A Study on the Cutting Force in Milling of Boron Carbide Particle Reinforced Aluminum Composite

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ABSTRACT

In this study, cutting forces in the face milling operation of boron carbide particle reinforced aluminum metal matrix composite were investigated. Composite samples were produced using powder metallurgy technique. Then, milling operations were conducted using coated and uncoated tools at three different cutting speeds (100 m/min, 150 m/min and 200 m/min) and feed rates (0.05 mm/z, 0.10 mm/z, 0.15 mm/z). Experimental results showed that the cutting force increased with increasing feed rate significantly whereas, cutting speed and tool type had little effect on the cutting force.

Keywords: Metal matrix composite; cutting force, milling process; machining.

1. INTRODUCTION

Machining of ceramic reinforced metal matrix composites (MMCs) is required frequently to attain net shape and good surface finish. Conventional machining operations; i.e. turning, milling, drilling, are applicable to these materials widely. However, hard ceramic reinforcements in composite materials decrease machinability since they cause serious abrasive tool wear during machining /1-5/. Studies on milling of metal matrix composite materials are so rare /6-13/. In a previous study by Coelho et al. /6/, the face milling of SiC reinforced aluminum composites was conducted. It was mentioned that flank wear rate increased with increasing cutting speed in milling operation but it changed slightly in turning and drilling operations. In addition, Cronjager and Meister /7/ studied the machinability of particle and fiber reinforced MMC materials in milling operation with polycrystalline diamond tools. They also observed that tool wear increased with increasing cutting speed remarkably. In another work, Lane /8/ made an investigation on the end-milling and face-milling of cast MMCs with the aid of different tools. It was pointed out that carbide tools had a limited tool life. Furthermore, Chandrasekaran and Johansson /9/ investigated dry face milling of centrifugal cast tubes of Al/SiC composites. They found the best tool performance when SiC content in volume was 23% and feed rate was 0.18 mm/z. Recently, milling of B_4C particle reinforced aluminum metal matrix composite was studied using various cutting speeds, feed rates and tools /10-13/. It was concluded that that the flank wear of all investigated tools increased with increasing cutting speeds /10/. Moreover, when the cutting speed was increased, surface roughness decreased significantly for all investigated tools /12/. Furthermore, the flank wear of all investigated tools decreased with increasing the feed rate /13/.

In this study, cutting forces in the milling of B4C particle reinforced aluminum composites were investigated. The main aim was to analyze the effect of cutting speed, feed rate and type of tool on the cutting force in milling of these composites.

2. EXPERIMENTAL PROCEDURE

Experimental study in this work contained two main steps:

2.1. Composite production

2.2. Milling experiments

2.1. Composite production

Boron carbide particle reinforced aluminum composites were produced via powder metallurgy technique. First of all aluminum, copper and boron carbide powders were supplied commercially. Then, powder size measurement was conducted to determine the average size. The average sizes of the aluminum, copper and B_4C powders were found to be 37 μm, 33 μm and 16 μm, respectively. Next, these powders were mixed in a container for 1 hour at 80 rpm to maintain uniform distribution. After that, the mixed powder were cold compacted to get green composite having weak mechanical properties. Finally, liquid phase sintering operation at 25 MPa and 585 °C for 10 min. under an inert nitrogen atmosphere was made to get the full density composite of Al-4%Cu/B_4C_p. Produced composite samples were 50 mm x 50 mm x 10 mm in size.

2.2. Milling process

In face milling of the composites, a computer numerical controlled vertical machining center (Johnford VMC-550 Fanuc Series O-M) having a power of 15 kW and capable of a working speed of 3500 rev/min was used. Figure 1 shows the general view of the experimental set-up for milling operation.

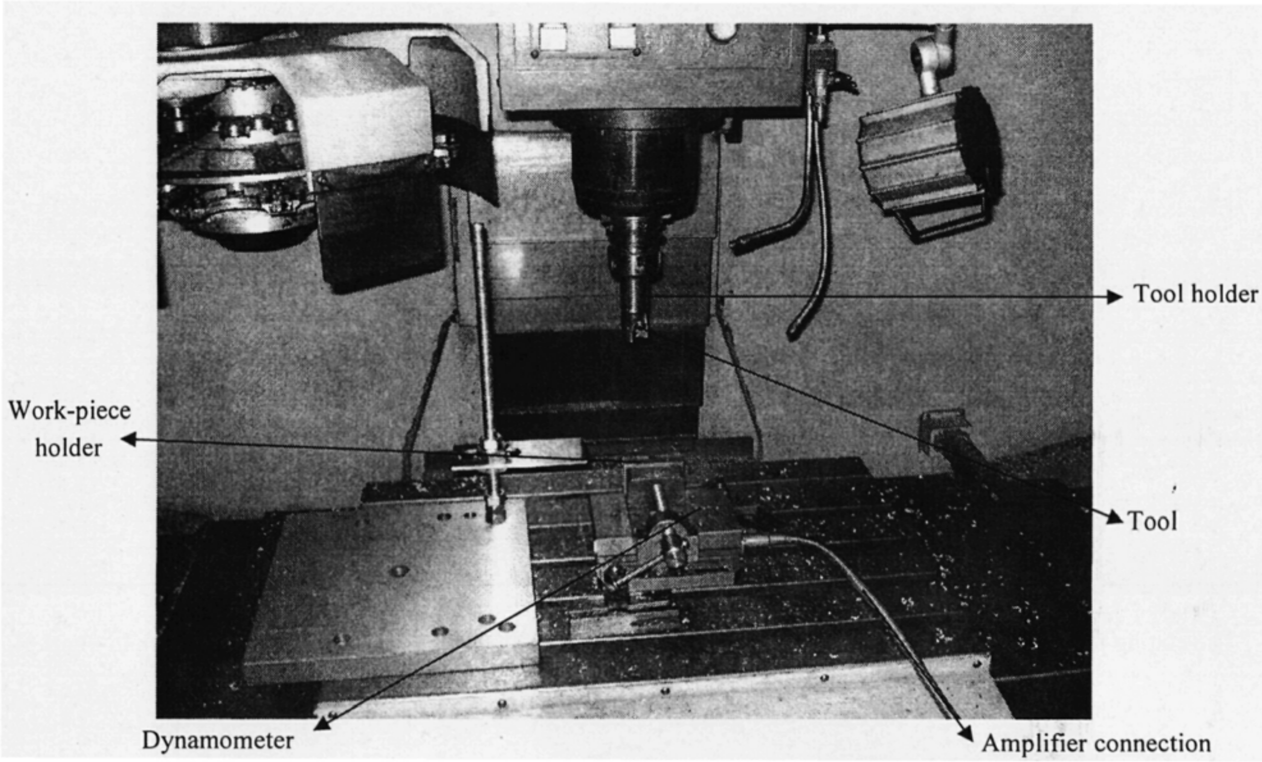
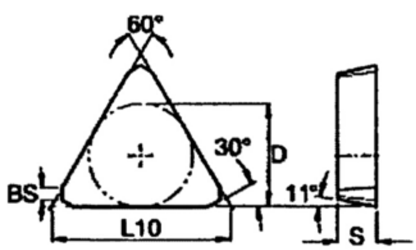


Figure 1: General view of the experimental set-up

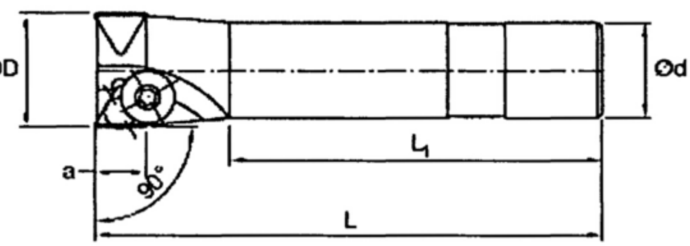
Cutting speed, feed rate and tool type were considered as the variable parameters. The cutting speeds of 100, 150 and 200 m/min and the feed rates of 0.05, 0.10 and 0.15 mm/z (feed/tooth) were taken into account, whereas, two types of tools; uncoated cementide carbide (HBF K20) and TiAlN coated cementide carbide (BK510 K20) were used.

Figures 2 and 3 depict the geometry of the cutting tool and tool holder used in this work, respectively. Depth of cut of 1.5 mm was kept constant in the milling of the composites. No liquid coolant was used. Cutting forces 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. The data of cutting forces were extracted from the Dynoware Software.



ISO code number	S	D	L10	BS
TPKN 1603 PD-R	3.18	9.52	16.5	1.2

Figure 2: Geometry of the tools used in the milling process. Dimensions are given in mm.



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FKR/L 15 17 32 32 16	32	32	125	90	14.5

Figure 3: Geometry of the tool holder. Dimensions are given in mm.

The cutting force components (Fx, Fy and Fz) values were received from the dynamometer and shown in Figure 4.

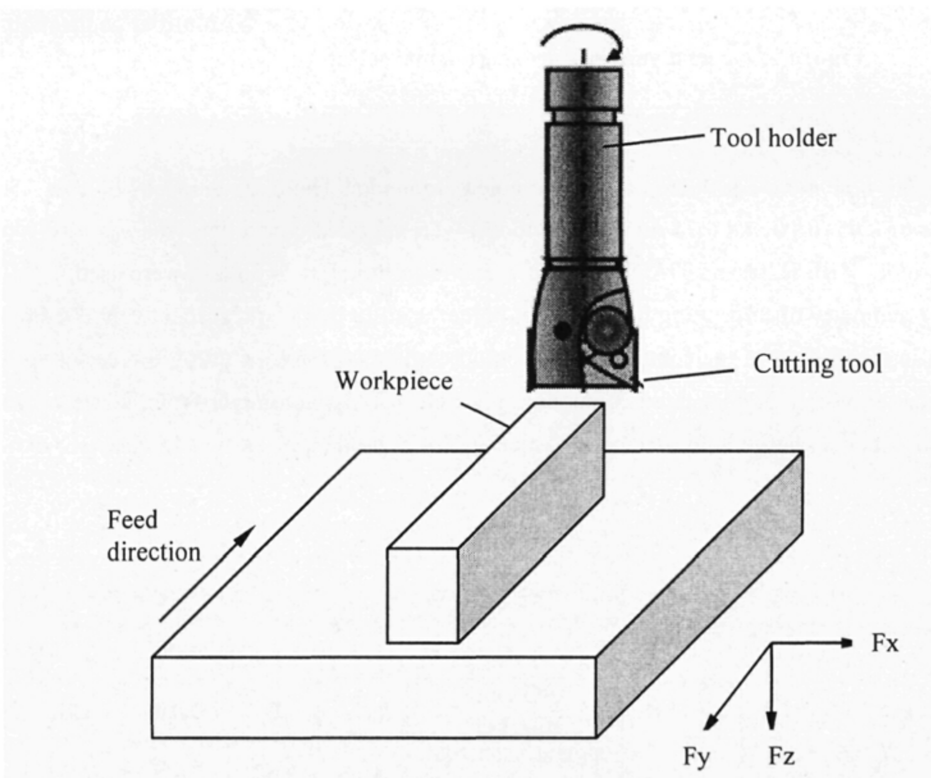


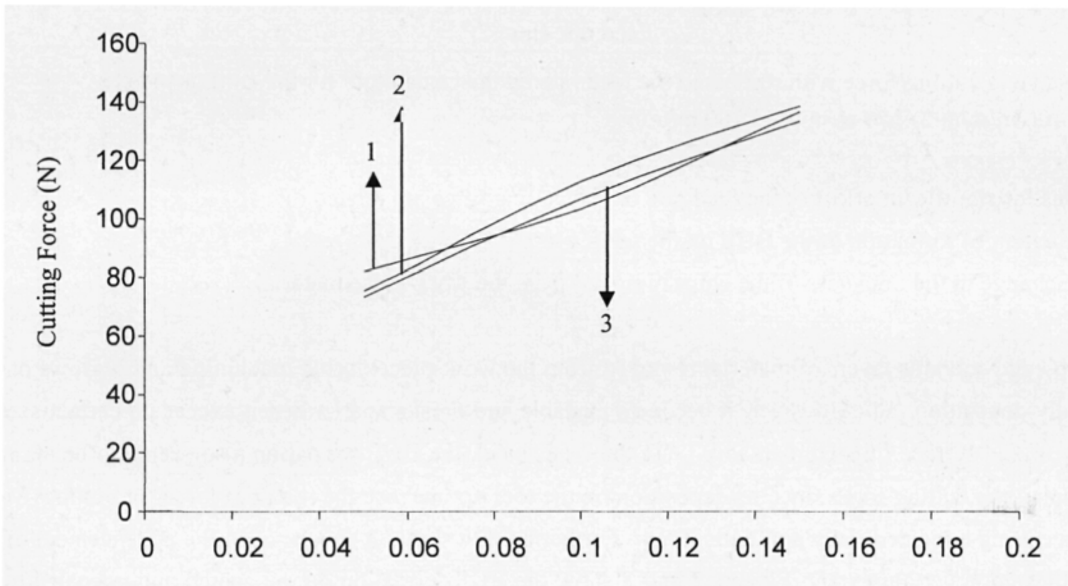
Figure 4: Schematic view of the cutting operation and components of the cutting force.

After finishing milling experiments, microscopic observations on the tools were performed with the aid of scanning electron microscopy (SEM) to analyze the formation of built-up edge (BUE) and its effect on the cutting forces.

3. RESULTS AND DISCUSSION

The cutting forces in three axis acting on the tool are illustrated in Figure 4. F_x is the instantaneous feed component (the projection of resultant cutting force in the X direction) whereas, F_y is the instantaneous normal component (the projection of resultant cutting force in the Y direction). And also F_z, the instantaneous vertical component, is the projection of resultant force in the Z direction acting on the work-piece. The main cutting force is related to the force applied in X direction so that F_x was considered as the cutting force for comparison of parameters.

Figure 5 depicts the change in the cutting force acting on the composite specimen when uncoated tool was used. One can see that cutting force increases almost linearly with increasing feed rate. It is around 82 N at the feed rate of 0.05 mm/z but it reaches ~ 137 N when the feed rate is increased to 0.15 mm/z. In addition, cutting forces have an ignorable effect on the cutting force. In other words, the cutting forces at different cutting speeds are comparable and close to each other for the same feed rates.



Feed rate (mm/z)

Figure 5: Change in cutting force with respect to the feed rate on the uncoated tool for the cutting speeds: 1) 100 m/min, 2) 150 m/min, 3) 200 m/min.

Figure 6 shows the variation in the cutting force versus feed rate at different cutting speeds for the coated tool. Again, there is a linear relationship observed between the cutting force and feed rate. The lowest cutting force is nearly 60 N and found at the feed rate of 0.05 mm/z and the cutting speed of 100 m/min, whereas the highest one is around 143 N and obtained for the feed rate of 0.15 mm/z and the cutting speed of 150 m/min. 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.

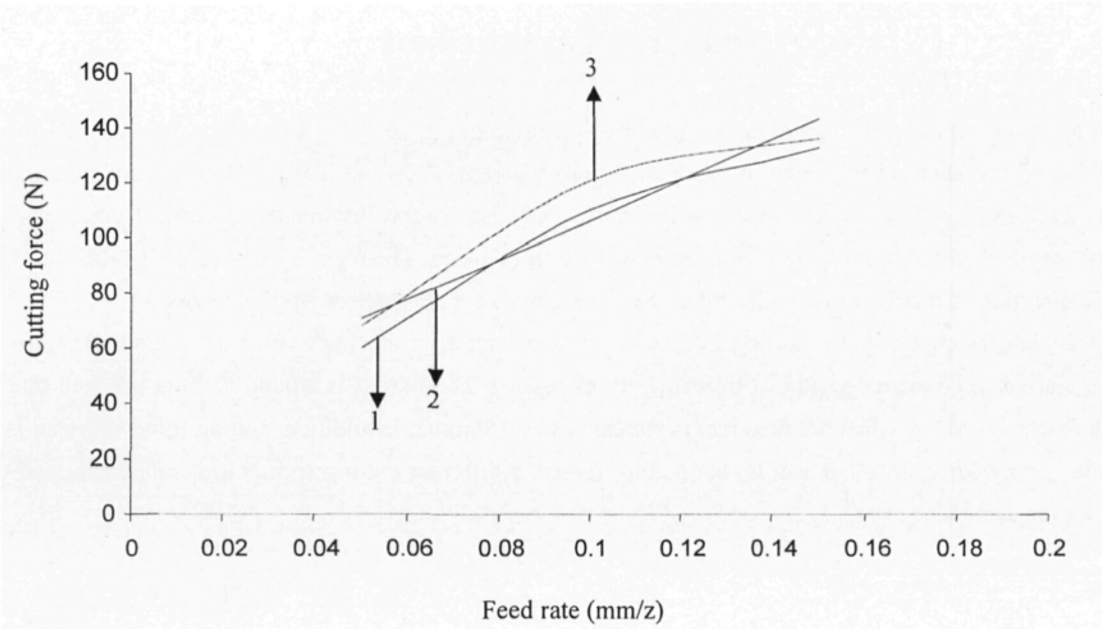


Figure 6: Change in cutting force with respect to the feed rate on the coated tool for the cutting speeds: 1) 100 m/min, 2) 150 m/min, 3) 200 m/min.

The reasons for significant effect of the feed rate on the cutting force are related to:

1. The extent of formation of the BUE on the tools.
2. The change in the thickness of the chips removed from the work-piece material.

1. Built-up edge contains layers of material removed from the work-piece during machining and it grows on the tool tip by gradually deposition /14/. However, it becomes unstable and breaks apart when it exceeds a certain size /14/. It affects tool wear and surface finish remarkably. On the other hand, the BUE formation also seems to be an important factor influencing the cutting force since its deposition on the tool tip increase the required force for cutting. Moreover, it changes the cutting edge geometry and dulls it /14/. Furthermore, it shows a resistance to the advancement of the tool on the work-piece at a certain extent. Figures 7 and 8 show the BUE formation on the coated and uncoated tools with respect to the feed rate, respectively. It can be apparently seen that the deposition and size of the BUE increases with increasing feed rate. The height of the BUE changes between 100 μm and 350 μm depending on the feed rates and cutting speeds.

2. When the feed rate is increased, the thickness of the chips removed from the work-piece material increases. Therefore, it results in the raise of the force required to cut the material. It is clear that the thicker the chips are removed, the higher the cutting force is required.

It is generally observed that type of tool has no effect on the cutting force practically. Nevertheless, its significant effect is only seen at the lowest cutting speed and feed rate considered in this study. One can derive from Figures 5 and 6 that at the cutting speed of 100 m/min and the feed rate of 0.05 mm/z the cutting force is ~ 82 N for the uncoated tool and 60 N for the coated tool. It is due to the fact that the coated tool has a lower friction coefficient than uncoated one.

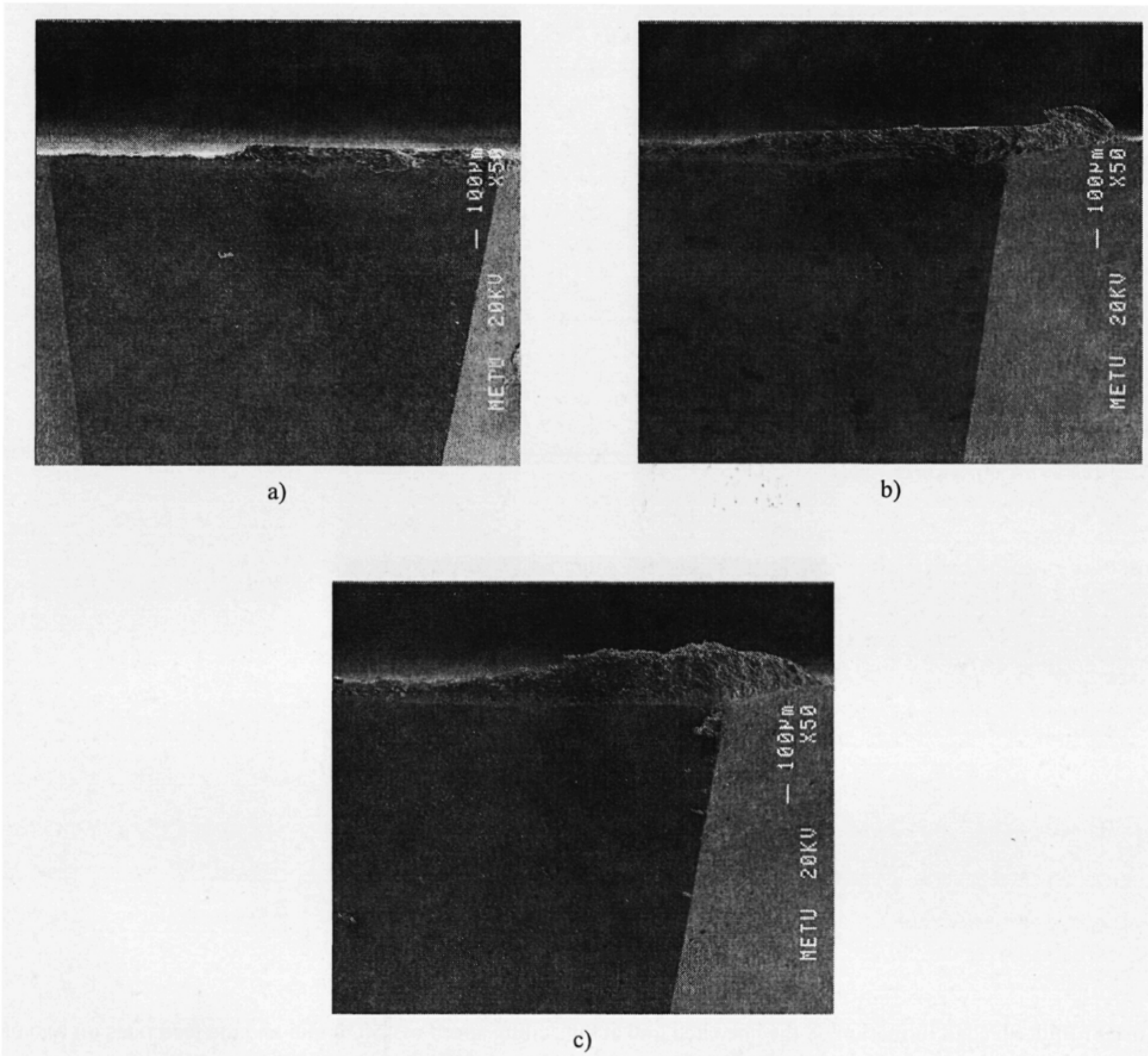


Figure 7: Micro-photos of the coated tool at the cutting speed of 200 m/min and for the feed rates of: a) 0.05 mm/z, b) 0.10 mm/z, c) 0.15 mm/z (X50).

This reduces the resistance to the advancement of the tool on the work-piece composite material. In addition, at such low cutting speed and feed rate, the BUE formation is found to be very low and its effect on the cutting force is fairly low. However, an increase in the feed rate increases the effect of both the BUE and thickness of the chips on the cutting force so that performances of the tools with respect to cutting force become closer.

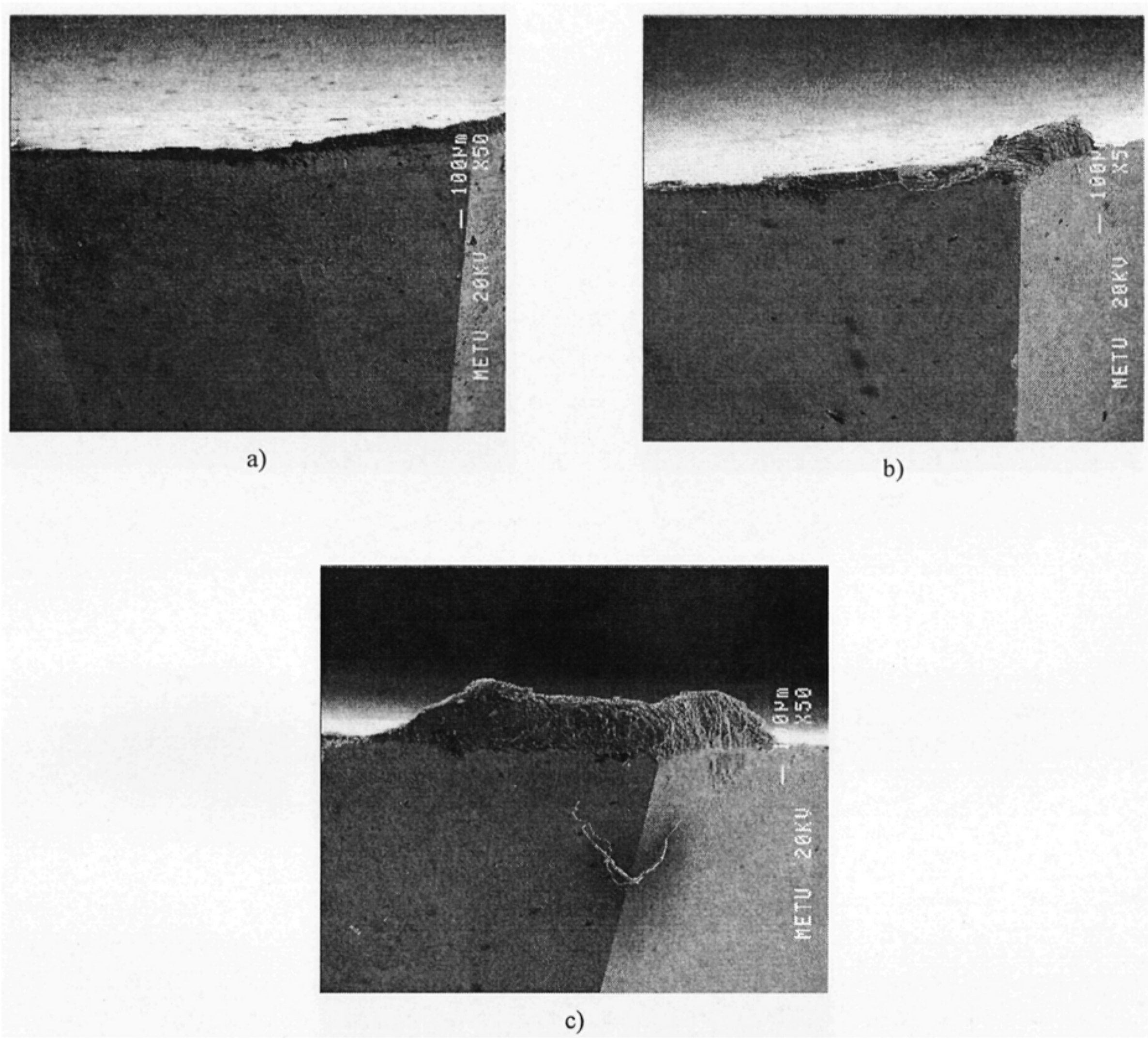


Figure 8: Built-up edge formation on the uncoated tool at the cutting speed of 150 m/min and the feed rates of: a) 0.05 m/min, b) 0.10 m/min, c) 0.15 m/min (X50).

4. CONCLUSIONS

In this study, the cutting forces in the face milling of the boron carbide reinforced aluminum composite were studied. According to the experimental data gathered, the main conclusions can be drawn as follows:

1. Cutting force was mainly affected by the feed rate. When the feed rate was increased, the cutting force increased rapidly.
2. Cutting speed had no significant effect on the cutting force.
3. Both coated and uncoated tools exhibited similar performance with respect to the cutting force except for the milling process at the cutting speed of 100 m/min and the feed rate 0.05 mm/z.

REFERENCES

1. M.J. Koczak, S.C. Khatri, J.E. Allison, M.G. Bader, Metal-Matrix composites for ground vehicle, aerospace and industrial applications, in Fundamentals of Metal-Matrix Composites, (Editors: S. Suresh, A. Mortensen, A. Needleman), 1993.
2. O. Quigley, J. Monaghan, P. O'Reilly, Factors affecting the machinability of an Al/SiC metal-matrix composite, J. Mater. Process. Technol. 43, 21-36 (1994).
3. N.P. Hung, F.Y.C. Boey, K.A. Khor, Y.S. Phua, H.F. Lee, Machinability of aluminum alloys reinforced with silicon carbide particulates, J. Mater. Process. Technol. 56, 966-77 (1996).
4. A.R. Chambers, The machinability of light alloy MMCs, Composites Part A, 27A, 143-147 (1996).
5. M. El-Gallab, M. Sklad, Machining of Al/SiC particulate metal-matrix composites Part I: Tool performance, J. Mater. Process. Technol. 83, 151-158 (1998).
6. R.T. Coelho, S. Yamada, T. leRoux, D.K. Aspinwall, M.L.H. Wise, Conventional machining of an aluminum based SiC reinforced metal matrix composite (MMC) alloy, Proc. of the 30th MATADOR, Manchester p.125-133 (1993).
7. L. Cronjager, D. Meister, Machining of fibre and particle-reinforced aluminum, Ann. CIRP 41, 63-66 (1992).
8. C.T. Lane, Machining characteristics of particulate-reinforced aluminum, in Fabrication of Particulates Reinforced Metal Composites, ASM, Ohio, USA p.195-201, (1990).
9. H. Chandrasekaran, J-O. Johansson, On the behaviour of fibre/particle reinforced aluminum alloy matrix composites in milling and grinding. 2nd Int. Conf. on Machining of Advanced Materials (MAM) Aachen Germany (1996).
10. M.S. Karakaş, A. Acır, M. Übeyli, B. Ögel, Effect of cutting speed on tool performance in milling of B4Cp reinforced aluminum metal matrix composites, J. Mater. Process. Technol. 178, 241-246 (2006).
11. M. Übeyli, M.S. Karakaş, A. Acır, B. Ögel, Study on performance of uncoated and coated tools in milling of Al-4%Cu/B4C metal matrix composites, Mater. Sci. Technol. 23(8), 945-950 (2007).
12. M. Übeyli, A. Acır, M.S. Karakaş, T. Demir, On the surface roughness of Al-4%Cu/B4C metal matrix composites machined by milling operation, Sci. Eng. Compos. Mater. 15, 131-139 (2008).
13. M. Übeyli, A. Acır, M.S. Karakaş, B. Ögel, Effect of feed rate on tool wear in milling of aluminum metal matrix composites reinforced with boron carbide, Mater. Manuf. Processes, 23, 865-870 (2008).
14. S. Kalpakjian, S.R. Schmid, Manufacturing Engineering and Technology, Fifth Edition, Pearson Prentice Hall, (2006).