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CUTTING TOOL WEAR MECHANISMS WHEN MACHINING PARTICULATE REINFORCED MMCs

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Abstract

In this study, machining tests were performed on SiC/Al metal matrix composites (MMCs) using uncoated, triple layer coated, diamond coated cemented carbides and cubic boron nitride (CBN) cutting tools at various cutting speeds under a constant feed rate and depth of cut. The MMCs were fabricated through a melt stirring-squeeze casting route and contained SiC particles of 30, 45 and 110 μm in mean sizes. The effects of reinforcement particulate size and cutting speed on tool wear mechanisms of the various cutting tools were investigated. In order to determine tool wear modes and mechanisms, the worn cutting edges were examined under the scanning electron microscope (SEM). The SEM examination revealed that tool flank wear was the dominant wear mode for all the cutting tools. In addition to abrasive wear mechanism, chipping particularly at high cutting speeds was found to be effective for uncoated and coated cemented carbide tools. Both abrasive and adhesive wear mechanisms were found to be effective for CBN and diamond coated cemented carbide cutting tools. Additionally, chipping of CBN cutting tools was observed when machining MMC material containing relatively large particles (110 μm in size).

Key Words: Machining, Tool wear mechanisms, Metal matrix composites (MMCs)

1. Introduction

The need for performance improvement in aerospace, automative and sport industries led to the development of metal matrix composites (MMCs). Due to their high specific strength and stiffness at room and elevated temperature, good creep, fatigue and wear resistance, MMCs have found wide application areas in the above industries. Especially, particulate reinfored MMCs are of particular interest since they are far much cheaper than long fiber reinforced ones and offer superior wear resistance. They also exhibit lower anisotropy than do long fiber reinforeced MMCs [1-4].

MMCs have been in use in aerospace industry since the 1970s and in automotive industry since mid 1980s. However, their full potential has not been realised yet despite their superior properties over monolithic alloys. One of the reasons for this is that their machinability still poses significant problems. The presence of hard reinforcement particles in MMCs causes rapid tool wear [5-10]. Since, MMC parts obtained by various techniques require machining operation in order to obtain the necesary dimensional and geometrical properties. A good surface finish is also essential for many engineering components [4].

Cemented carbide cutting tools, widely used in metal cutting industry, wear rapidly due to the presence of hard reinforcement particles like SiC or Al_2O_3 in particulate reinforced MMCs [4,11,12]. That is not surprising as these reinforcement particles are harder than cemented carbide tools. Therefore, cutting tools harder than reinforcement particles present in the MMCs are required to machine these materials. Although some ceramic cutting tools are harder than these reinforcement materials, they wear more rapidly than cemented carbide ones [13,14]. Polycrystalline diamond (PCD) tools are recommended for machining particulate reinforced MMCs, especially for finish machining. On the other hand, cubic boron nitride (CBN), close to diamond in hardness, was also used to machine MMCs [2,14,15]. Work carried out by Looney et al. [14] and Hung et al. [15] showed that CBN cutting tools can also be an alternative to PCD tools for

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machining particulate MMCs. However, due to the high cost of PCD and CBN cutting tools, sometimes it is also necessary to use cemented carbide cutting tools for machining particulate reinforced MMCs, especially for short runs and small number of parts.

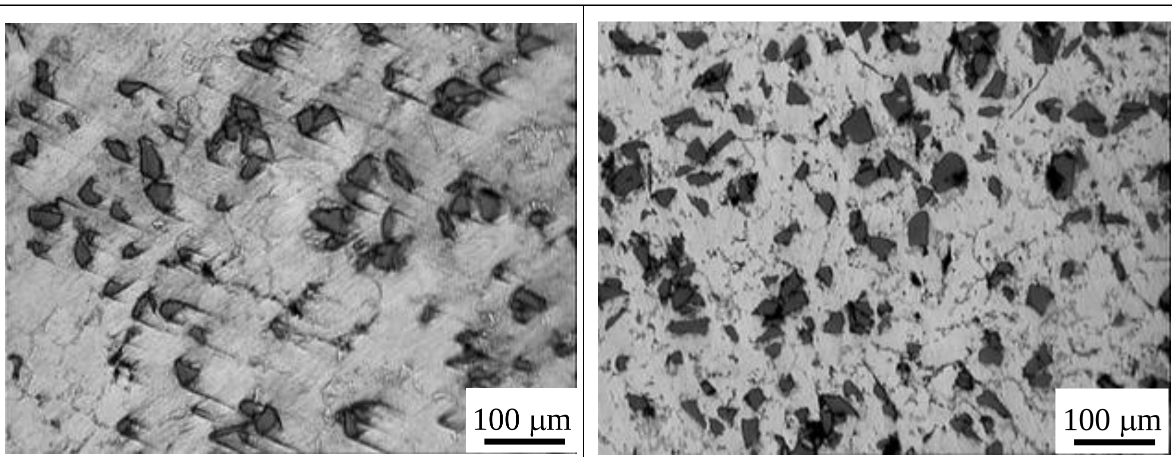
Cutting tool life is one of the most important considerations in machining. Rapid wear results in short tool life. Understanding of the nature of tool wear is essential for the tool life improvement. In this study, machining tests were carried out on particulate reinforced MMCs using various cutting tools and tool wear mode and the dominating wear mechanisms were examined.

2. Material and Method

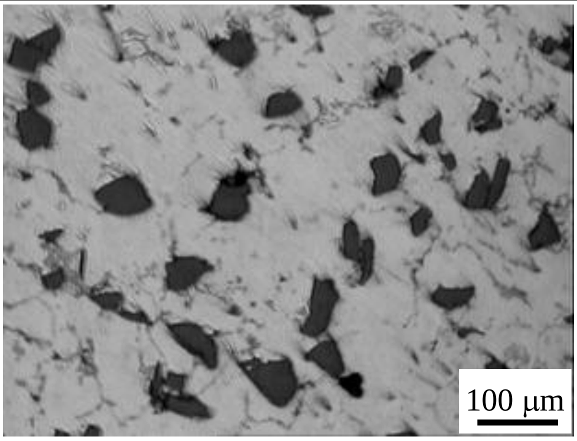
The MMCs were fabricated through a melt stirring-squeeze casting route and contained SiC particles of 30, 45 and 110 μm in mean sizes. The details of which are described elsewhere [2]. The microstructures of the MMCs with different SiC sizes are shown in Fig. 1. The matrix material was a 2014 Al alloy. The chemical composition of the matrix and the list of MMC grades fabricated are given in Table 1 and 2, respectively.

The machining tests were performed by single point continuous turning of the MMC specimens in cylindrical form. The workpiece specimens were 120 mm long and 28 mm in diameter. Coolant was not used during the tests. Tests with uncoated, triple layer coated (TiC, Al_2O_3 and TiCN) cemented carbides and cubic boron nitride (CBN) tools were carried out on a Dyna CNC lathe while tests with CVD diamond coated cemented carbide on a Johnford TC35 CNC turning centre. The uncoated, triple layer coated cemented carbides and CBN tools were commercial grade inserts produced by Mitsubishi Carbide with the geometries of SPMN 120308, SPMN 120308 and CCGW 09T308G2, respectively. The uncoated and triple layer coated carbide tools which had UC5005 and Hti10, respectively, Mitsubishi Carbide designations equivalent to K10 grade in ISO were clamped mechanically on a rigid tool holder. Its code was SSBCR-2020-K12. This resulted in a cutting geometry of 5° of side rake angle, 0° of back rake angle and 6° of side relief angle. The code of tool holder for CBN tools was SCGCR-1616-H09. This resulted in a cutting geometry with side rake angle of 0°, back rake angle of 0° and side relief angle of 7°. The CVD diamond coated tools were also commercial grade inserts with the geometry of TNMG 160408 FN-ALP-N DIA which were clamped mechanically on a CTANR-2525-M16 tool holder. All the tool holders were coded according to ISO 5608.

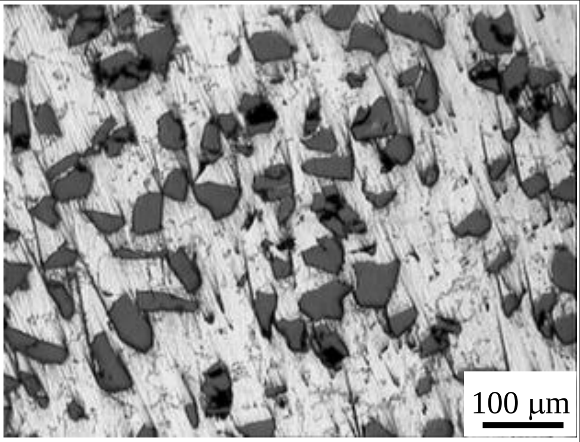
Cutting speeds used for the uncoated and triple layer coated cemented carbide tools were ranged from 20 to 80 m/min and increased in steps of 20 m/min. For the CVD diamond coated cemented carbide tools, cutting speeds were ranged from 25 to 125 and increased in steps of 25 m/min. Considerably higher cutting speeds were used for the CBN tools due to their high hardness. Cutting speeds used for CBN tools were ranged from 50 to 200 m/min and increased in steps of 50 m/min. Feed rate and depth of cut for all the tools used were kept constant at 0.12 mm/rev and 1 mm, respectively. Worn cutting tools were examined using a JOEL JSM-5600 scanning electron microscope (SEM).



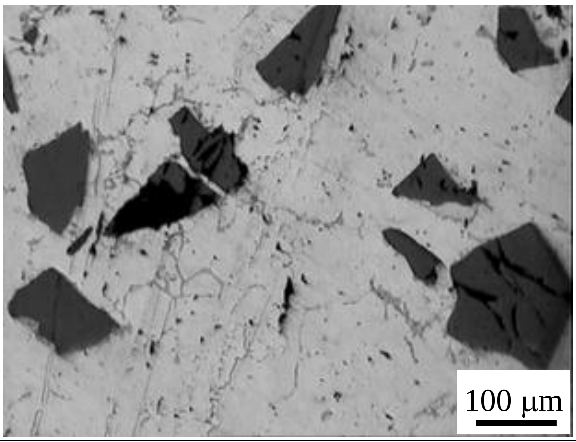
Al-SiC 8%-30 μm	Al-SiC 16%-30 μm



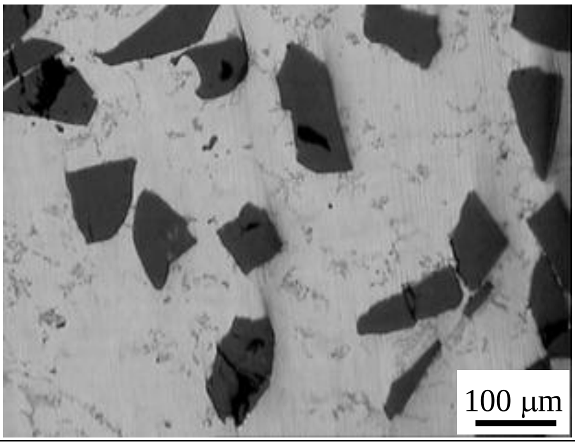
Al-SiC 8%-45 μm



Al-SiC 16%-45 μm



Al-SiC 8%-110 μm



Al-SiC 16%-110 μm

Figure 1. Microstructure of the MMCs

Table 1. Chemical composition of matrix material

	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Sn	Ti	Sb	Al
%	0.66	0.504	4.49	0.62	0.6	0.11	0.01	0.03	0.03	0.005	0.025	0.04	92.9

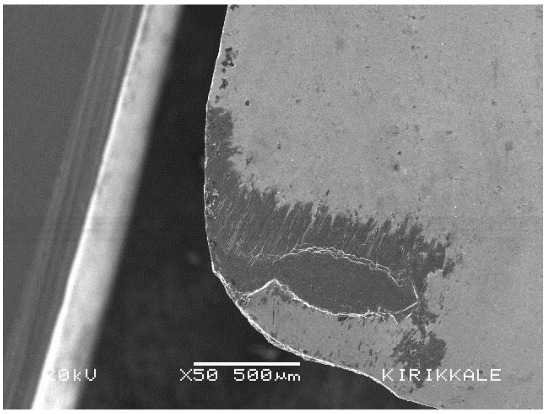
Table 2. MMCs prepared for machinability tests

Material	Grain size of SiC particles	Weight percentage of SiC particles
Al-SiC 8%-30 μm	30 μm	8
Al-SiC 16%-30 μm	30 μm	16
Al-SiC 8%-45 μm	45 μm	8
Al-SiC 16%-45 μm	45 μm	16
Al-SiC 8%-110 μm	110 μm	8
Al-SiC 16%-110 μm	110 μm	16

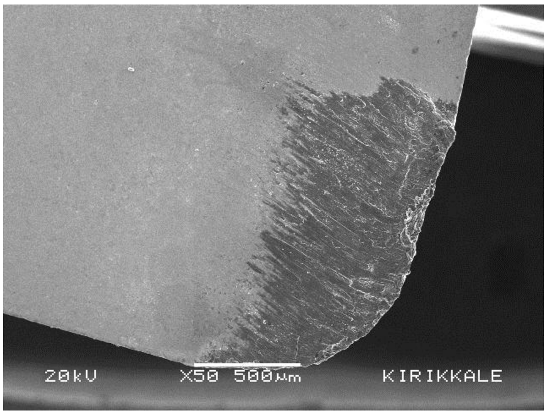
3. Result and Discussion

3.1 Uncoated and Triple Layer Coated Cemented Carbide Tools

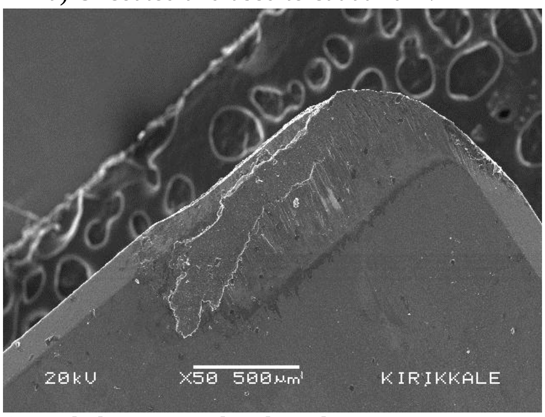
Dominant wear mode of the uncoated and triple layer coated cutting tools was found to be flank wear although negligible crater wear was also observed (Fig. 2). The SEM images in Fig. 2 show both the uncoated and triple layer coated worn tools used to machine Al-SiC 8%-45 μm MMC at 20 and 80 m/min cutting speeds. The images in Fig. 2 a) and c) belong to cutting tools used to machine the MMC at 20 m/min whereas the other images in Fig. 2 b) and d) belong to tools used to machine the MMC at 80 m/min. It can be deduced from these images that abrasive wear mechanism controlled the tool wear when machining at 20 m/min cutting speed. Abrasive wear is normally characterised by the presence of grooves parallel to the cutting direction on cutting tool flank face. Although the SEM images in this work were taken from the cutting tool rake face, the progressive wear of the cutting edge is the indication of abrasive wear. Abrasive wear of cemented carbide cutting tools in machining of particulate Al-SiC MMCs were also reported by other researchers [12,16,17]. On the other hand, significant edge chipping is shown in Fig. 2 b) and d). High cutting speed was considered to result in edge chipping. It was also reported by Paramanik et al. that [18] impact between particle and tool increases at high cutting speeds and this, in turn, induces easier fracture causing chipping at the cutting edge.



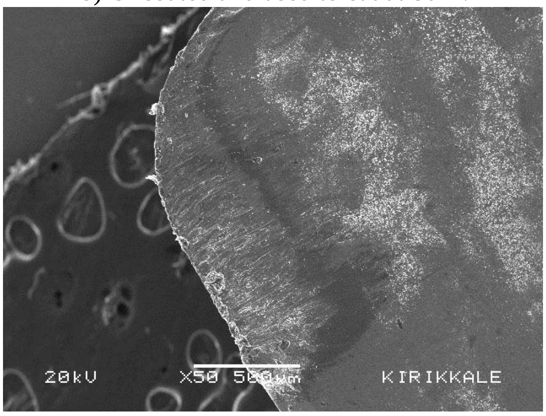
a) Uncoated and used to cut at 20 m/min



b) Uncoated and used to cut at 80 m/min



c) Triple layer coated and used to cut at 20 m/min



d) Triple layer coated and used to cut at 80 m/min

Figure 2. SEM images of the worn uncoated and triple layer coated cemented carbide tools used for machining Al-SiC 8%-45 μm MMC at 20 and 80 m/min cutting speeds [1].

Abrasive wear can be effective in two ways: two-body abrasion and three-body abrasion. Two-body abrasive wear can easily be determined from wear grooves on the cutting tool. However, three-body abrasive wear can not easily be determined. Li and Seah [17] reported the occurrence of three-body abrasion of cemented carbide tools in the machining of particulate reinforced MMCs. They stated that the scratches and craters found on the flank wear surface were the indications of three-body abrasion.

Fig. 3 shows a worn cutting tool used to machine Al-SiC 16%-30 μm MMC at 20 m/min. This SEM image was taken from the rake face of the tool and shows some SiC particles embedded into the cutting tool and fractured. The three-body abrasion is clearly seen from this image.

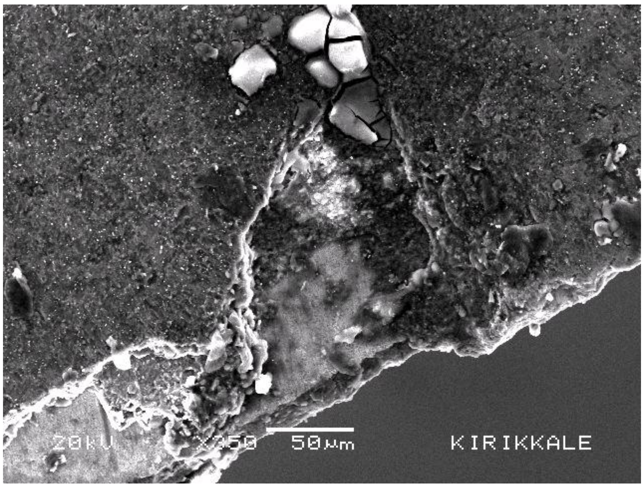


Figure 3. SEM image of the worn uncoated cemented carbide tool used for machining Al-SiC 16%-30 µm MMC at 20 m/min showing three-body abrasion

3.2 Diamond Coated Cemented Carbide Tools

SEM examinations showed that the diamond coating was completely worn away in the cutting zone. Fig. 4 shows the worn cutting tool used to machine Al-SiC 8%-30 µm MMC at 25 m/min cutting speed. From this SEM image, the dominant wear mechanisms can not be seen clearly as the workpiece material adhered to the worn area. This SEM image also shows the built-up edge (BUE) on the cutting edge. In order to observe the wear mechanisms clearly, SEM images at high magnification were also obtained. The images in Fig. 5 were obtained at high magnification for the tools used to cut Al-SiC 16%-45 µm MMC at 25 and 125 m/min cutting speeds. It is seen from these images that the dominant wear mechanisms are mainly abrasive and adhesive at low cutting speed, Fig. 5a. On the other hand, only abrasive mechanism seems dominant at high cutting speed, Fig. 5b.

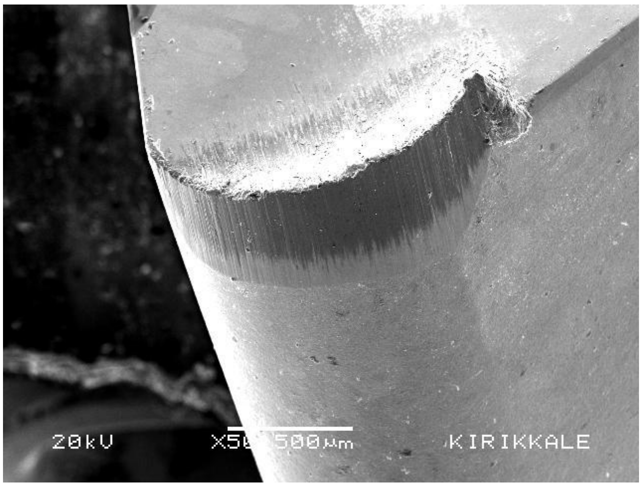
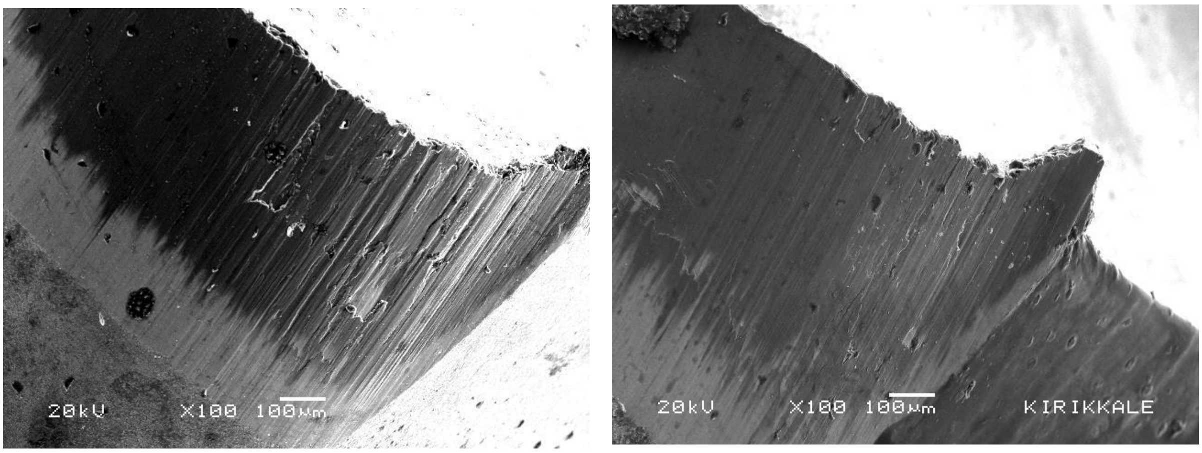


Figure 4. SEM image of the worn diamond coated cemented carbide tool used for machining Al-SiC 8%-30 µm MMC at 25 m/min.



a) b)

Figure 5. SEM images of the worn diamond coated cemented carbide tools used for machining Al-SiC 16%-45 µm MMC at a) 25 and b) 125 m/min.

3.3 Cubic Boron Nitride Tools

The cutting tools used to machine Al-SiC 16%-110 µm MMC exhibited significant amount of fracture as shown in Fig. 6. This can be attributed to the heavy impact effect of relatively large SiC particles present in the Al-SiC 16%-110 µm MMC.

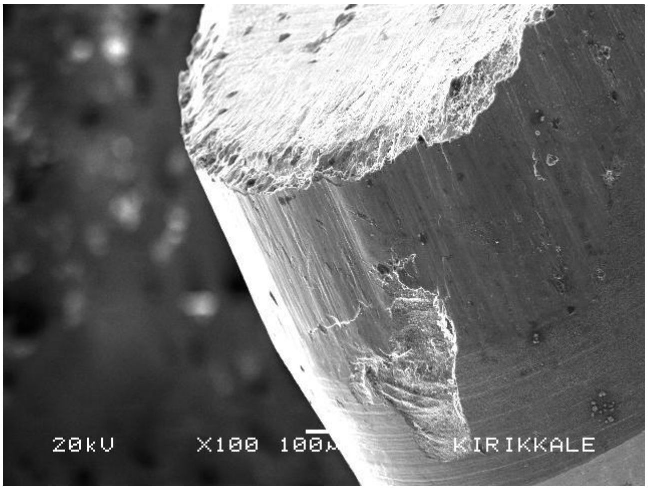


Figure 6. SEM image of the worn CBN tool used for machining Al-SiC 16%-110 µm MMC at 100 m/min [2]

For tools used to machine Al-SiC 16%-30 µm and Al-SiC 16%-45 µm MMCs, the dominant wear mechanisms could not be determined clearly as the workpiece material adhered to the cutting edges at 100 and 150 m/min cutting speed. Andrewes et al. [11] reported that when machining MMCs using PCD cutting tools, the initial flank wear starts with the abrasive effect of the hard particles and the workpiece material adheres to these abrasive grooves strongly due to the high pressure generated at the tertiary cutting zone as machining progresses. Each time, a workpiece film adheres and breaks off as a result of the hard abrasive particles present in the workpiece, small diamond particles are also removed from the PCD cutting tool surface. This cyclic process leads to progressive loss of the PCD tool material. Unlike Andrewes et al. [11], CBN cutting tools were used in this study but it was assumed that similar mechanisms controlled the tool wear during the initial stages. That is because, CBN is close to diamond in hardness and harder than the SiC particles. When the cutting speed was increased to 200 m/min, the mechanisms dominating the tool wear became clear as shown in Fig. 7. Fig. 7 shows the SEM images of tool used to machine Al-SiC 16%-45 µm MMC at 200 m/min. The bottom SEM image in Fig. 7 indicates that that abrasion and adhesion are the mechanisms dominating the tool wear [2].

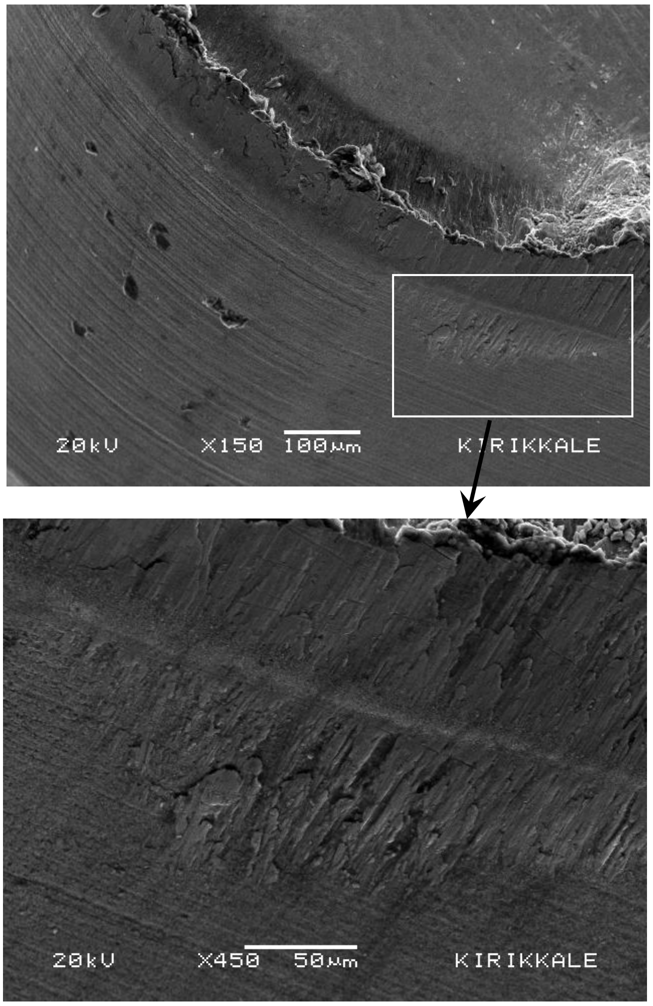


Figure 7. SEM images of the worn CBN tool used for machining Al-SiC 16%-30 μm MMC at 200 m/min [2]

4. Conclusion

Machining tests were carried out on SiC/Al metal matrix composites (MMCs) using uncoated, triple layer coated, diamond coated cemented carbides and cubic boron nitride (CBN) cutting tools. The influences of reinforcement particulate size and cutting speed on tool wear modes and mechanisms were investigated. Based on the results obtained, the following conclusions can be drawn:

- SEM investigation revealed that tool flank wear was the dominant wear mode for all the cutting tools. On the other hand, machining of the MMC containing relatively large SiC particles (110 μm) using CBN cutting tools resulted in both the cutting edge and nose fractures.
- For the uncoated and triple layer coated cemented carbide tools, abrasive wear mechanism was found to be effective at low cutting speeds and chipping at high cutting speeds. In addition to two-body abrasive wear, three-body abrasive wear mechanism was also clearly observed for the uncoated cemented carbide tool.
- For the CBN and diamond coated cemented carbide cutting tools, abrasion and adhesion were observed as the predominant wear mechanisms.

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