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Full Length Research Paper

Study of cutting force and surface roughness in milling of Al/Sic metal matrix composites

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In this experimental study, composite samples containing silicon are produced with powder metallurgy technique by sintering under argon atmosphere. The effect of cutting speeds, feed rates and different cutting tool types on cutting forces and surface roughness are investigated in the face milling operation of silicon carbide particle reinforced aluminium metal matrix composites. Machining operations are conducted using coated and uncoated tools. Main cutting force (F_x) and surface roughness (Ra) are measured for at four different cutting speeds (300, 350, 400 and 450 m/min) and three different feed rates (0.1, 0.15, 0.20 mm/tooth) and two depth of cut (0.5, 1 mm). As a result of experimental evaluation for coated and uncoated tools, main cutting force increased with increasing feed rate and depth of cut whereas, it is decreased significantly by higher cutting speed. On the other hand, Al-SiC produces the worst surface finish with increasing feed rate and depth of cut in the uncoated tools whereas, the surface roughness in the coated tools are decreased under the same cutting conditions. The best surface roughness is obtained with increasing cutting speed for both uncoated and coated tools.

Key words: Metal matrix composite, face milling, machining, cutting forces, surface roughness.

INTRODUCION

Recently, the reinforced metal matrix composites (MMCs) are widely used in aerospace, automotive, electronic and medical industries. Silicon carbide (SiC) and alumina (Al_2O_3) as the matrix phase in the production of metal matrix composites are used the popular reinforcement in the literature (Rohatgi, 1990; Monaghan, 1994; El-Gallab and Sklad, 1998; Koczak et al., 1993). Net shaping and good surface finish of particulate metal matrix composites (PMMCs) are very important for machining operations. However, PMMCs show poor machinability because of the fact that their reinforcements cause serious abrasive tool wear and the worst surface finish during machining (El-Gallab and Sklad, 1998; Koczak et al., 1993; Quigley et al., 1994; Hung et al., 1996; Chambers, 1996). Generally, the machininability of the MMCs from the available literature are very commonly related to turning process. These studies were contained of tool wear, cutting force and surface roughness (El-Gallab and Sklad 1998; D'Errico and Calzavarini, 2001; Polini et al., 2003; Ciftci et al., 2004; Kannan and Kishawy, 2008; Dabade et al., 2009). However, a study of the machinability of the MMCs in the milling operations is very limited as regards the machining cutting parameters and tool wear to the work piece surface roughness and cutting force. In previous studies, machining of SiC reinforced aluminium composites in the milling operations was investigated and the flank wear rate on cutting tool with increasing cutting speed was increased (Coelho et al., 1993). In another work, machinability of particle and fibre reinforced MMCs materials in milling operation with polycrystalline diamond tools was conducted (Cronjager and Meister, 1992). It was obtained that cutting force increased with increased tool wear remarkably and surface roughness increased with higher in feed rate. Furthermore, the face milling of SiC reinforced aluminium matrix composites at high cutting speeds was examined by Sun et al. (2004). Sun et al. (2004) found that cutting force, cutting temperature and surface roughness increased with increasing cutting speed. In recent studies, machinability of B_4C particle reinforced aluminium metal matrix composite by milling

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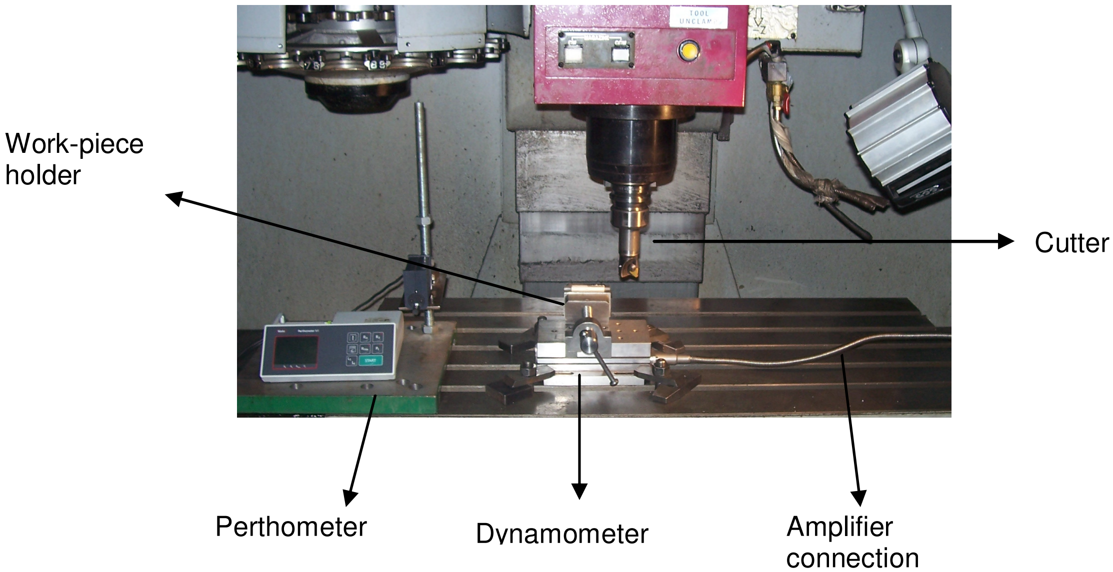


Figure 1. General view of the experimental set-up.

operation was performed using various cutting speeds, feed rates and cutting tool types (Karakaş et al., 2006; Übeyli et al., 2007; Übeyli et al., 2008; Übeyli et al., 2008; Acır et al., 2009). In these studies, optimum cutting parameters, tool flank wear, mean cutting force and surface roughness were investigated for coated and uncoated tools and different cutting parameters. The flank wear was increased of all investigated tools with increasing cutting speeds whereas, flank wear of all investigated tools decreased with increasing feed rate (Karakas et al., 2006; Ubeyli et al., 2007; 2008). On the other hand, the surface roughness decreased drastically for all tools with increasing cutting speed (Ubeyli et al., 2008). In addition, main cutting force was mainly affected by feed rate, but, cutting speed had no significant effect of B_4C particle reinforced aluminium metal matrix composite (Acir et al., 2009). In another study, the effect of main cutting parameters on cutting force and surface roughness in machining alumina reinforced Al-6Zn 2Mg-2Cu composites was studied. The cutting force and surface roughness were affected by feed rate (Ubeyli et al., 2010).

In this study, cutting forces and surface roughness in the milling of reinforced aluminum composites containing SiC particle are investigated. The influence of cutting speed, feed rate, depth of cut and type of tool are determined on main cutting force and surface roughness under dry machining conditions.

EXPERIMENTAL PROCEDURE

Production of MMCs

The MMCs containing Aluminum mixed 7%wt Si (-10 micron), and 5%wt SiC (-8 micron) powders were mixed for 30 min in a three dimensional turbula. Mixed powders were compacted under 600 MPa pressures. Specimens were sintered at 600°C in flowing Ar atmosphere for 60 min. The final dimensions of the fabricated composites were 50×30×10 mm.

Machinability tests

The machining tests (face milling of the composites were performed) in a computer numerical controlled vertical machining center (Johnford VMC-850 Fanuc Series O-M) having a power of 7.5 kW and capable of a working speed of 6000 rev/min. The view of the experimental set-up for milling operation is shown in Figure 1.

Coolant was not used during the tests. The used cutting tools were commercial grade K20 inserts and produced by Walter with geometry of TPKN1603PPR. Uncoated cementide carbide and TiCN+TiN coated cementide carbide were used in machining tests. The cutting speeds of 300, 350. 400 and 450 m/min, the feed rates of 0.1, 0.15 and 0.20 mm/tooth and the dept of cut of 0.5, 1 mm were taken as cutting parameters. The tool data and cutting parameters have been summarized in Table 1.

Cutting forces (Fx, Fy and Fz) acting on the composite samples were measured with a Kistler three component piezoelectric dynamometer type 9257B which was connected to a series of multi-channel charge amplifier type Kistler 5070A. On the other hand, surface roughness measurements were performed by Mahr Perthometer M1.

RESULTS AND DISCUSSION

Evaluation of main cutting force

The cutting force components (F_x, F_y, F_z) and surface roughness in milling are measured for different cutting parameters. The main cutting force (F_x) is related to the force applied in X direction. F_y is the instantaneous normal component in the Y direction whereas, F_z is the projection of resultant force in the Z direction acting on

Table 1. Tool data and cutting parameters.

Cutting conditions	Parameters
Cutting tools	Uncoated/coated (CVD) cementide carbide
Cutting speed (m/min)	300-350-400-450
Feed per tooth (mm/tooth)	0.1-0.15-0.20
Axial depth of cut (mm)	0.5-1
Radial depth of cut (mm)	10
Cutting length (mm)	50
Number of tooth	Single
Approach angle	90◦
Nose radius (mm)	0.8
Rake angle	0◦
Relief angle	11◦
Insert angle	60◦
Tool holder diameter (mm)	32

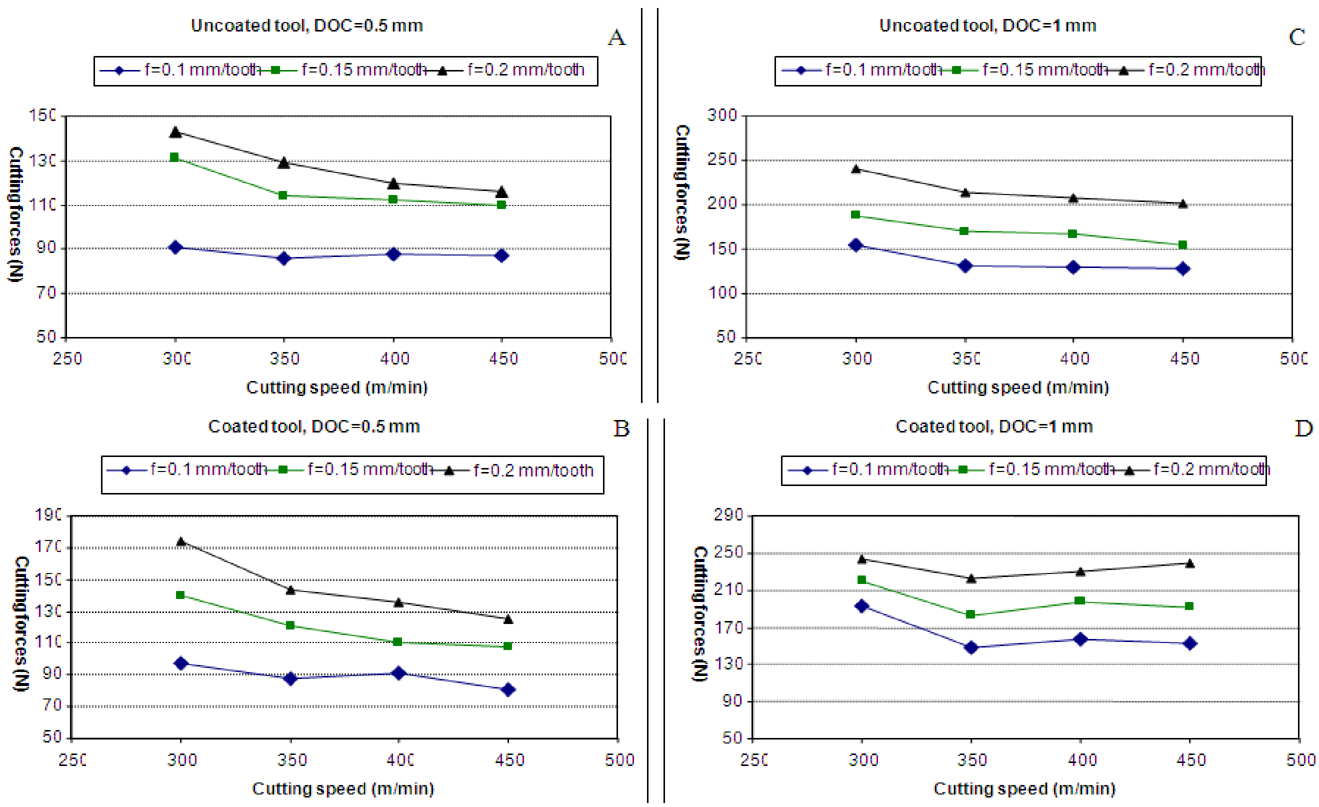


Figure 2. Change in main cutting force with respect to the cutting speed.

the work-piece. In this study, F_x plays a key role in determining the cutting force of the tool. Therefore, F_x is taken into consideration for comparison of parameters in this study.

Figure 2 (A-D) shows the changes in F_x with respect to the cutting speed on the cutting tool for different feed rates and depth of cut. It can be seen from Figure 2A that the F_x increases from 91 N for f= 0.1 mm/tooth to 143 N for f= 0.2 mm/tooth of uncoated tools to cutting parameters V=300 m/min and depth of cut 0.5 mm. On the other hand, F_x values in coated tools for the same cutting parameters increases from 97 N to 174 N (Figure 2B). However, F_x decreases with increasing cutting speed the same cutting parameters of every two stages (Figure 2A-D). Similarly, as seen from experimental results and Figures 2C and 2D, the F_x values in the uncoated and

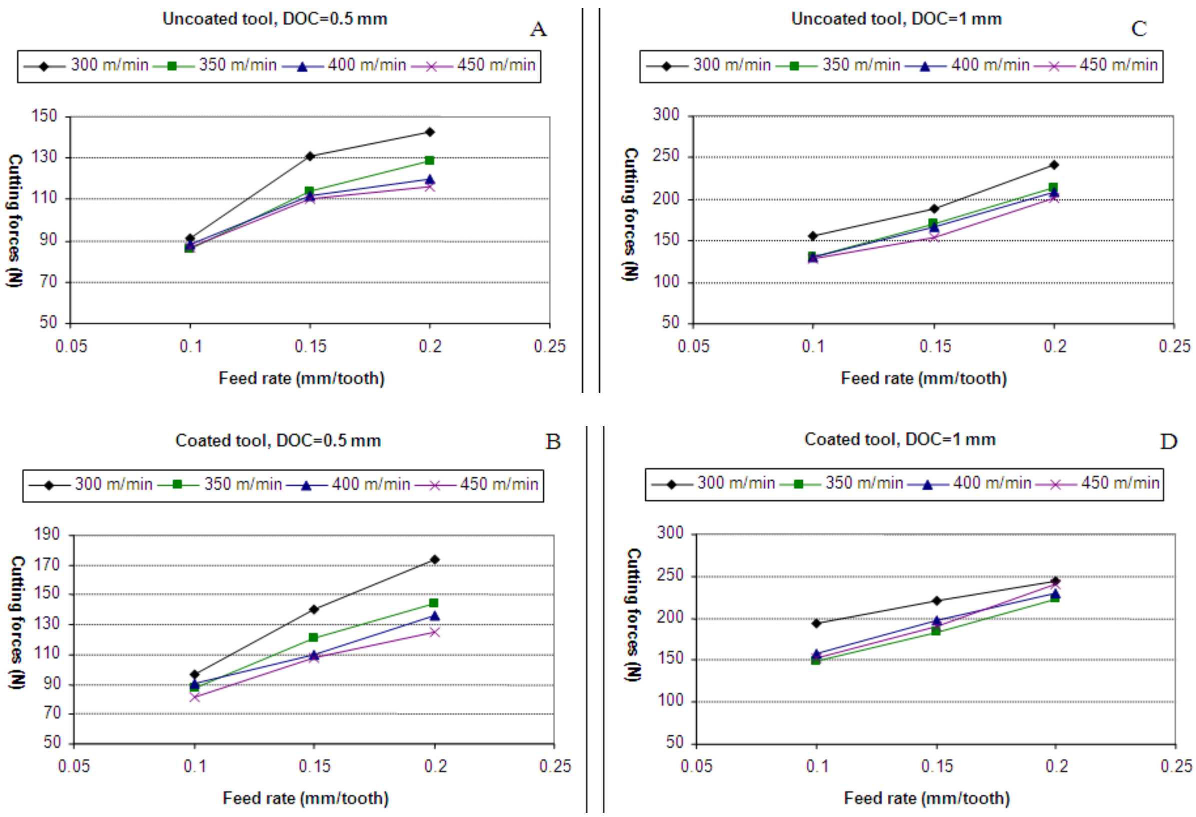


Figure 3. Change in main cutting force with respect to the feed rate.

coated tool for depth of cut 1mm are approximately two fold higher than the obtained F_x values from depth of cut 0.5 mm. Obtained F_x experimental results according to the cutting speed on the cutting tool for different feed rates and depth of cut show similarly behaviour for all the cutting parameters and conditions. In other words, the effect of cutting speed on the F_x cutting force is at low levels according to feed rates and depth of cut.

Figure 3 (A-D) depicts the change in F_x cutting force with respect to the feed rate on the cutting tool for different cutting speed and depth of cut. One can see that cutting force increases almost linearly with increasing feed rate for all the cutting parameters. It is around 91 N and 87 N at the feed rate of 0.1 mm/tooth but it reaches -143 and 116 N when the feed rate is increased to 0.2 mm/tooth of uncoated tools for cutting parameters V=300 and 450 m/min and depth of cut 0.5 mm (Figure 3A). On the other hand, it is around 97 and 81 N at the feed rate of 0.1 mm/tooth but it reaches -174 and 125 N when the feed rate is increased to 0.2 mm/tooth of coated tools, V=300 and 450 m/min and DOC=1 mm (Figure 3B), respectively. Generally, the cutting forces are decreased with increasing cutting speeds, but the cutting force with respect to the feed rate is higher. In other words, even though a significant change in the cutting force with respect to the feed rate is observed, the effect of cutting speed on the cutting force is at very low levels. In addition, the higher depth of cut leads to an increase in the cutting force as about two fold (Figure 3A-D). Moreover, the formation of the built up edge (BUE) (Shaw, 1984; Bootthrody, 1981) on the tools and change in the thickness of the chips removed from the work-piece material is very important on cutting force values. When the feed rate and depth of cut are increased, the ratio of the chips removed from the work-piece material increases. Therefore, it results in the raise of the force required to cut the material.

Evaluation of surface roughness

Measured work piece surface roughness values (Ra) after machining tests are shown in Figure 4 (A-D). These values are the averages of three surface roughness measurements. These figures have been constructed to illustrate the main effects of cutting speed, feed rate and depth of cut parameters on the surface roughness for each tool type. It was known that Ra is mostly affected by cutting parameters.

The Ra values of against feed rate at different cutting conditions are shown in Figure 4A to D. It is observed that the surface finish is affected by the increased cutting speed. One can observe that Ra values in the uncoated tools are almost identical except some small deviations

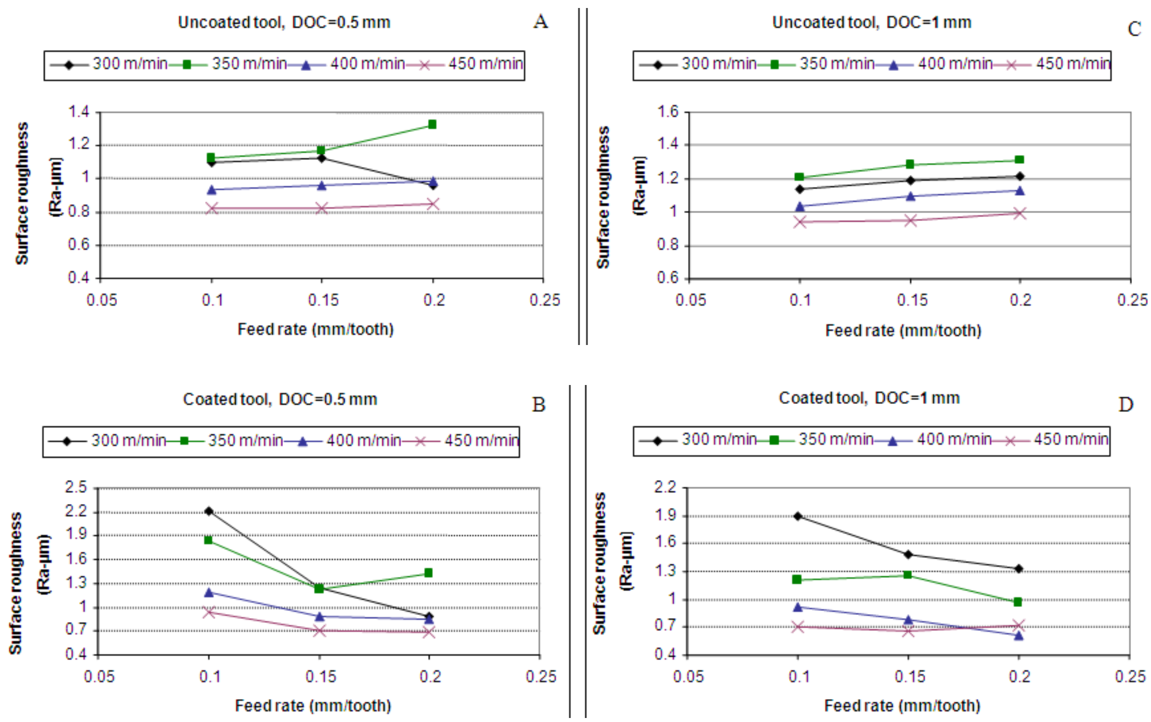


Figure 4. Change in surface roughness with respect to the feed rate.

which depend on feed rate. However, Ra in the uncoated tools is decreased with increased cutting speed whereas; it is increased by increased feed rate. One can observe that Ra values are 1.096 and 0.824 µm with 0.1mm/tooth for 300 and 450 mm/min cutting speed, respectively while it is 0.96 µm and 0.845 for 0.2 mm/tooth with the same cutting speeds of depth of cut 0.5 mm (Figure 4A). The Ra values at the feed rate 0.1 mm/tooth of 1mm depth of cut are 1.141 and 0.945 µm for 300 and 450 mm/min cutting speed respectively with uncoated tools whereas; Ra values becomes 1.216 and 0.996 µm feed rate 0.2 mm/tooth for the same conditions (Figure 4C).

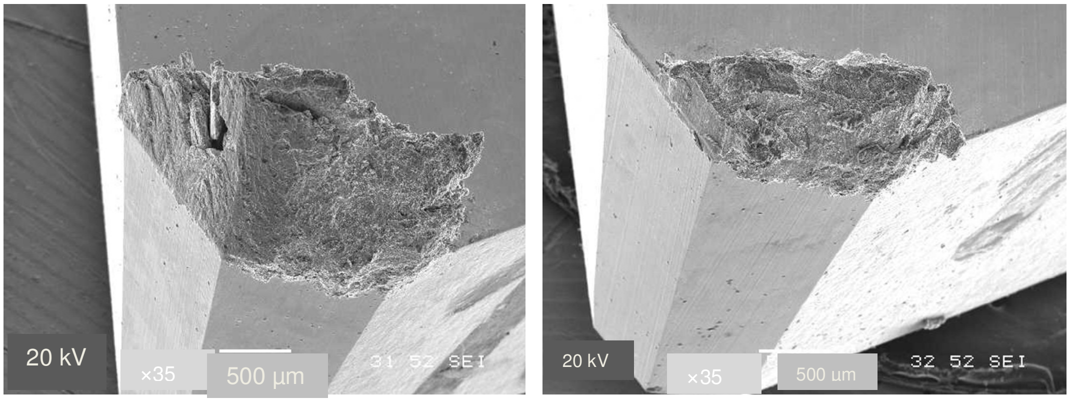
On the other hand, Ra in the coated tools is decreased with feed rate as well as cutting speed according to uncoated tools. In coated tools, the Ra values feed rate of 0.1 mm/tooth are 2.22 and 0.939 m for 300 and 450 mm/min cutting speed respectively while, these values feed rate of 0.2 mm/tooth are 0.886 and 0.686 m with the same cutting speeds for depth of cut 0.5 mm (Figure 4B).

If the depth of cut is increased to 1 mm, the highest Ra is obtained for 0.1 and 0.2 mm/tooth feed rate with 300 mm/min cutting speed. On the other hand, the Ra values with increasing cutting speed become closer for 0.1 and 0.2 mm/tooth feed rate and the lowest surface roughness is obtained as shown in Figure 4A-D. Compared to the Ra for uncoated and coated tools, uncoated tools also gives higher Ra with increasing feed rate and higher depth of cut whereas, coated tools leads to lower Ra values with increasing feed rates for depth of cut and cutting speed. It is considered that both the high temperature cutting zone and BUE lead to the significantly high Ra. The increasing cutting temperature is affected by feed rate. Therefore, this case leads to weak bonding effect between SiC and Al matrix, and built-up edge is formed by the material removed from the work-piece during machining as shown in Figures 5 and 6. It is considered that BUE effect the worst surface finish. In addition, the Ra is affected by cutting speed. The best surface roughness is obtained with increasing cutting speed. According to Figure 5, coated tools were given better Ra than uncoated tools in the high cutting speed.

Conclusions

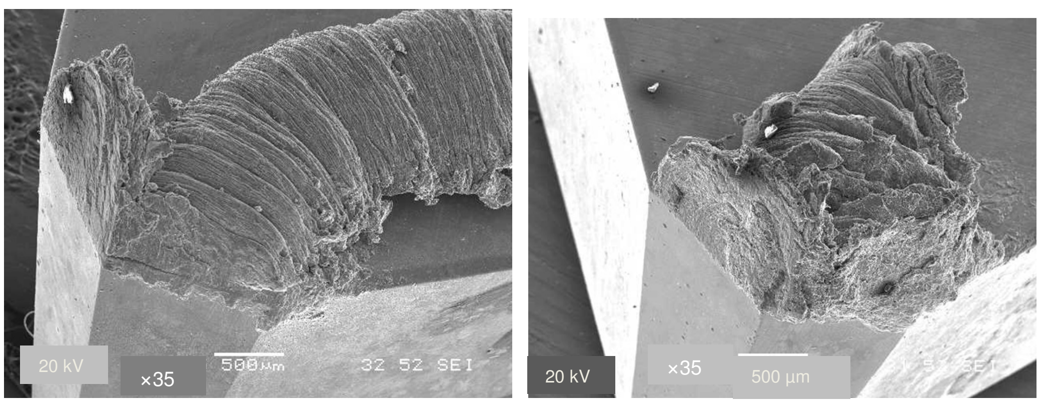
The main results of this study are summarized below:

(i) The main cutting force is affected by the increased feed rate and depth of cut. Increasing the feed rate and depth of cut leads to increase in the cutting force for all cutting conditions.
(ii) Cutting force was mainly affected by the cutting speed. When the cutting speed is increased, the cutting force decreased rapidly. On the other hand, the cutting force is increased by higher feed rate. The better cutting force is obtained with 0.1 mm/tooth and 400 m/min cutting speed in all cutting conditions.
(iii) Both coated and uncoated tools exhibited different performance for surface roughness. Surface roughness



a b

Figure 5. Built-up edge formation on the uncoated tool a) cutting speed of 300 m/min, feed rate = 0.1 mm/tooth and DOC= 1 mm, b) cutting speed of 450 m/min, feed rate = 0.1 mm/tooth and DOC= 1mm (×35).



a b

Figure 6. Built-up edge formation on the coated tool a) cutting speed of 400 m/min, feed rate = 0.1 mm/tooth and DOC= 1mm, b) cutting speed of 400 m/min, feed rate = 0.2 mm/tooth and DOC= 1 mm (×35).

in the uncoated tools is increased with feed rate whereas; the Ra in coated tools is decreased by feed rate. It is considered that BUE is effect changing surface finish.

(iv) The Ra is affected by cutting speed. The best surface roughness is obtained with increasing cutting speed whereas; the worst surface roughness is measured by increasing feed rate. Generally, the ideal surface roughness is obtained with the lower feed rate and higher cutting speed.

(v) The better performance was obtained with coated tools in cutting speed of 450 m/min in terms of surface roughness.

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