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A comparative study on the machinability of Mg-based composites: Cemented carbide and cubic boron nitride tools performance

Ali Asgari[1], Mohammad Sedighi[2] and Hassan Delavar[3]

Abstract

Machining of metal matrix composites (MMC) is a challenging process as they are difficult to cut and cutting tools get worn out in a short time. In this paper, the performance of two industrial carbide grades and a cubic boron nitride (CBN) tool are assessed when machining of AZ91/SiC composites. Mg-based composites with different volume fractions and particle sizes are machined at various cutting conditions to evaluate the tools wear resistance and finished surface. The surface of the worn-out tools and machined samples are analyzed by scanning electron microscope (SEM), energy-dispersive X-ray spectroscopy (EDS), and roughness tester. Results revealed that the tool wear increased for composites reinforced by smaller particles regardless of the tool type. Additionally, tool grade TH1000 resulted in longer tool life when machining of Mg-based composites compared to the CP500 grade so that at a cutting speed of 70 m/min and feed rate of 0.1 mm/rev, tool life improved nearly 250%. CBN tools showed the best performance when machining of Mg-based composites as tools became worn out after 255 s which is considerable compared to carbide tools. Also, the finished surface caused by cemented carbide CP500 indicated the worst quality.

Keywords

Metal matric composites, machining, cemented carbide, cubic boron nitride, wear, roughness

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Introduction

Metal matrix composites MMCs have received considerable attention among industries and researchers due to having special features like a high strength-to-weight ratio, excellent mechanical properties, and resistance to wear and creep.[1–3] Among the MMCs, Mg-based composites could find a special position as they are light enough to be used in some industries such as automotive, medical, and sports applications.[4–6] Magnesuim is a soft material and is machined easily and only some surface integrity concerns are observed,[7,8] but adding hard ceramic reinforcement particles such as SiC, Al_2O_3, B_4C, etc. makes MMCs too hard, thus including them in the category of difficult-to-cut materials, meaning tool wear occurs shortly.[9–11] Machining technologies and machinability of materials have been paid attention to by researchers in recent years.[12,13] For the case of MMCs, numerous studies have already been published by researchers.[14–17] Boswell et al.[18] investigated the effects of machining parameters such as cutting speed, feed rate, and depth of cut on the surface features of the metal matrix composite under dry cutting conditions. They used a carbide insert for the cutting analysis. The minimum surface roughness was obtained at feed rate 0.30 mm/rev, depth of cut 1.0 mm, and cutting speed 100 m/min.[18] Niu and Cheng[19] pointed out the dynamic cutting force gets affected by the feed rate directly when micro drilling of Al2024/SiC/45p composite, but cutting speed is not influential as such. Chambers[20] investigated the machinability of

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Al-based composites reinforced with 5% Safill and 15% SiC particles, suggesting that K10 cemented carbide inserts are not proper as they were worn out shortly. Suresh et al.[21] presented a study to optimize the machining parameters when turning of Al-SiC-Gr hybrid metal matrix composites using grey-fuzzy algorithm. They used tungsten carbide tool insert TNMG 120408 for the experiment. The best surface roughness and minimum tool's flank wear was obtained in the composite containing 10% SiC-Gr with the turning conditions of cutting speed of 200 m/min, and feed rate of 0.075 mm/r at a constant depth of cut of 1 mm. Arokiadass et al.[22] evaluated the machining characteristics of LM25 Al/SiCp composite when end milling process. They used statistical approaches to optimize the flank wear. Manna and Bhattacharayya[23] showed that the temperature and built-up edge (BUE) cause tool wear when machining the Al/SiCp15% at high cutting speeds. Kılıckap et al.[24] conducted a comparative study on flank wear of TiN coated and uncoated cemented carbide tools during turning Al metal matrix composites containing 5% SiC particles. According to their research, the cutting speed was the most important factor, influencing the tool wear performance. Moreover, as compared to the uncoated ones, the TiN-coated cutting tools showed better performance which then resulted in a finished surface of workpiece. Sahin[25] studied the flank wear behavior of various multi-layer coated cemented carbide tools during machining the Al-based composite reinforced with 10 and 20 vol% SiC reinforcements. It was shown that the presence of TiN as a top layer of multi-layer coated on carbide tools results in the best performance. Moreover, by increasing the content of particles, the cutting time decreased substantially. Ozben et al.[26] assessed machinability of Al-based MMC with different SiC particle volume fractions of 5%, 10%, and 15%. It was depicted that enhancement of the volume fraction of reinforcements significantly decreased the tool life due to the presence of hard ceramic particles. Also, Sibel Tinga et al. observed severe tool wear in the machining of the composite containing even low volume fraction of reinforcements 3% B4C. They additionally reported that increase in cutting speed improved the surface quality.[27] Kannan and Kishawy[28] pointed out that at higher cutting speeds, the effect of coolant on the tool life was more significant as compared to the lower cutting speed when machining A356/SiCp composites with 20% reinforcement. It was suggested that at lower cutting speeds, mechanical wear mechanisms and the lack of formation of a lubricating film decrease the friction between the cutting tool and the abrasive reinforcements, hence accelerating tool wear.[28] Bhushan et al.[29] investigated the influence of both feed rate and cutting speed on tool wear and surface roughness of machined 7075 Al alloy SiC composite using carbide inserts. It was recommended that cutting speed and feed rate should be within the range of 180–220 m/min, and 0.1–0.3 mm/rev, respectively to achieve an optimum surface roughness. Also, in order to accomplish minimum flank wear, machining should be conducted at feed rate of 0.1 and cutting speed of less than 200 m/min. Davim and Baptista[30] investigated the correlation between the cutting force and tool wear during drilling and turning of an A356/ SiCp 20vol% composites using PCD tools. The main wear mechanism was shown to be abrasion while adhesion was believed to have secondary effects. Bushlya et al.[31] studied the wear mechanisms of CBN and PCD tools when machining of the Al-20 vol% SiCp composite. They argued that the built-up layer formed on tool surfaces would protect the diamond and CBN grains in the tool material against both diffusional and abrasive wear. Liu and Zong[32] predicted PCD wear volume during machining an Al/ 45vol% SiCp composite. The grades containing fine diamond grains showed less wear resistance and tool life during the cutting process. El-Gallab and Sklad[33] investigated the tool performance during machining of an Al/ SiCp20% composite. They pointed out that grooves and micro-cutting are the main causes of wear in machining of MMCs. Muthukrishnan et al.[34] observed severe wear on the primary and secondary flank surfaces at high cutting speeds when machining an Al/ SiCp10% using PCD tools. Pedersen and Ramulu[35] mentioned that abrasive SiC particles made the TiCN/ TiN coatings worn away during the facing of ZK60A/ SiCp20% in a short machining distance. They pointed out that SiC particles were not met fracture during machining and applied a severe abrasion on the flank face. Bai et al.[36] assessed the influence of ultra-sonic in machining of Al-based composites reinforced with 25 vol.% SiCp particles to evaluate how they affect the surface quality. Dabade et al.[37] studied the surface quality of machined Al/SiCp composite for volume fractions 10% and 30% to analyze the quality of the surface affected by defects like pits, smeared materials, and porosity. Xiong et al.[38] analyzed the surface quality of a machined Al-based composite reinforced by TiB_2 particles and they found different defects such as micro cracks, matrix tearing, and voids. Szalóki et al.[39] observed BUE formation reduces the surface quality when machining of aluminum-based composites reinforced by SiC fibers.

Although many studies have been published on the machining of metal matrix composites, there are very limited studies in the case of Mg-based composites. For instance, Pedersen and Ramulu[35] used TiCN/TiN coated carbide cutting tools to evaluate the tool wear characteristic when machining of SiCp/ZK60A composite. They mentioned abrasion wear as the primary wear mechanism in the machining process. Teng et al.[40] investigated the micro drilling of a nanoparticle-reinforced Mg-based MMC with a 2-flutes AlTiN-coated tungsten carbide. They observed tool corner fracture and chip adhesion on the cutting edge during the machining. Weinert and Lange[41] pointed out approximately the same tool life for cemented carbide tools and TiAlN-Coating tools when drilling of AZ91

Table 1. Chemical composition of AZ91, as matrix materials.

Mg	Ni	Zn	Al	Mn	Cu	Fe	Si
Base	0.0008	0.80	8.73	0.20	0.0017	0.001	0.017

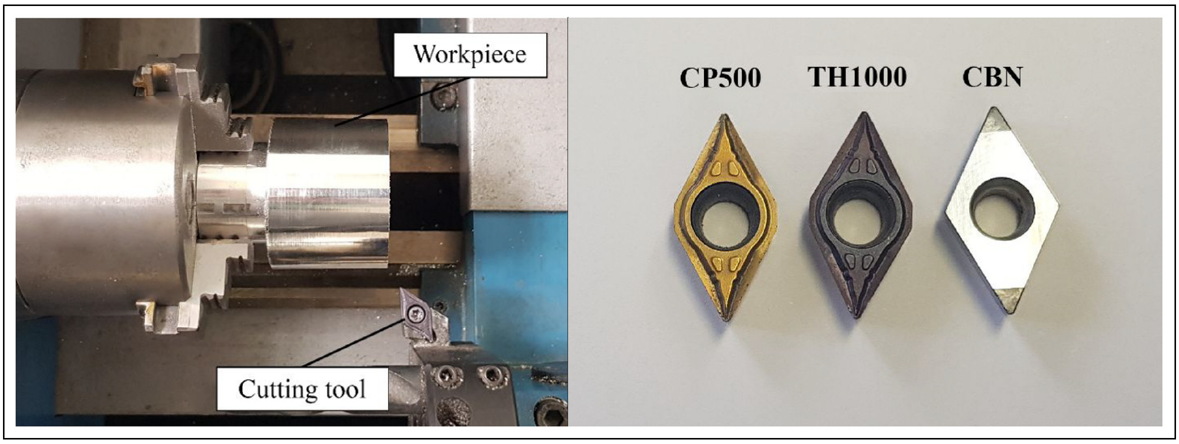

Figure 1. Machining set-up when cutting of Mg-based composites.

composite reinforced with Al_2O_3-Vol.5% and SiC-Vol. 15%. Given, there is a big gap in the machining of Mg-based composites and tools performance that should be bridged. Asgari and Sedighi[42] optimized machinability of AZ91/SiC composites by considering effects of cutting speed and feed rate. Asgari and Sedighi[43] analyzed surface integrity of machined Mg-based composites with respect to surface and subsurface defects with 3D surface topography, SEM images, and EDS analyses. According to the published papers, no study has specifically focused on the comparative study of cemented carbide and CBN tools performance in Mg-based composites machining in which combination of machining parameters, composite reinforcement size, and volume fraction effects are taken into consideration.

In this research, the performance of CBN and two cemented carbide tools CP500 and TH1000 when machining of AZ91/SiC composites are compared. Workpieces with different reinforcement volume fractions and particle sizes are utilized. Also, machining parameters such as cutting speed and feed rate effects on the tool life are taken into consideration to study how they affect the tools performance and surface quality. Tool wear and mechanisms are evaluated through SEM and EDS analyses. Furthermore, surface quality of the machined composites are assessed using roughness measurement.

Experimental procedure

A stir casting technique is employed to fabricate the Mg-based composite workpieces containing different volume fractions of 2.5% and 5%. At first, AZ91 with the chemical composition shown in Table 1 is melted at 730°C. Then the furnace is switched off and a mechanical stirrer is applied for 10 min to mix the molten magnesium containing SiC particles with different size of 45 and 9 μm. This process is continued until the temperature of 640°C. Hereafter, the molten and SiC particles are stirred magnetically for about 3 min while the mechanical stirrer is switched off, to further improve distribution of SiC particles within the semi-solid molten, then the mixed material was cooled down to reach room temperature.[44] Eventually, all specimens fabricated by stir-casting are machined cylindrically to reach dimensions 50 mm in diameter and 70 mm in length, respectively.

Addition of SiC particles into AZ91 magnesium alloy improved mechanical properties of the material such as yield and ultimate stresses. Also, hardness of materials enhanced through composite fabrication, compared to the magnesium alloy.[44]

To assess the machinability of the composites, a CNC turning machine was utilized. CBN and Cemented carbide inserts DCMT11T304-F1 with grades TH1000 and CP500 are used for the longitudinal turning. For all experiments, the depth of cut is considered equal to 1 mm when machining. Also, the machining process was paused every 5 s to measure the flank wear V_B of the tools. The process was continued until the V_B equal to 200 μm was observed. The machining set-up including the composite workpiece and cutting tools are shown in Figure 1.

As here the effect of machining parameters is assessed, first a design of the experiment is done to reduce the number of experiments. Table 2 presents the number of experiments and the cutting conditions.

Table 2. Design of experiments for machining of AZ91/SiC composites.

Number	Coating type	Vol. (%)	Particle size (μm)	V (m/min)	f (mm/rev)	a_p (mm)
1	TH1000	2.5	9	30	0.05	1
2	TH1000	2.5	9	70	0.05	1
3	TH1000	2.5	9	70	0.1	1
4	CP500	2.5	9	30	0.05	1
5	CP500	2.5	9	70	0.05	1
6	CP500	2.5	9	70	0.1	1
7	CP500	5	9	30	0.05	1
8	CP500	5	9	70	0.05	1
9	CP500	5	9	70	0.1	1
10	CP500	5	45	30	0.05	1
11	CP500	5	45	70	0.05	1
12	CP500	5	45	70	0.1	1
13	CBN	2.5	9	70	0.1	1
14	CBN	2.5	45	70	0.1	1
15	CBN	5	45	70	0.1	1

For each cutting condition, the machining process is accomplished and tool wear is measured by an optical microscope. The machining process is stopped once tool wear reaches 0.2 mm as finishing process is concerned.[42] In order to evaluate the tool's performance, a scanning electron microscope (SEM), TESCAN VEGA//XMU, equipped with Energy-dispersive X-ray spectroscopy (EDS) is utilized. The surface roughness of the specimens was measured by roughness tester SURFAESCAN and its profilometer moved a distance of 4.8 mm with a constant speed of 0.3 mm/s. Figure 2 represent the flow diagram of this study.

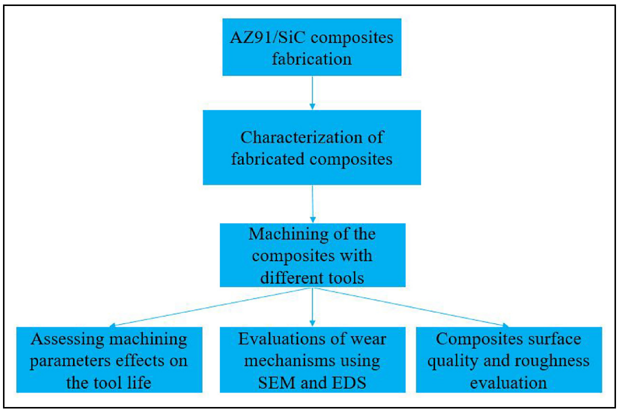

Figure 2. Flow chart representing the steps of current study.

Results and discussion

In this section, the performance of CBN and carbide tools are evaluated when machining of composites by considering the machining parameters such as cutting speed and feed rate. Also, the effects of reinforcement volume fraction and size on tool wear are assessed. Finally, the tool wear is analyzed using EDs and SEM images.

Effect of composite and machining parameters on tool life

As AZ91/SiC composites were fabricated by a stir casting process in which the entire materials were mixed at temperatures around the melting point, according to the equation (1), SiC particles react with the matrix and new phases are formed[45]:

$$\begin{aligned} 4Al + 3SiC &\rightarrow Al_4C_3 + 3Si \\ Si + 2Mg &\rightarrow Mg_2Si \end{aligned} \tag{1}$$

Microstructure of the Mg-based composites-vol. 5% along with the elements are shown in Figure 3. Here one can see how SiCs and Mg_2Si are distributed in the composites. These hard phases can wear the machining tools in a short time as will be discussed later.

In the case of composites, particle volume fraction is one of the most important parameters of cutting MMCs when tool life is concerned. Increasing the amount of reinforcements leads to more wear on the tool faces which even can result in breakage of tools. Figure 4 shows the effect of volume fraction on the tool wear. As can be seen from the figure, wear rate for the composites with high value of reinforcements increase. The more reinforcements within the composite, the more contact happens between the tool surface and SiC particles which are very hard compared to matrix materials, so the surface of tool will be worn out in a short time. Additionally, the composites containing further ceramic particles increase the formation chance of intermetallic hard phases like Mg_2Si throughout the composite, further accelerating the tool wear.

Also, as shown in Figure 4, increasing the cutting speed leads to a higher wear rate which is a result of more contact between the tool and the workpiece. As wear during machining of MMCs, in particular AZ91/SiC, resulted from the hard parts, the time that inserts

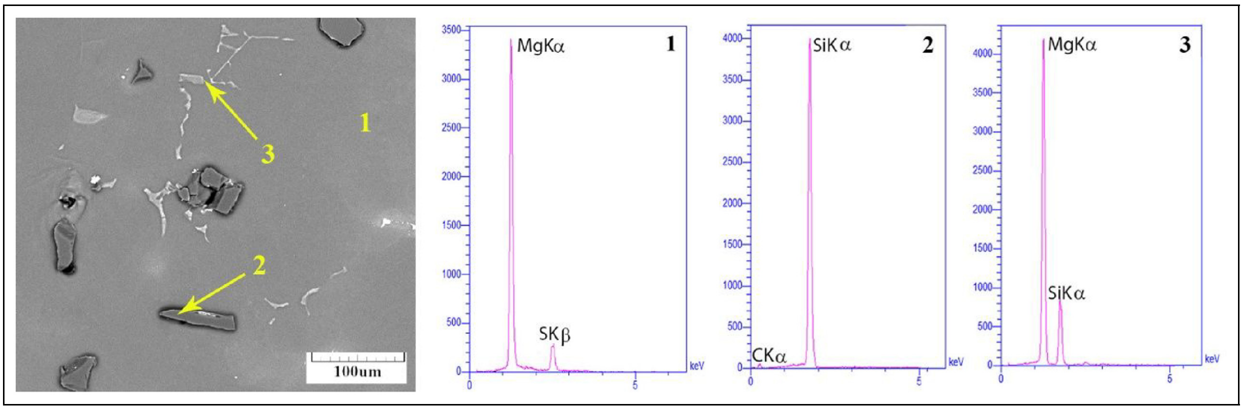

Figure 3. Microstructure of AZ91/SiC composites-vol. 5% and its most important elements.

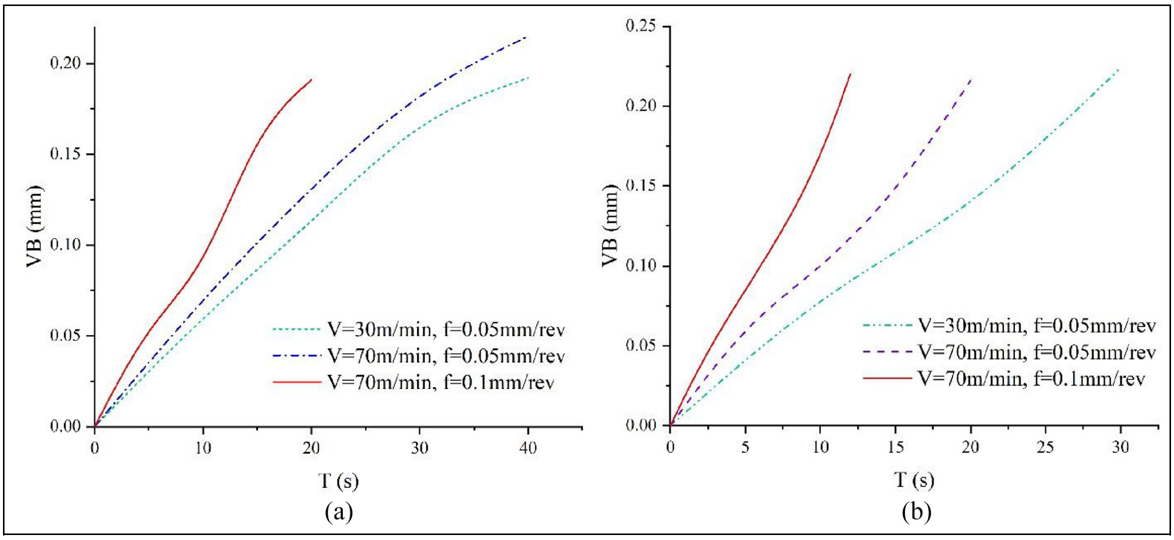

Figure 4. Effect of volume fraction on the tool life when machining of AZ91/SiC with particle size of 9 μm and different volume fractions: (a) 2.5% and (b) 5%.

contact with samples is important since it somehow defines the times' particles scratch the surface of the tool. Increasing the feed rate generally leads to higher forces and consequently higher wear rates.

As mentioned earlier, two carbides with different coatings are considered to evaluate the effect of coating on the tool life when machining of AZ91/SiC composites. According to the results shown in Figure 5, using inserts with grade TH1000 results in better tool life. For instance, in the worst cutting condition, in the eyes of tool wear, inserts with grade TH1000 enhance the tool life by about 250%. It should be mentioned that at both low cutting speed and feed rate, tools with different grades show nearly the same performance.

Particle size also affects the tool's life directly. In other words, when particles become small, for a certain volume fraction, the number of particles increases, meaning that tool has this chance to meet SiC particles many times, so the tool will be worn out easily and in a short time. As can be seen from Figure 6, machined samples with the smaller size of reinforcements do not show a significant difference. It can be attributed to the sharp corner of SiC particles. As a matter of fact, sharp edges play the most important factor in wear when machining, and reducing the particle size does not guarantee the smoothing of the edges and corners. At the highest cutting speed and feed rate, CP500 grades show better performance (35%) when machining of composites with reinforcement size of 45 μm compared to the machining of composites with smaller particle sizes (9 μm).

As shown in the previous figures, carbide tools do resist the wear caused by MMC machining only for a short time. CBN tools work better compared with the carbide ones in terms of tool wear. Figure 7 illustrates the flank wear of a CBN tool. In machining of AZ91/SiC composite reinforced with 5% volume fraction of SiC particles with 9 μm size, reaching flank wear 200 μm at the highest cutting speed and feed rates takes around 240 s. Other MMCs such as volume fraction

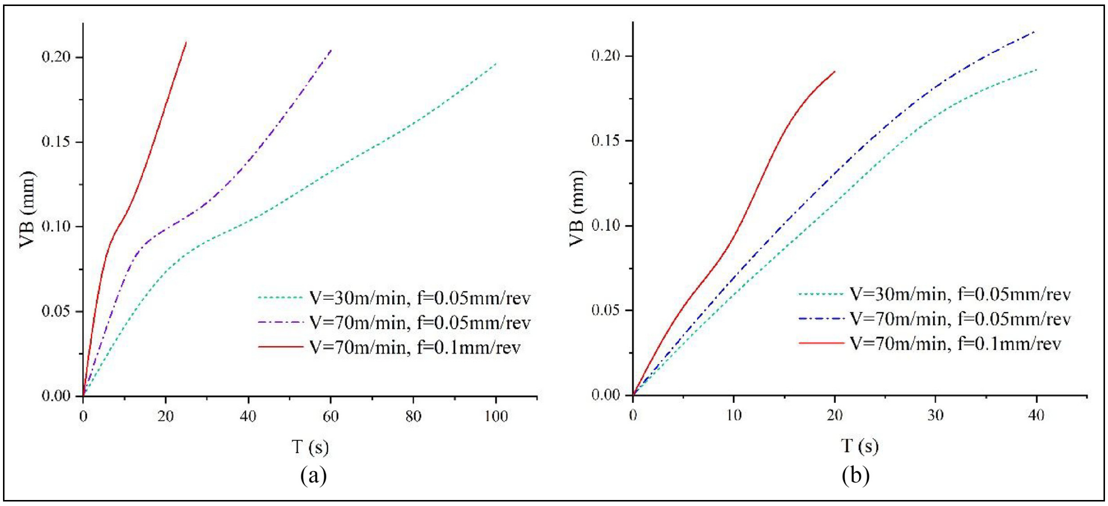

Figure 5. Effect of coating type on the tool life when machining of AZ/SiC composite with particle size of 9 μm: (a) TH1000 and (b) CP500.

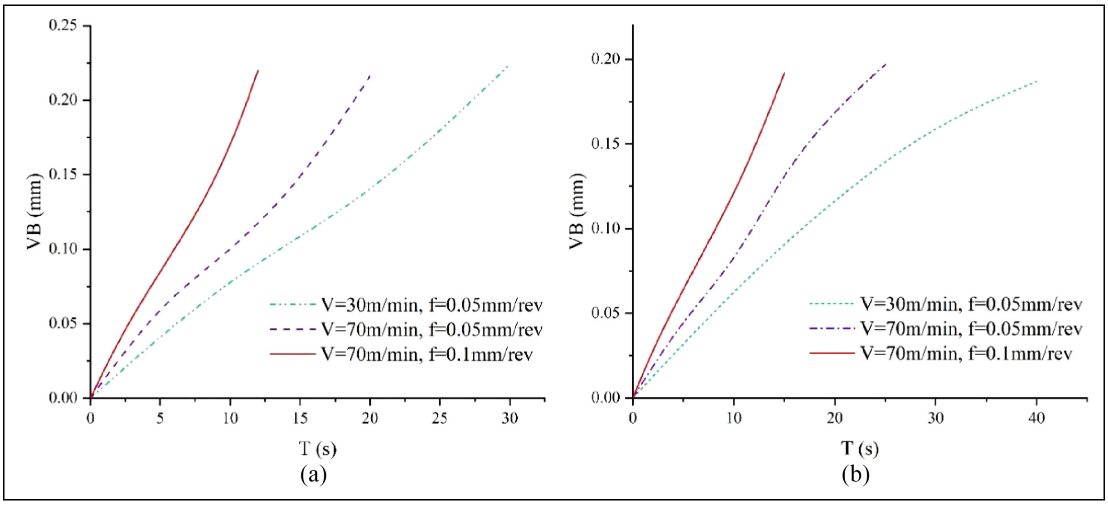

Figure 6. Effect of particle size on the tool life of CP500: (a) 9 μm and (b) 45 μm.

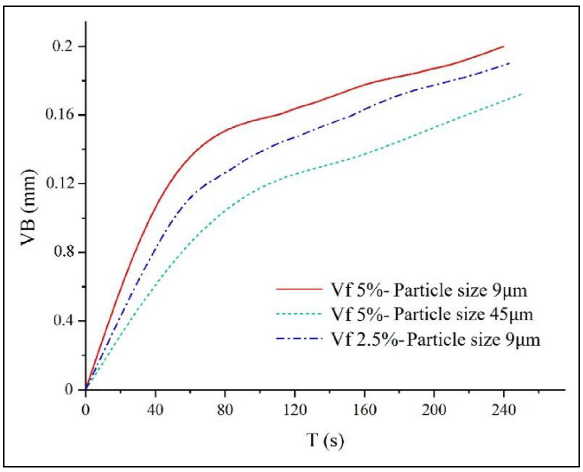

Figure 7. CBN tool life when machining of AZ91/SiC composites at the highest cutting condition, cutting speed 70 m/min and feed rate 0.1 mm/rev.

5% with 45 μm and 2.5% with 9 μm showed longer tool life. Comparing the tool wear in CBN inserts with carbide tools indicates that reaching flank wear 200 μm in CBNs lasts at least 12 times more than carbides. Also, the results showed that reduction of particle size from 45 to 9 μm has more effect on the tool life compared reduction of volume from 5% to 2.5%.

Wear mechanism

Metal matrix composites contain ceramic particles which are very hard and abrasive so that they grind the tools in a short time. Here one can see how SiC particles wear the surface of tools. In order to analyze the tool wear mechanisms when the machining of Mg-based composites, SEM images of the samples are utilized. Figure 8 shows SEM results for two cemented carbides with different coatings. According to the figure, close to the cutting tool edge, there are severe

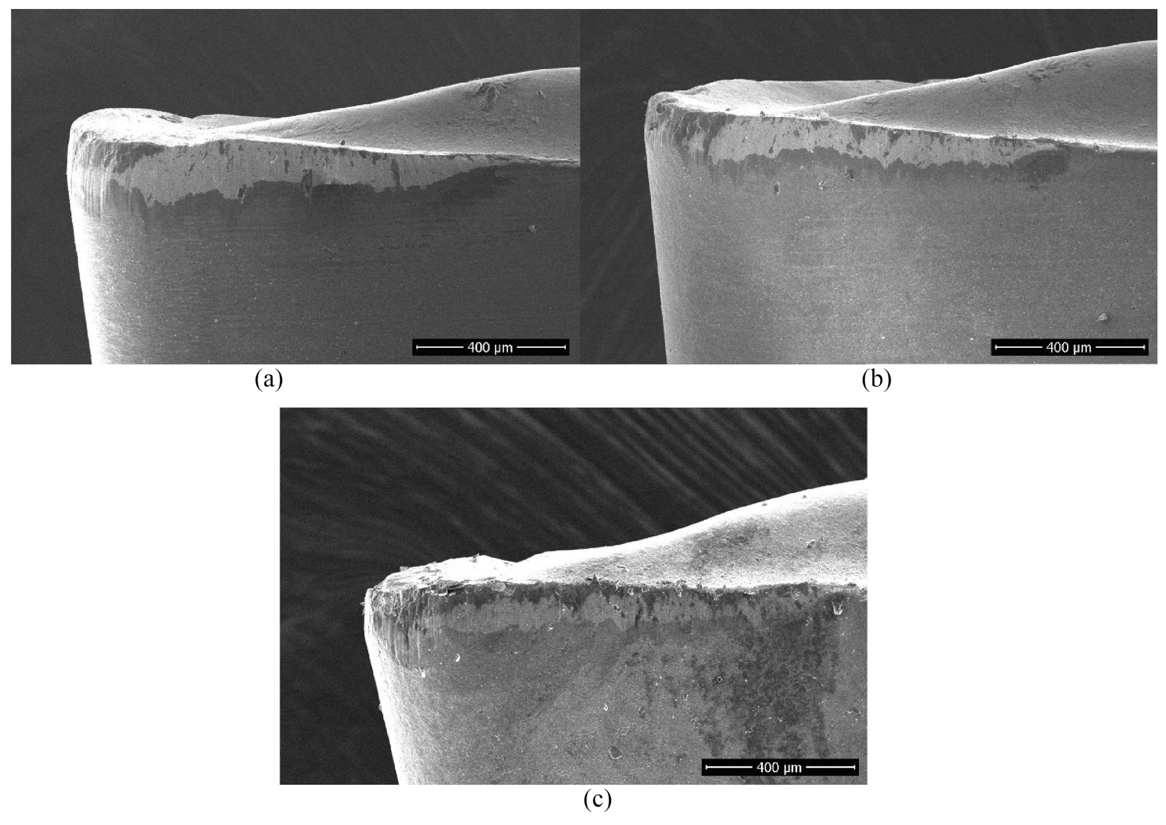

Figure 8. SEM images of the wear on the tool surface when machining at cutting speed 30 m/min and feed rate 0.05 mm/rev: (a) tool grade TH1000 and AZ91/SiC-5%vol with the particle size of 9 μm and (b) tool grade CP500 and AZ91/SiC-5%vol with the particle size of 45 μm, and (c) tool grade CP500 and AZ91/SiC-5%vol with the particle size of 9 μm.

abrasion marks showing wear owing to the contact of SiC particles and tool surface. Additionally, tool grade CP500 when machining of the composites containing SiC-5% with 9 μm particle size results in more adhered composite material on the edge compared to composite containing SiC with the particle size of 45 μm.

Figure 9 shows the SEM images of tool wear with high magnification. As shown in the figure, SiC particles included in the composites wear the flank surface by scratching and making some grooves. Regarding the figure, comparing Figure 9(a) with (b), composites with greater particle size impose harsh grooves onto the surface, but generally further contacts when machining of composites reinforced by small particles lead to a higher wear rate as seen in Figure 6. Hence, composite workpieces act like a grinder on the coating and tungsten carbide and the tool life decreases drastically. Also, according to Figure 8(a), SiC particles severely wear the edge of the tool and change its geometry when chips move on the rake face during the machining process.

Figure 10 shows SEM images of the tool rake face. As can be observed from the picture, machining with CP500 results in build-up edge formation. Although build-up edge can save the tool surface from being worn out, but in general, high resistance-to-wear of grade TH1000 results in better tool life compared to grade CP500, confirmed in Figure 5.

Magnesium composite, coating, and tungsten carbide materials are differentiated by elemental analysis in Figure 11 to characterize flank wear. According to the figure, AZ91/SiC composite materials are adhered on the flank face. Here abrasion marks caused by SiC particles can be seen clearly. Also at point 3, some magnesium is detected on the coatings, but as the process is assumed temperature-independent, abrasion is likely the predominant wear mechanism.

To analyze the wear on the flank face of the inserts, EDS maps are presented in Figure 12. In the figure, different colors show different elements. As can be seen, tool grade TH1000 has a coating layer including element Si. Also, the first layer contains Ti and Al. Compared to the TH1000 grade, grade CP500 does not have Si on the second layer. Additionally, tool grade CP500 contains more Ti in the first coating compared to TH1000. Magnesium-based composites adhered to the most part of the tool edge when the composite is machined by CP500.

Similar to the wear mechanisms on the carbide tools, abrasive wear on the flank surface of CBN tools are seen. Figure 13 shows how SiC particles make the CBN tools surface worn out. As seen apparently, grooves resulted by very hard SiC particles emerged on the

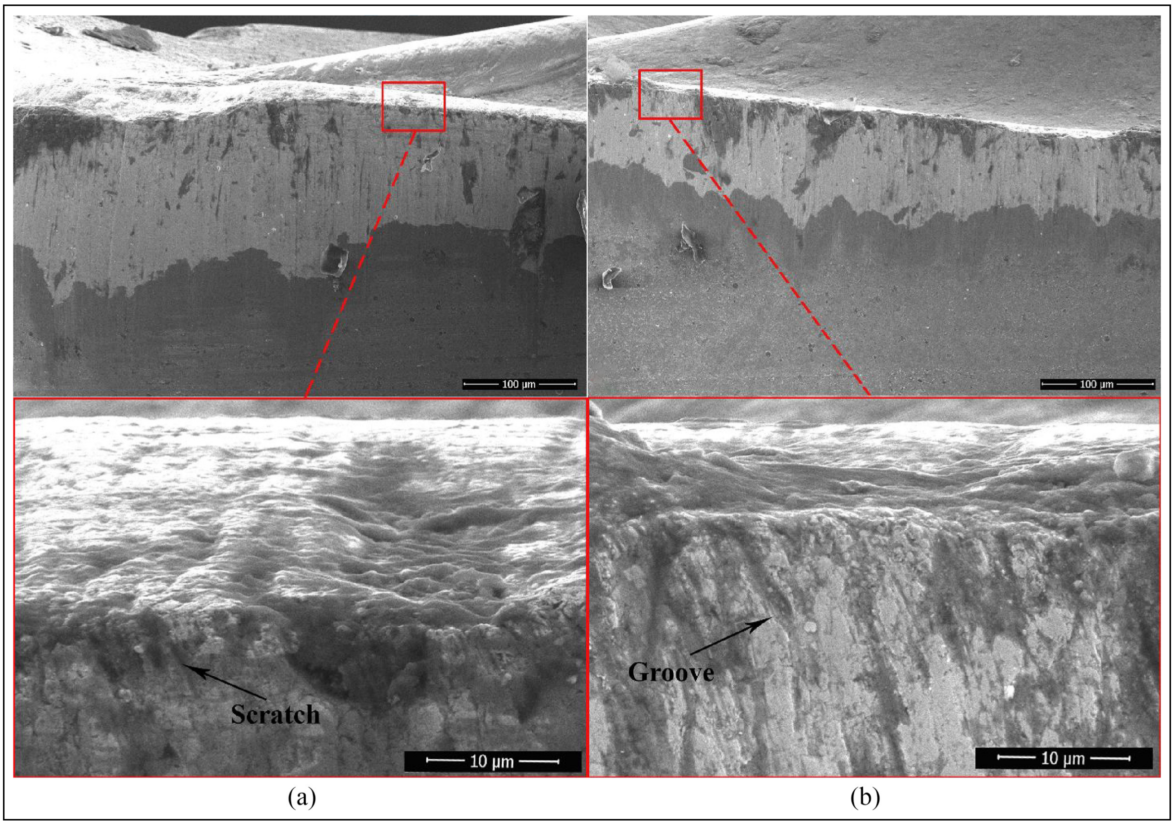

Figure 9. Wear on the flank face of inserts: (a) tool grade TH1000 and AZ91/SiC-2.5%vol with the particle size of 9 μm and (b) tool grade CP500 and AZ91/SiC-5%vol with the particle size of 45 μm.

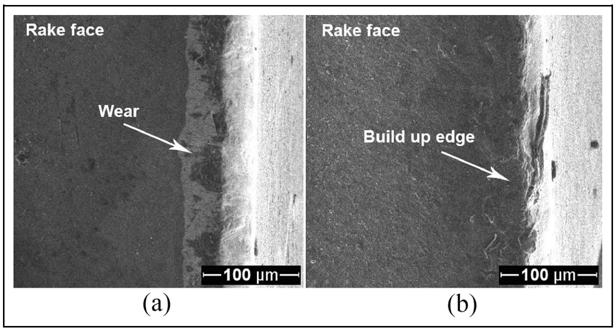

Figure 10. Rake face of tools after machining: (a) tool grade TH1000 and (b) tool grade CP500.

surface of tools. Unlike to coated carbide tools, no crack or breakage are observed on the CBN tools surface. Comparing Figure 13(a) and (b) confirms that based on the EDS analysis small amount of composites materials are adhered to the tool surface for composites with small particles. For composites with smaller particles, build-up edge formation reduced. It decreased protection of tool surface meaning more exposure to hard particles and in turn more wear rate.

Surface quality

Surface roughness is one of the main aspects of the surface quality of machined samples. Figure 14 shows the value of surface roughness after machining of AZ91/SiC composites in different cutting conditions as well as two carbide coatings. As shown in the figure, increasing the feed rate leads to higher roughness. According to the results, cutting speed does not have a significant effect on the surface roughness. Also, composites with a smaller particle size show better surface quality although small particles reduce the tool life in Figure 6. Additionally, machining of Mg-based composites with cemented carbide grade TH1000 results in better surface quality compared to tool grade CP500. It can be attributed to the build-up edge formation during the machining of AZ91/SiC with CP500 tool. In machining of Mg-based composites with CBN cutting tools, the surface roughness value reduces. Generally, using CBN tools results in less built-up edge formation and less adhered materials on the tool edges leading to better surface quality. Apart from less tendency of sticking materials onto the tool surface, CBN tools resist to wear compared to carbide tools causing sharp edges and in turn better surface quality.

In the machining of AZ91/SiC composites, reaching a high-quality surface is a major concern. The presence of SiC particles induces a discontinuity in the deformation behavior and when the cutting tool touches a SiC particle, there can be different approaches. First, SiC particles will be broken and small debris will be left on the machined surface. If it is considered that SiC debris

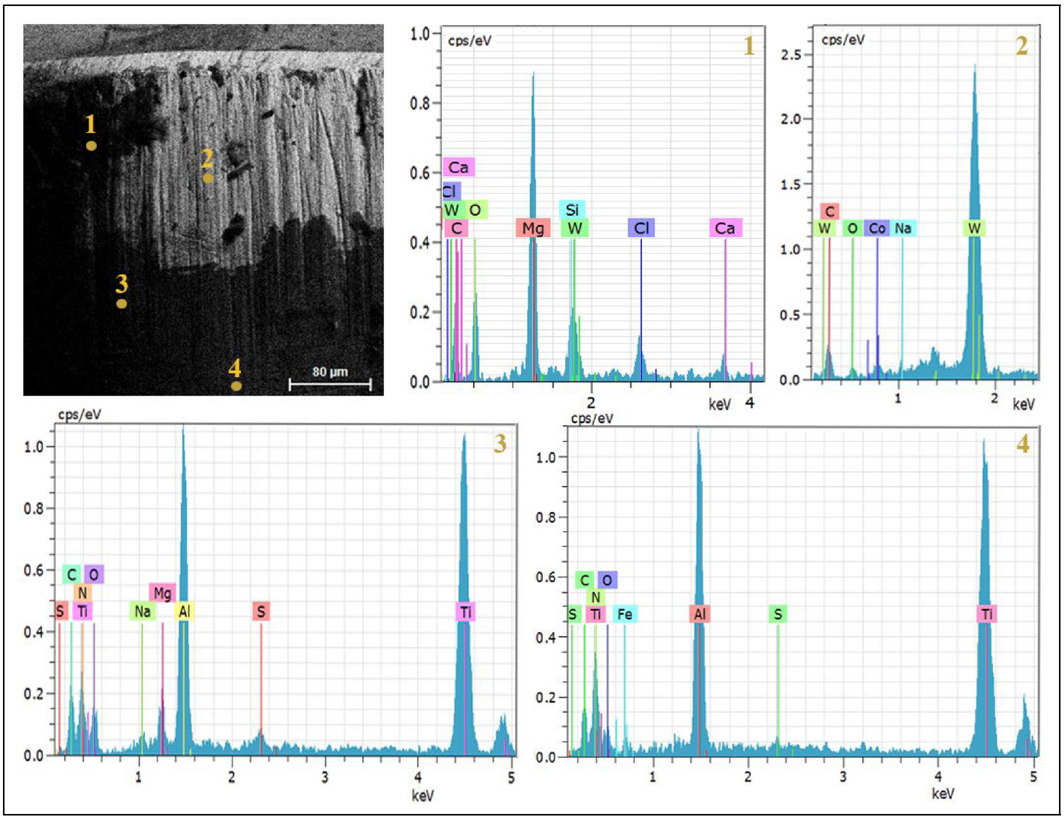

Figure 11. EDS analysis of tool grade TH1000 after machining of AZ91/SiC composites with particle size of 9 µm and volume fraction of 2.5% at cutting speed 30 m/min and feed rate 0.05 mm/rev.

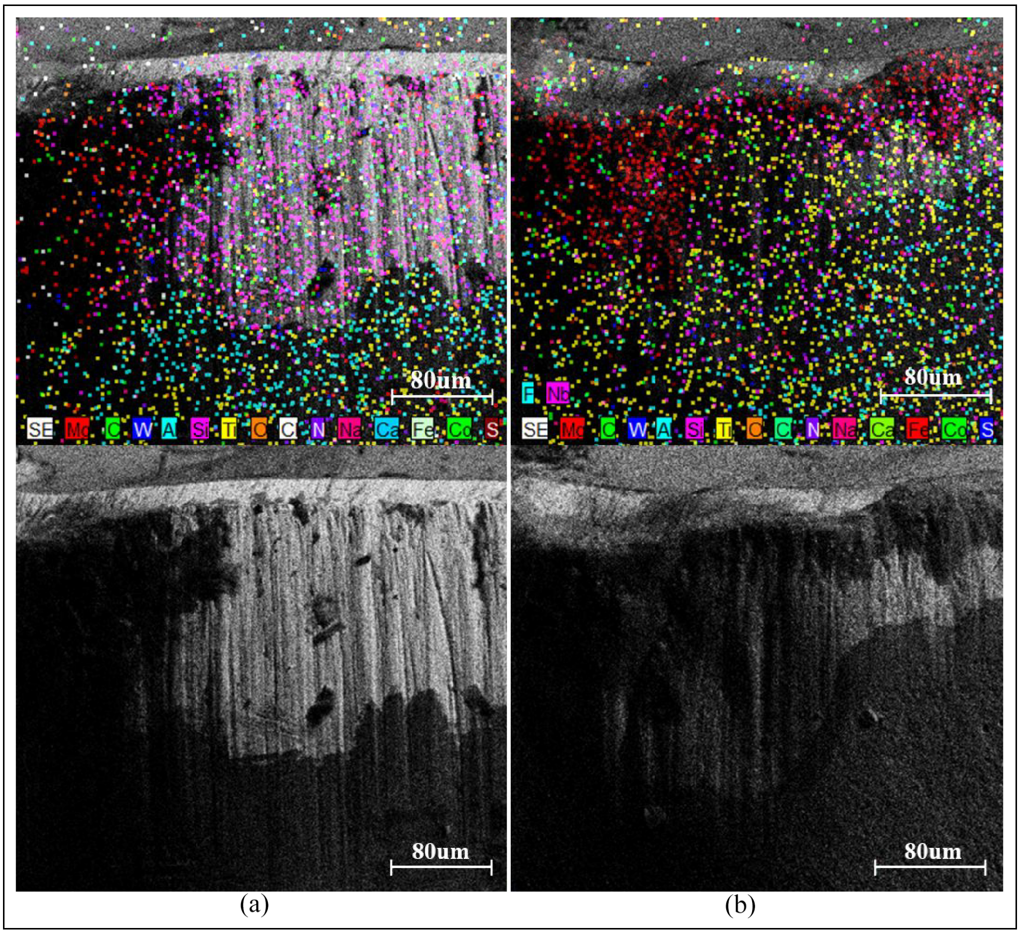

Figure 12. EDS map of flank surfaces at cutting speed 30 m/min and feed rate 0.05 mm/rev: (a) tool grade TH1000 and AZ91/SiC-2.5%vol with the particle size of 9 µm and (b) tool grade CP500 and AZ91/SiC-5%vol with the particle size of 9 µm.

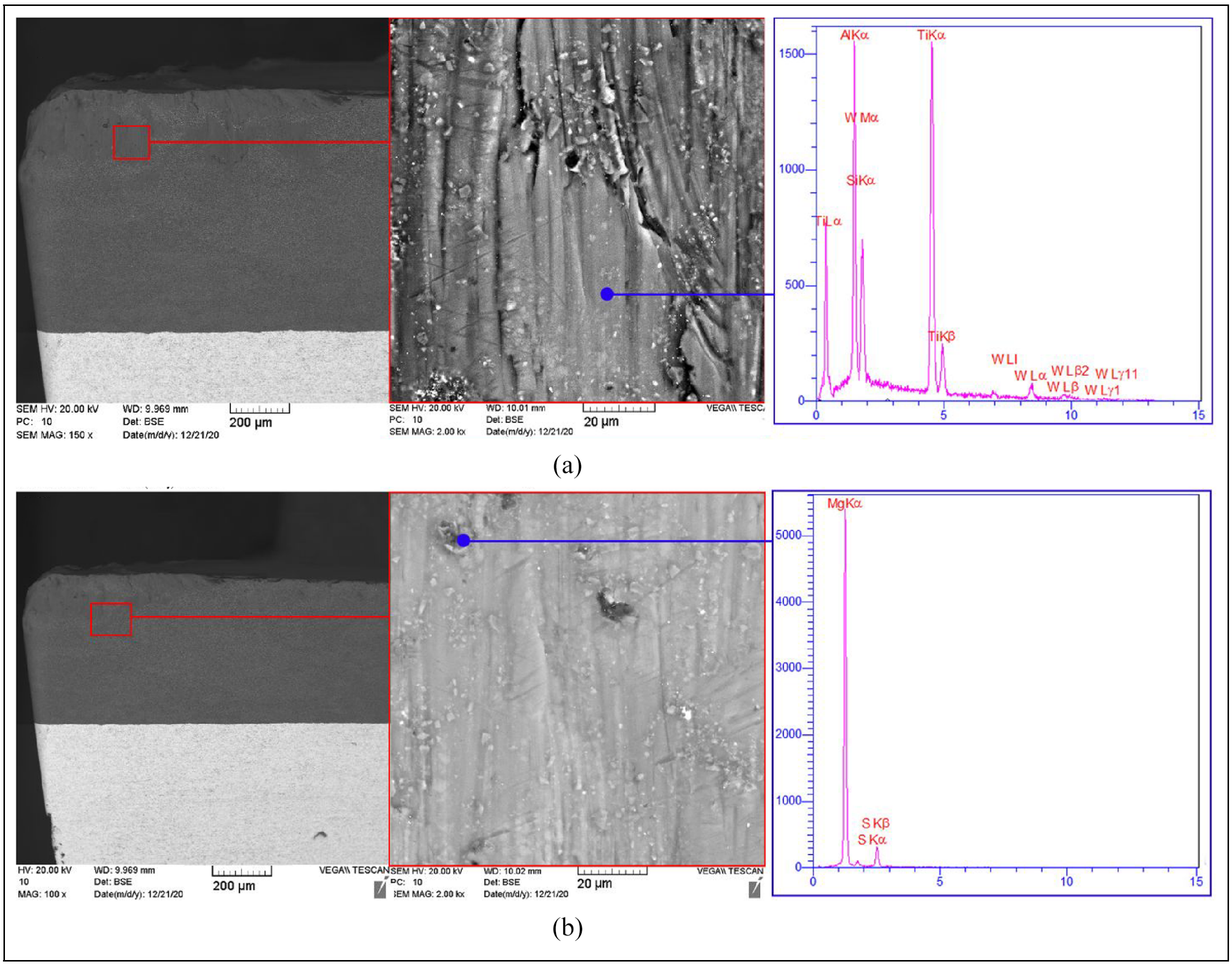

Figure 13. Abression wear on the flank face of CBN tool when machining of AZ91/SiC composites-vol 5% with different particle size at cutting speed 70 m/min and feed rate 0.1 mm/rev: (a) particle size 45 µm and (b) particle size 9 µm.

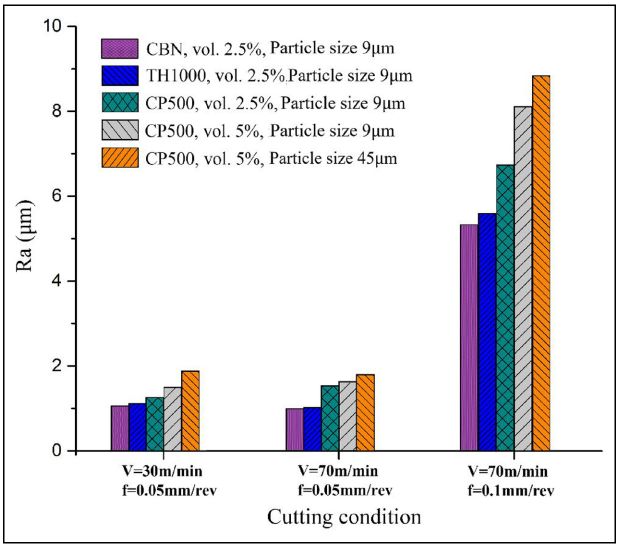

Figure 14. Surface roughness of machined AZ91/SiC composites for different cutting tools.

is put between the tool and specimen surface, they will scratch the sample surface even in microscopic scales. Second, some SiC particles are close to the surface as well as most of their body are inside of AZ91. Here, the passing cutting tool pushes them further and the force applied by the tool leads to some unwanted deformation around the particles. Third, the machining tool cuts an AZ91 layer above the SiC particles so that the particles emerge. Here, SiC particles can gradually move out. As a matter of fact, induced residual stress due to the difference between SiC and AZ91 thermal expansion when composite fabrication by stir casting will be released and this stress acts as a force behind the particles to move them out over time.[43] Figure 15 shows the EDS analysis of a machined surface. As can be seen, there are different defects on the finished surface such as feed marks, swelled layers because of SiC presence and stuck tungsten carbide from tool surface.

While the casting process of the composites, SiC reacts with the AZ91 and some elements will be included at the particle boundaries. Figure 16 shows an EDS line through the interface of boundaries of SiC and base materials.[43] According to the figure, the black areas contain some elements like Al, C, Mg, and Si. These elements make the boundary brittle and, the initiated micro-cracks can propagate during the

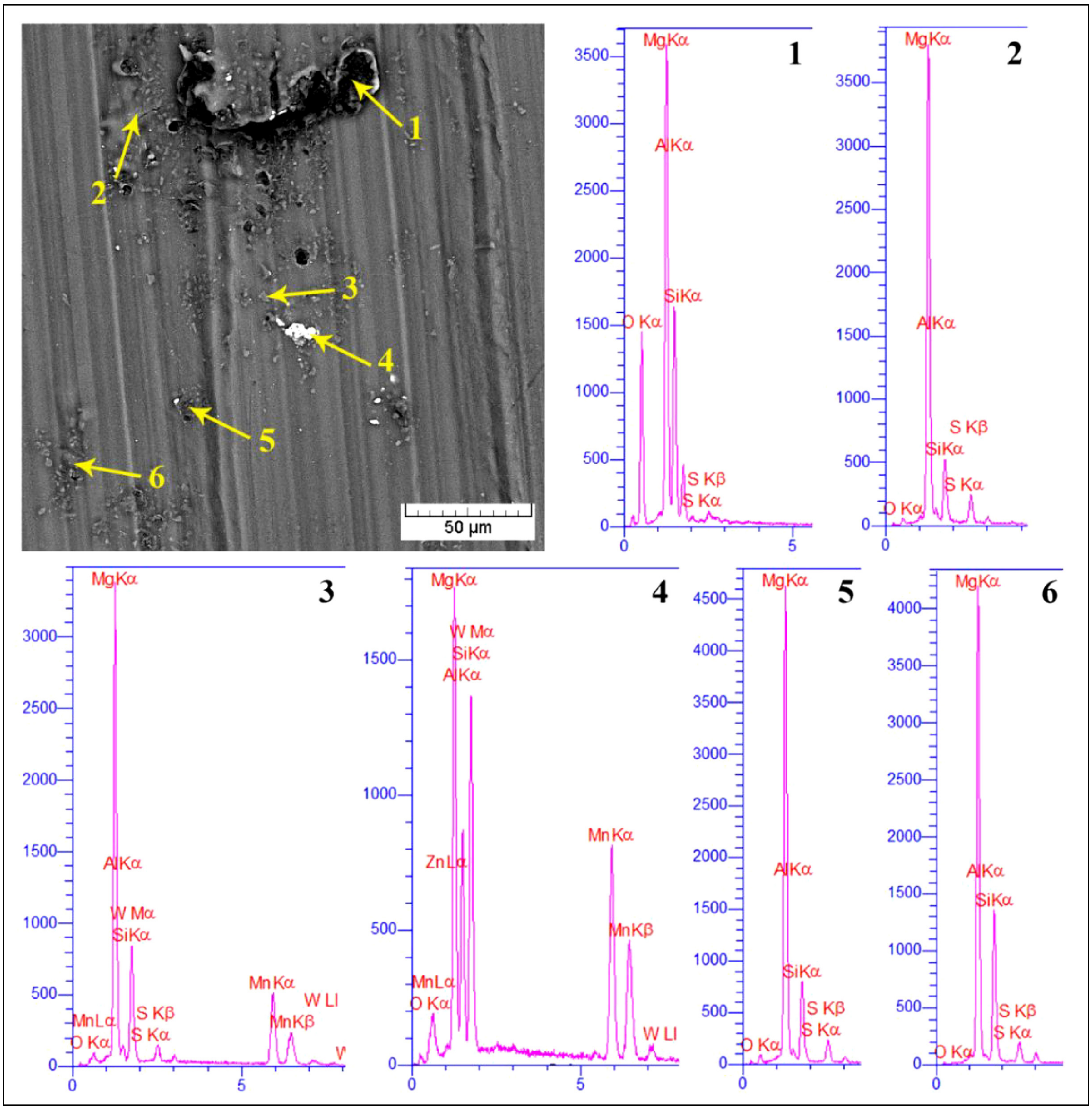

Figure 15. EDS analysis of the AZ91/SiC machined surface.

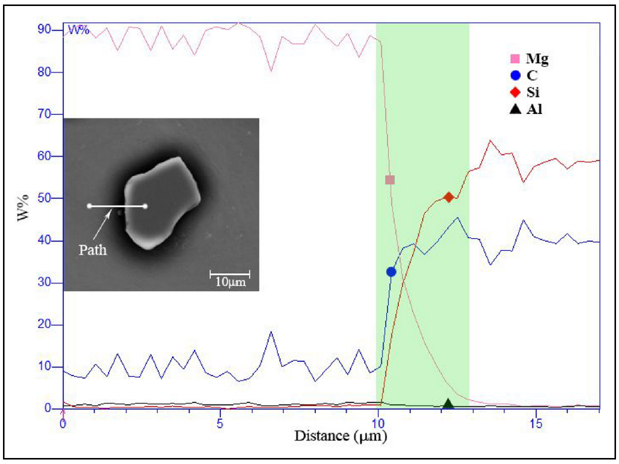

Figure 16. EDS analysis-line of the particle boundary indicating the interfaces.[43]

machining. If the crack propagation's length is enough to surround the particle, particle boundaries become weak and it might even be pulled out leading to reduction in surface quality.

In terms of the hole left behind particle detachment, residual stress induced when composite fabrication by stir casting can be another reason. Since the magnesium thermal expansion coefficient differs from the SiC coefficient, when composite molten is cooled down, shrinkage in AZ91 is more than in SiC particles. Hence, compressive stress is formed around the particles. When the tool cuts the composite, some stress fields are released, and unbalancing in stress pushes particles outside of the composite.

Figure 17 illustrates SEM images of the machined surface of AZ91/SiC composite. According to the figure, there are some surface defects like micro cracks,

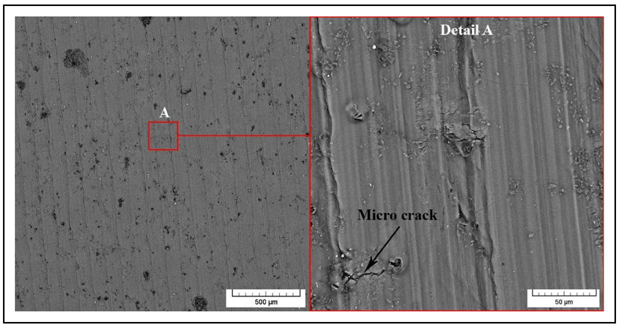

Figure 17. The machined surface of AZ91/SiC composite by grade TH1000, particle size of 9 μm, and vol. 5%.

swelling, segregation, and so forth that increases the roughness and reduces the surface uniformity. It should be noted that as MMCs are hard, they wear the cutting tools in a short time, and changing the tool geometry imposes unwanted deformation to the samples surface especially when it comes to the machining of AZ91/SiC composite since magnesium is soft and can be deformed easily.

Conclusion

In this research, two grades of carbide cutting tools TH1000 and CP500 as well as CBN are considered to analyze their performance when machining of AZ91/SiC composites. In this regard, the effect of machining parameters, reinforcement size, and composite volume fraction on the tool life and surface quality of machined samples are evaluated. Regarding the results, following conclusions can be drawn:

- Increasing the cutting speed and feed rate results in a higher wear rate when machining of AZ91/SiC composites. Also, machining of composites with higher amount of reinforcements leads to severe wear rates as SiC particles in MMCs, have more contact with tools during machining.
- Cemented carbide grade TH1000 gives rise to better performance compared to grade CP500 when machining of AZ91/SiC composites so that at a cutting speed of 70 m/min and feed rate of 0.1 mm/rev, tool life improved nearly 250%.
- Composites reinforced by small particles (9 μm) caused further contact between the tool and the workpiece. Hence, the smaller the particles become, the higher the wear rate occurs.
- SEM and EDS analyses confirm that abrasion is the most dominant wear mechanism when machining of the Mg-based composites for three cutting tools of CP500, TH1000, and CBN.
- Tool grade TH1000 results in better surface quality compared to the CP500. Additionally, although adding finer particles leads to lower tool life, it improves the finished surface. Also, the more volume fractions become, the less surface quality is resulted. Machining with CBN tools would lead to the best surface quality compared to carbide tools although the difference of surface roughness is not that much considerable.
- Machining of AZ91/SiC composites with smaller particles results in better surface quality. Also, the less volume fraction becomes, the more surface quality is obtained.
- In machining of AZ91/SiC composites, surface defects like micro cracks, unwanted deformation, and the spaces left behind of pulled out particles reduce the surface quality.
- Using CBN tools improved the machinability of Mg-based composites, in terms of tool life, around 250% and 500% compared to grade TH1000 and CP500, respectively.

Future prospects

- The effect of cutting fluid specification on the machinability of AZ91/SiC composites and tool wear performance is highly recommended for the future research.
- Optimization of AZ91/SiC composite machinability, considering the minimum quantity lubrication (MQL).

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Appendix

Notation

Notation	Definition	Unit
V	Cutting speed	m/min
f	Feed rate	mm/rev
$\mathbf{a_p}$	Depth of cut	mm
$\mathbf{V_B}$	Flank wear	μm
Vf	Volume fraction	%
Ra	Average surface roughness	μm