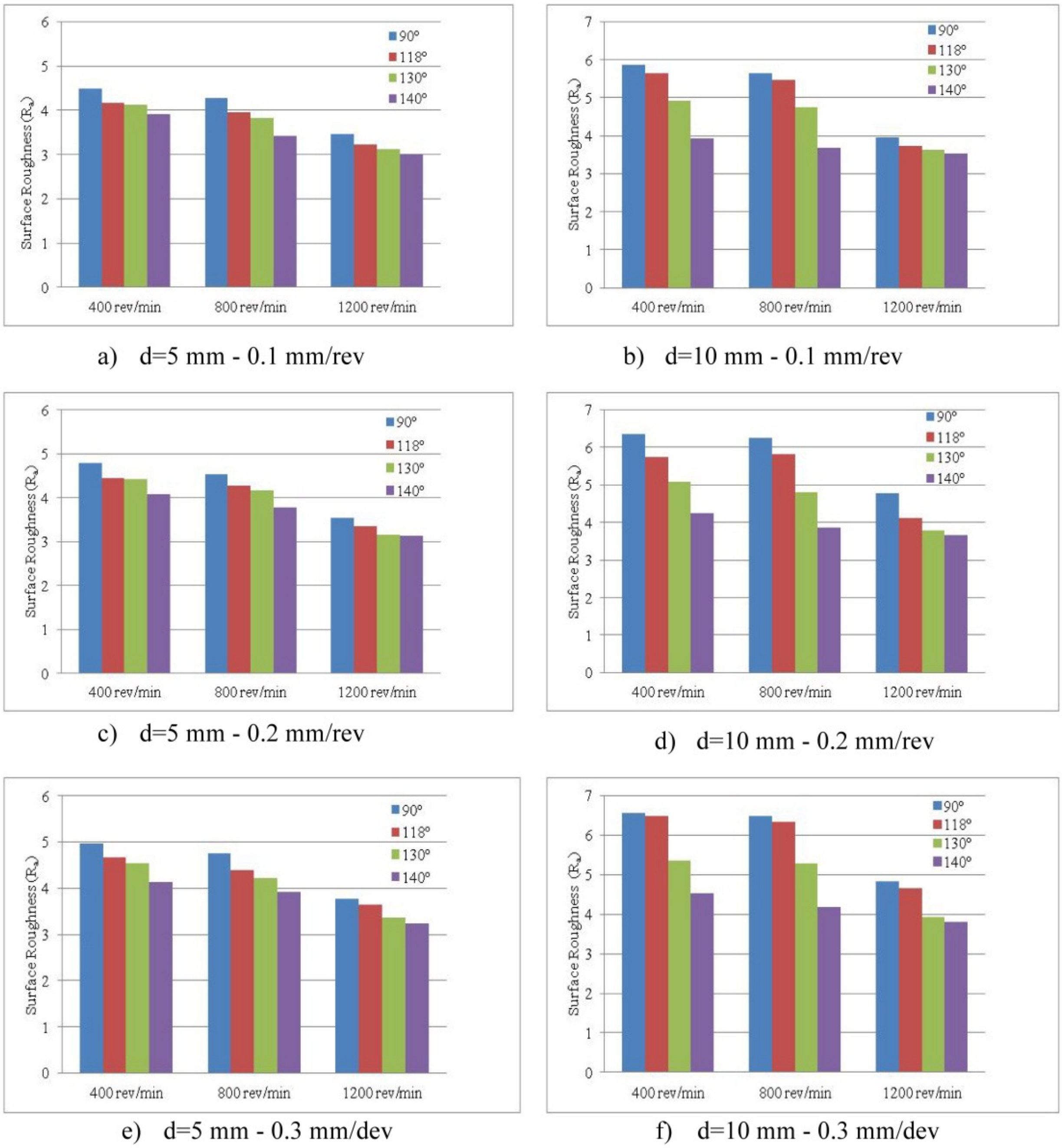
Figure 1. The space between the drilling axes (Thickness 10 mm)

N type double-end DIN 338/RN HSS drill bits with 30º helix angle were used in drilling process. Hardness value of these cutting tools was 65 HRc. Each cutting tool was used once in the experiments, and each experiment was repeated three times in accordance with the similar studies [9,11-14,21,22]. The images of BUEs formed on the cutting tool as a result of the drilling processes were taken by means of Leo Evo 40 model Scanning Electron Microscope (SEM).

After combinational drilling processes, the samples were cut with a cutting disc in the middle in parallel with the hole axis in order to measure the roughness of the hole surface. Then, the surface roughnesses were measured with Mitutoyo SJ-201 surface roughness measurement device. In the measurement of the roughness, sampling length and sampling number were chosen by considering the former studies [7,8,16,19,21] as 0.8 mm and 5 (0.8x5), respectively. The other sampling length values of this device were 0.25 mm and 2.5 mm. Generally, the roughness was measured at three different points in parallel with the hole axis in accordance with the studies in literature [7,12,16,18]. But in this study, in order to evaluate the measurements accurately, the measurements were taken from 5 different points, and then Ra values were determined by considering the average of these values.

3. Results and discussion

The graphics in Figure 2 were illustrated to enable one a comprehensive assessment of the effects of drilling parameters on the surface roughness in the drilling of Al 5005 without using cooling fluid.



a) d=5 mm - 0.1 mm/rev
b) d=10 mm - 0.1 mm/rev
c) d=5 mm - 0.2 mm/rev
d) d=10 mm - 0.2 mm/rev
e) d=5 mm - 0.3 mm/dev
f) d=10 mm - 0.3 mm/dev

Figure 2. The change of the surface roughness with the drilling parameters

As seen from the graphics, the surface roughness decreases with the increase of rotation speed. In former studies [18,23], this case was attributed to the decrease in the cutting and feed force. The most considerable reasons of the decrease in these forces are the decrease in the contact region between the tool and work piece and the decrease in the shear strength in the cutting region due to the increase in the heat of tool-work piece depending on the cutting speed [18,24].

Also, it was supposed that the influence of BUE on the tool and material increased negatively since the amount of BUE resulting from the adhesive wear increased due to the increase in the feed and cutting forces. As mentioned in the literature, in the machining processes of many alloys including more than one phase in own structures BUE formed due to the adhesion of the chips on the tool surface and cutting edge because of the work hardening [23]. It can be said that BUE especially forming at low cutting speeds affects the surface roughness negatively. since Aluminum and its alloys includes more than one phase. In order to explain this case clearly, BUE formations occurring on the cutting tool edges were also investigated in this study (Figures 3 and 4 a-c). All the images corresponding to the whole cutting parameters were not presented since there were a lot of parameters in the experiment and they were investigated in other sections separately, but the SEM images expressing the mentioned case clearly were presented.

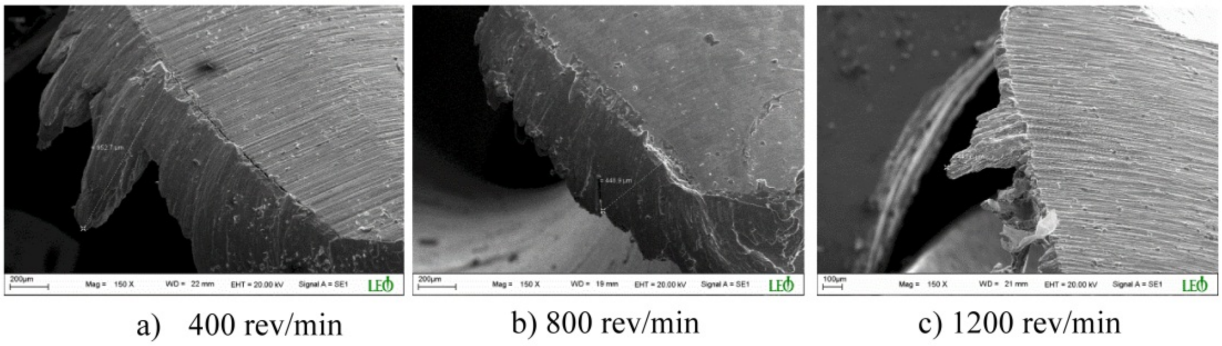


Figure 3. SEM images of BUE formation on the cutting edges. (0.2 mm/dev-118°- Ø5 mm)

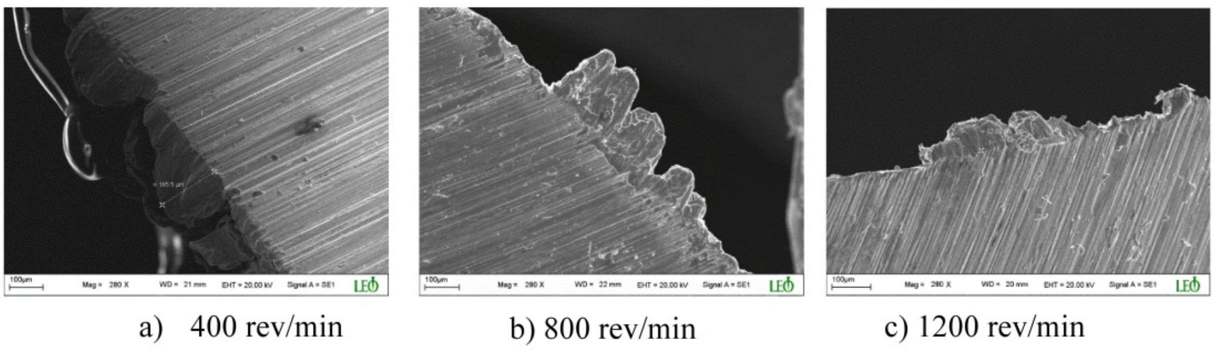


Figure 4. SEM images of BUE formation on the cutting edges. (0.1 mm/rev-118°-Ø10 mm)

As seen from the SEM images in Figures 3 and 4 a-c, BUE formation decreased and had a minor effect on the surface roughness because of the increase in the rotation speed, so surface roughness decreased (Figures 4a-f). Since BUE formed on the cutting tool edge during the drilling had an unstable structure, the surface roughness increased. Thus, because of big and unstable BUE due to low cutting speeds (Figures 3, 4 a and b), the surface roughness increased further and a bad surface was formed (Figures 2 a-f). The decrease in BUE due to the increase in cutting speed can be ascribed to the increase in temperature [23,25]. Since high cutting speeds resulted in much more increase in the temperature, BUE on the cutting edge lost its hardness and strength, and in the continuing cutting process it couldn’t resist the tensions on itself and it was removed from the cutting edge (Figure 3 and 4 c). Hence, high cutting speeds reduced the tendency to the formation of BUE, and resulted in the decrease in the surface roughness values of the work piece (Figures 2 a-f). Since BUE formed on the cutting edges also spoiled the geometric structure of the cutting tool, the stable and ideal process of the cutting operation was damaged, so the roughness increased (Figure 2 a-f). Also, BUE formed on the cutting edges caused fracturing and abrasion on the cutting edges while it was separating from the cutting edges by the effect of thermal tensions [24]. This case increased the roughness of the hole surface depending on the size of BUE (Figures 4 a-c). The abrasion and fracturing formed on the cutting edge according to the different machining parameters were presented in Figures 5 and 6, respectively.

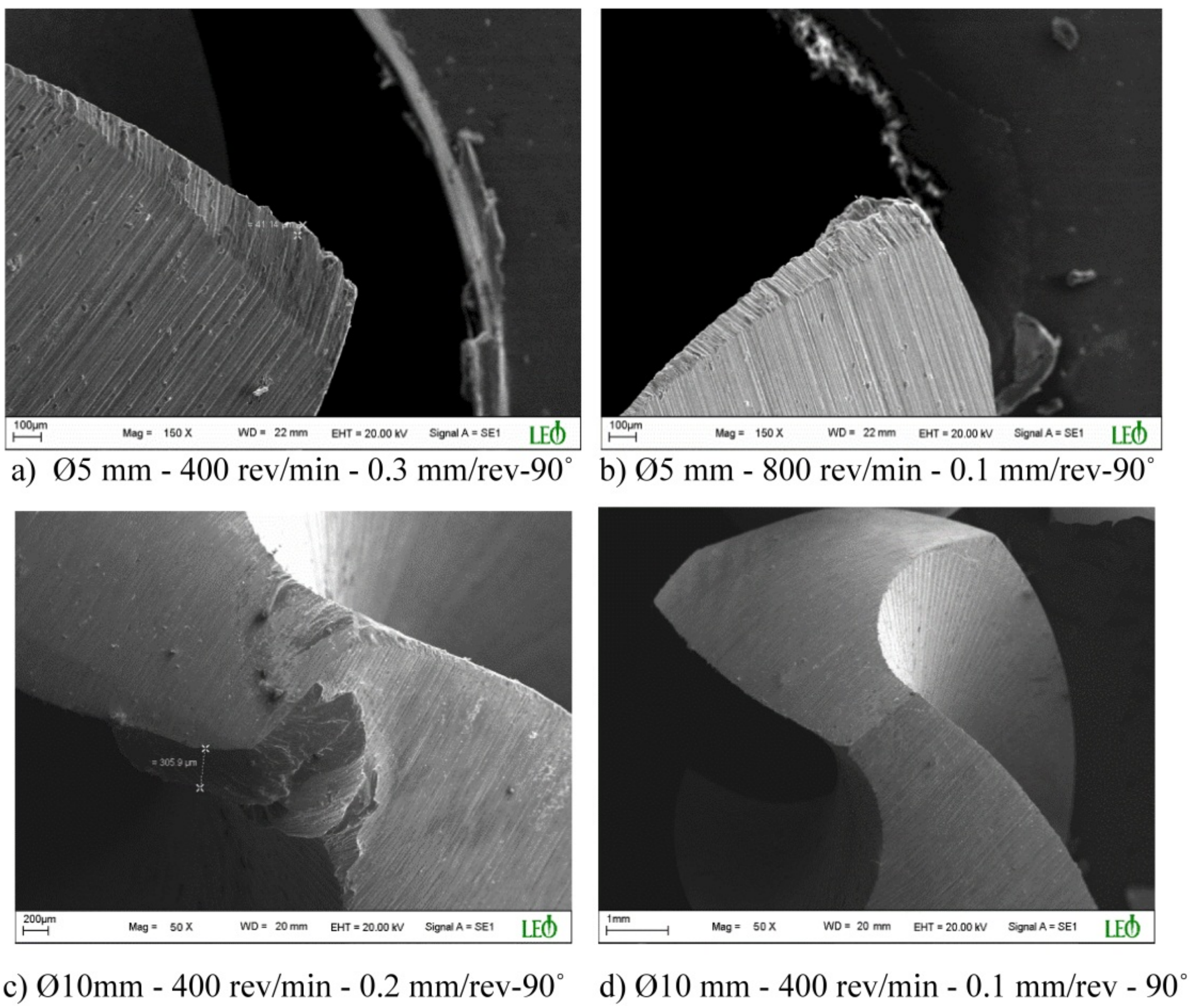
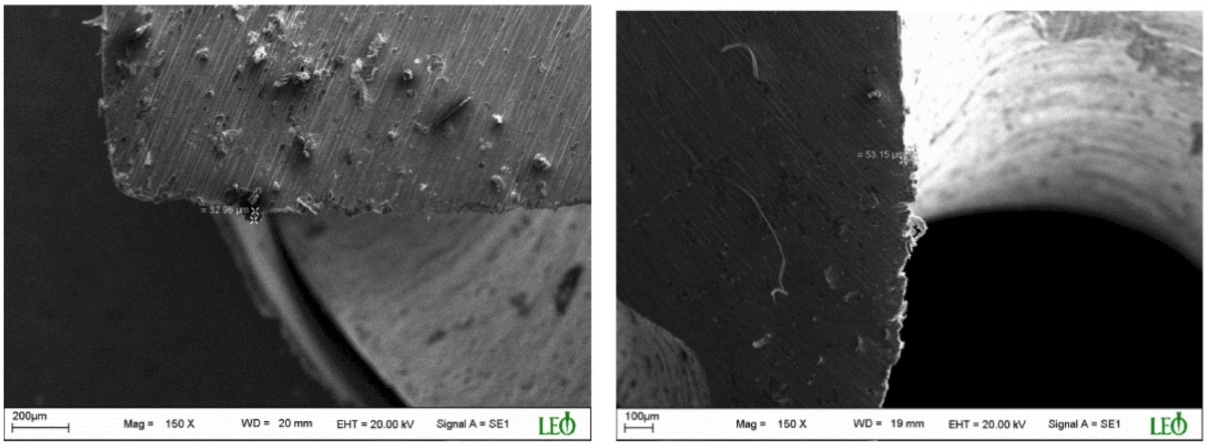
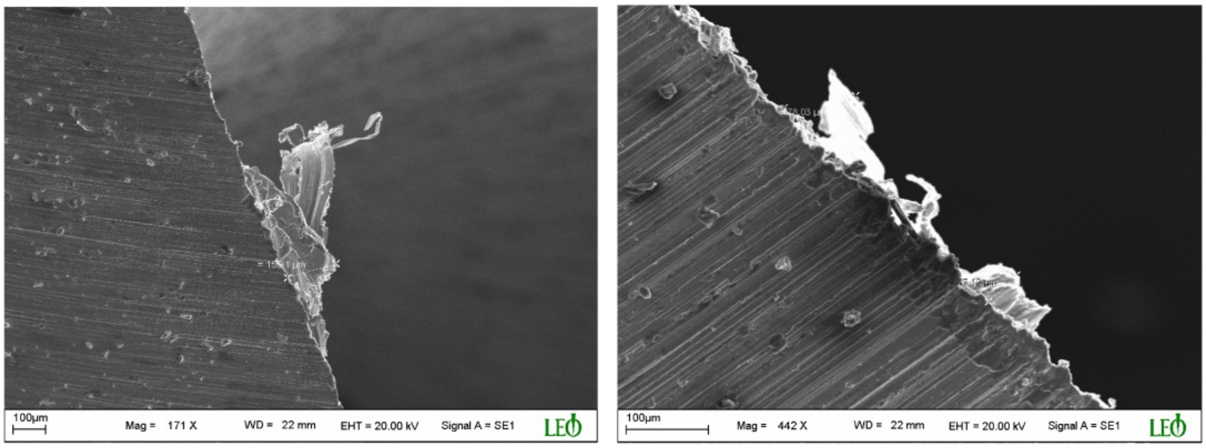


Figure 5. SEM images of the abrasion formed on the cutting edges



a) Ø5 mm- 400 rev/min - 0.2 mm/rev-118° b) Ø5 mm- 400 rev/min - 0.3 mm/rev-118°

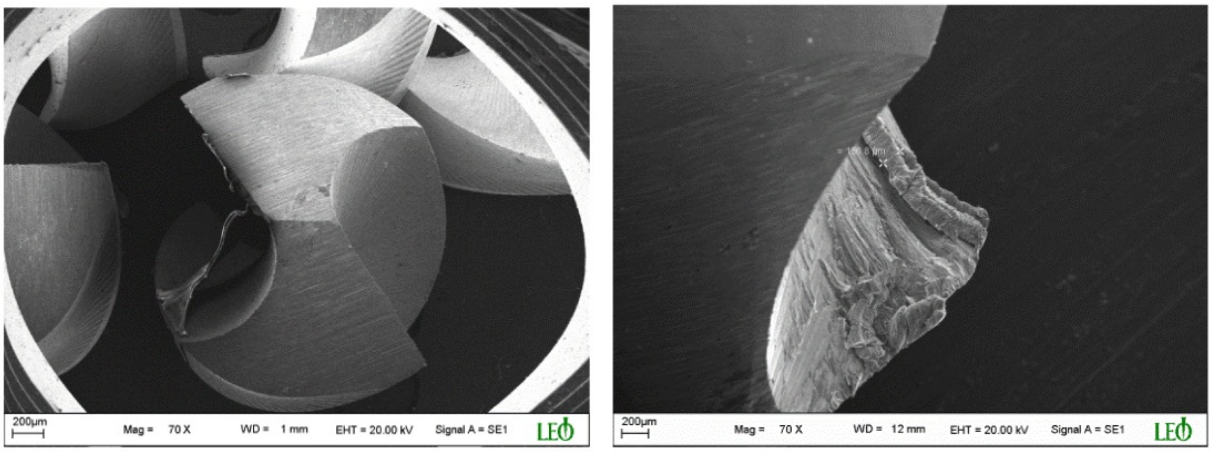


c) Ø10 mm- 1200 rev/min.- 0.3 mm/rev-118° d) Ø10 mm- 400 rev/min.- 0.2 mm/rev-130°

Figure 6. SEM images of the fractures formed on the cutting edges

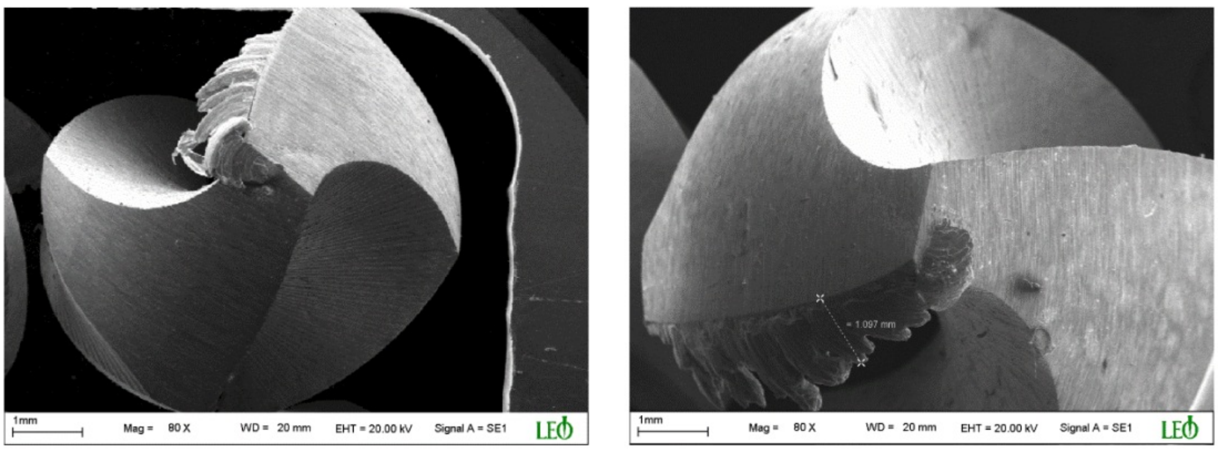
In a similar manner as BUE formation, the chips adhering to helical channels obstructed the effective removal of the chips by plugging the helical channels partially (Figure 7). This case was more prominent at low rotation speeds, and the roughness increased depending on the this case (Figures 2 a-f).

As seen from the Figure 2 a-f, surface roughness increased with the increase of the feed rate, since the amount of the chips increased due to the increase in the feed rate. Because the increase of the feed rate caused high feed rate, low shear angle and thick chip formation [26]. This case signified that machined surfaces were more influenced from the forces during the cutting process. Likewise, the increase in the feed rate resulted in high friction resistance, pressure and increase in temperature [23,25]. In this case, the chip experienced to shear tensions, and adhered to the cutting tool. The amount of the chip adhesion increased depending on the feed rate, and an unstable structure formed. In order to explain this case better, chip smearing formed on the cutting edge were also investigated (Figure 8). It was supposed that notch effect of these chips on the machined due to the adhesion between the chip and cutting edge caused a corruption on the surface quality (Figure 8). This case resulted in the increase in surface roughness.



a) Ø5 mm- 400 rev/min- 0.2 mm/rev-90˚ b) Ø5 mm- 400 rev/min.- 0.3 mm/rev-90˚

Figure 7. SEM images of the chips adhering to the helical channels.



90˚-0.1 mm/rev-800 rev/min 90˚-0.3 mm/rev-400 rev/min

Figure 8. SEM images of the smearing formed on the cutting tool.

In addition, surface roughness changes depending on the feed rate and cutting radius in turning as denoted $Ra=0.321(f^2/r)$ in the Ref. [27]. Where R_a is the roughness, f is the feed rate, r is the radius.

Monagham and O'Reily, determined that this relation was valid for the drilling process, and a similar relation emerged in the drilling of Al 5005 (Figure 2 a-f).

Similarly, as seen from Figure 2 a-f surface roughness improved with the increase of drill point angle. This case can be explained as follows: The values of plastic deformation region, cutting edge length and chip thickness obtained for the drills having point angles of 118°, 130° and 140° are greater than those obtained for the drill having point angle of 90°.

Furthermore, since the cutting tool was worn away faster due to the expansion of the friction surface of the cutting edge with the decrease of the point angle [28] the stability of the cutting process was influenced negatively, therefore the roughness increased as seen from the Figure 2 a-f. Also, the pressure applied on the hole surface was decreased owing to the decrease in radial force with the increase of the point angle. Hence, the roughness arisen on the surface was less in comparison with the drills having small point angles.

On the other hand, it was supposed that surface roughness was also influenced by BUE arisen on the cutting edge. The change in BUE on the cutting tool depending on the different point angles was illustrated in Figure 9. As seen, as the point angle decreased, BUE influenced the form of the cutting tool more negatively. Therefore, this case affected the stability of the cutting tool during the cutting process, and caused an increase in surface roughness (Figure 2 a-f).

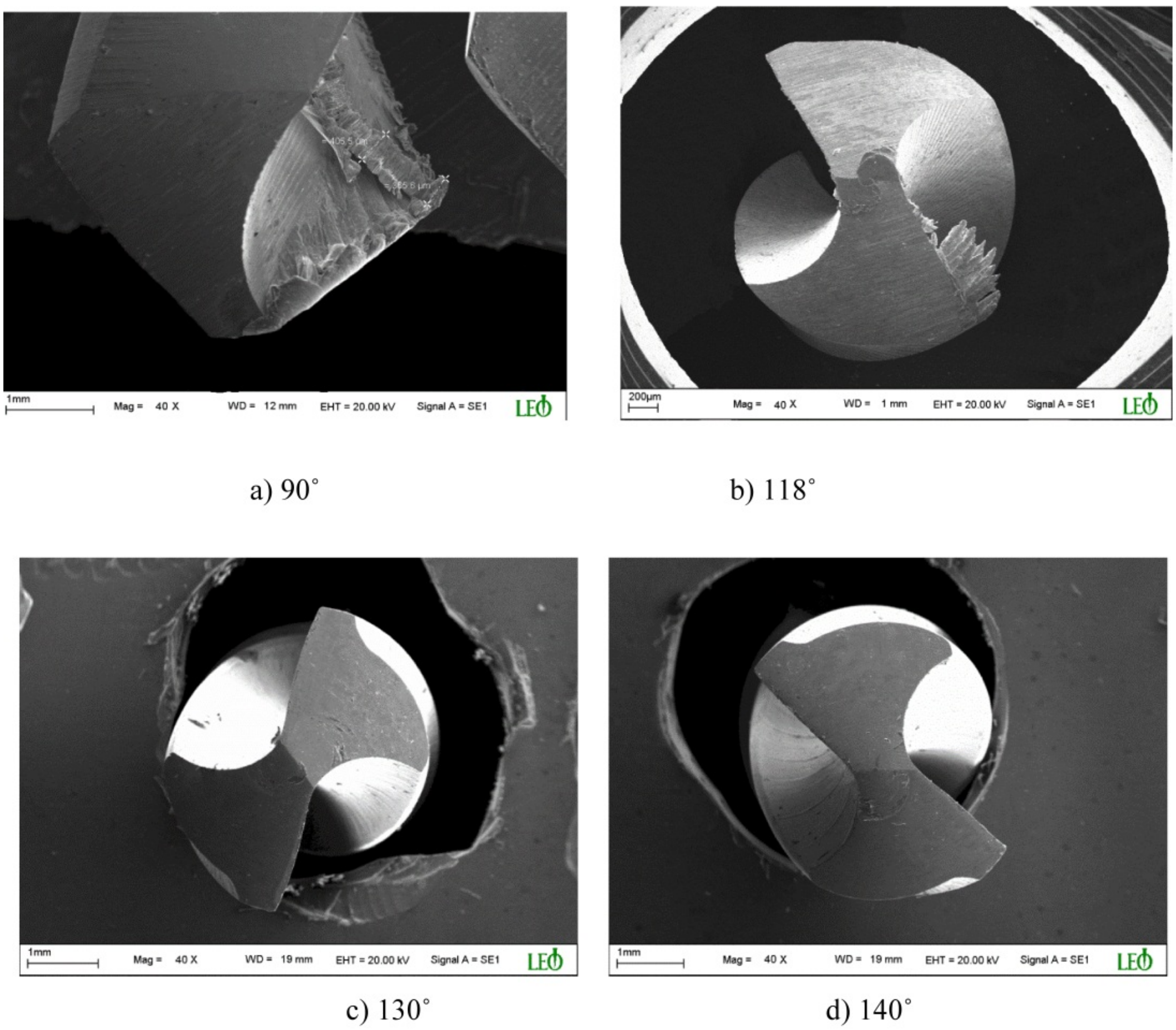
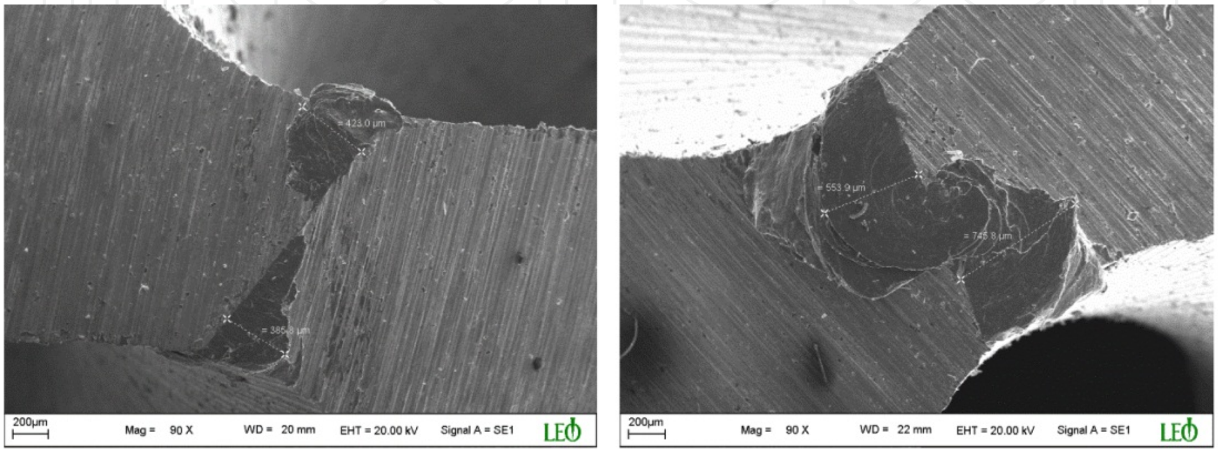


Figure 9. SEM images of BUE formation on the cutting edges at different point angles (1200 rev/min-0.1 mm/rev)

In addition, it was seen in the drilling process that the roughness values obtained for a drill with a diameter of Ø10 mm was bigger than those obtained for a drill with a diameter of Ø5 mm (Figure 2 a-f). This case was attributed to the increase of the forces due to the increase of the length of the cutting edge [23,28]. Also, as seen from Figure 10, it was supposed that the expansion of the deformation area due to the increase of drill diameter resulted in a rise in BUE formation which caused an increase in the roughness (Figure 2 a-f).



a) Ø5 mm b) Ø10 mm

Figure 10. SEM images of BUE formation on the cutting edges at different drill diameters. (800 rev/min-0.2 mm/rev-118°)

4. Conclusion

In this study, BUEs arisen on the cutting edges and the effect of drilling parameters (rotation speed, feed rate, drill diameter and point angle) on the surface roughness of the work piece were investigated experimentally in the drilling process of Al 5005 alloy on CNC milling machine. The inferences achieved were presented as follows:

i. The surface roughness decreased with the increase of the rotation speed and point angle, while it increased with the increase of the feed rate and drill diameter.
ii. It was observed that BUE arisen on the cutting edges caused fractures and wears on the cutting edges during the removal from the cutting edges.
iii. BUE formation decreased with the increase of the rotation speed, therefore the value of surface roughness decreased.
iv. BUE plugged the helical channels partially by adhering on them, and obstructed the effective removal of the chips.
v. BUE spoiled the form of the cutting tool more as the drill point angle decreased, and this case resulted in an increase in the surface roughness.

Author details

Erkan Bahçe*
İnonu University, Department of Mechanical Engineering, Malatya, Turkey

Cihan Ozel
Firat University, Department of Mechanical Engineering, Elazig, Turkey

5. References

[1] Smith, W.S., 2001. translation: Mehmet Erdoğan. Structure and Properties of Engineering Alloys. Vol.:2,

[2] Stringer, P., Byrne, G. ve Ahearne, E., 2010. ''Tool design for burr removal in drilling operations'', http://www.ucd.ie/mecheng/ams/news_items/Peter%20Stringer. pdf, 1-7.

[3] Kim, J., ve Dornfeld, D. A., 2002, ''Development of an Analytical Model for Drilling Burr Formation in Ductile Materials'', Transactions of the ASME, Vol. 124, 192-198.

[4] Puertas, I., Luis perez, C.J., 2003," Surface rougness prediction by factorial design of experiments in turning processes", Journal of Materials Processing Technology 143 – 144.

[5] Çoğun, C., Özses, B., 2002, "Effect Of Machining Parameters On Surface Roughness In Cnc Machine Tools", Gazi Üniv.Müh.Mim.Fak. Der. Vol. 17, No1, 59 – 75.

[6] Koelsch, J., 2001, ''Divining Edge Quality by Reading the Burrs'', Quality Magazine, December, 24-28.

[7] Karayel, D., 2008, "Prediction and control of surface roughness in CNC lathe using artificial neural network", Journal of Materials Processing Technology, 209: 3125–3137.

[8] Çetin, M. H., Özçelik, B., Kuram, E., Şimşek, B. T., Demirbeş, E., 2010,"Effect of Feed Rate on Surface Roughness And Cutting Force In The Turning of AISI 3041 Steel With Ep Added Vegetable Based Cutting Fluids", Selçuk University, II. National Machining Symposium, UTİS 2010, S:92-107, Konya, Turkey

[9] Nouari, M.; List, G.; Girot, F. & Gehin, D. 2005, Effect of machining parameters and coating on wear mechanisms in dry drilling of aluminium alloys. International Journal of Machine Tools & Manufacture, Vol. 45, No. 12-13, pp. 1436-1442, ISSN 0890-6955

[10] Lin T.R., 2002, Cutting behavior using variable feed and variable speed when drilling stainless steel with TiN-coated carbide drills. International J. Advance Manufacturing Technology. 19: 629-636.

[11] Lin, T. R. ve Shyu, R. F., 2000. ''İmprovement of Tool Life and Exit Burr using Variable Feeds when Drilling Stainless Steel with Coated Drills, Int. J. Adv. Manuf. Technol, 16, 308-313.

* Corresponding Author

[12] Kurt M., Kaynak Y. , Bakır B., Köklü U., Atakök G., Kutlu L., 2009,''Experimental Investigation And Taguchi Optımızatıon For The Effect Of Cuttıng Parameters On The Drilling Of Al 2024-T4 Alloy With Diamond Like Carbon (DLC) Coated Drills'', 5. Sixth International Advanced Technologies Symposium (IATS'09), Karabük, Turkey

[13] Dudzinski, D., Devillez, A., Moufki, A., Larrouquere, D., Zerrouki, V., Vigneau, J., 2004, ''A review of developments towards dry and high speed machining of Inconel 718 alloy'', Int. J. Mach. Tools Manufact. 44 (4), 439–456.

[14] Kılıckap, E., 2010, ''Modeling and optimization of burr height in drilling of Al-7075 using Taguchi method and response surface methodology'', Int J Adv Manuf Technol, DOI 10.1007/s00170-009-2469-x.

[15] Kılıçkap, E., 2009, ''Investigation of The Effect of Cutting Parameters on The Burr Formatıon In Drıllıng of Al-7075', I. National Machining Symposium, 142-150, Istanbul, Turkey

[16] Hanyu,H.; Kamiya,S.; Murakami,Y.; Saka,M., 2003,"Dry and semi-dry machining using finely crystallized coating cutting tools" Surface and Coatings Technology 173-174

[17] König W. and Grass P., 1989, "Quality Definition and Assessment in Drilling of Fibre Reinforced Thermosets", CIRP Annals, Vol. 38, No. 1, pp. 119-124.

[18] Tosun, N., 2006, ''Determination of optimum parameters for multi-performance characteristics, in drilling by using grey relational analysis'', *Int J Adv Manuf Technol* 28, 450–455.

[19] Sur G., Çetin H., Çevik E., Ahlatçı H., Sun Y., 2011, ''Determining the Influence of Ti Additive on Surface Roughness During Turning of AA6063 Alloy'', 6th International Advanced Technologies Symposium (IATS'11), Elazığ, Turkey.

[20] S. M. Darwish, A., M. El-Tamitni, 1997, ''Formulation of Surface Roughness Models for Machining Nickel Super Alloy with Different Tools'', Materials and Manufacturing ProcessesVol.12, No:3, 395-408,

[21] Tosun N., Kuru C. Altıntaş E. ve Erdinç E., 2010, 'Investıgatıon of Surface Roughness In Milling With Air And Conventional Cooling Method'', J. Fac. Eng. Arch. Gazi Univ. Vol 25, No 1, 141-146,.

[22] Obikawa, T., Kamata, Y., Shinozuka, J., 2006, ''High-speed grooving with applying MQL'', International Journal of Machine Tools & Manufacture, 46, 1854–1861,

[23] Şahin, Y., 2000, ''Principles of Metal Removing '', Vol. 1-2, Nobel Publisher.

[24] Kılıckap, E., Huseyinoglu M. and Ozel C., ''Emprical Study Regarding the Effects of Minimum Quantity Lubricant Utilization on Performance Characteristics in the Drilling of Al 7075'', J. Of the Braz. Soc. Of Mech. Sci.&Eng. Vol.XXXIII, No.1/53

[25] Özcelik, B., ve Bagci, E., 2006, ''Experimental and numerical studies on the determination of twist drill temperature in dry drilling'': A new approach, P I Mech Eng L-J Mat, 27, 920–927.

[26] Çakır, C., ''The Fundamentals of Modern Machining'', 1999, Uludağ University, Bursa, Turkey

[27] Monagham, J., O'Reily, P., 1992, ''The drilling of an Al/SiC metal matrix composite'', J Mater Process Tech, 33, 469-480.

[28] Akkurt, M., 2004, ''Metal Removing Methods And Machine'', Birsen Publisher, Istanbul, Turkey