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Tool wear and surface roughness

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Abstract

Metal matrix composites (MMC) introduced special features such as resistance to wear and high strength to weight ratio and these characteristics categorized them as difficult-to-cut materials in the field of machining. In the current paper, a novel study on the cutting fluid emulsion 5% role in the machinability of a magnesium-based metal matrix composite reinforced by silicon carbide (SiC) particles is presented. AZ91 magnesium alloy, with nominal composition Mg-9Al-1Zn, composites were made using stir casting method. Then, the composite samples were machined and the cutting parameters such as cutting speed, feed rate and side cutting edge angle were varied to assess their effects on the wear and surface roughness. To measure and analyze the wear, optical and scanning electron microscope (SEM) were used. Also, elemental analysis through energy-dispersive X-ray spectroscopy (EDS) was accomplished. Surface roughness of machined samples were measured by a profilometer and 3D surface topography. Results of SEM and EDS images indicated that SiC particles included in the composites act as grinders and remove the surface of tool even in a short time because of the severe abrasion. Additionally, surface of machined MMCs contains some defects such as cracks, broken SiC, and unwanted deformations. Using cutting fluid emulsion 5% enhanced the tool life as well as the surface quality remarkably for different cutting speeds, feed rates and cutting edge angles although finished surface of the samples were oxidized. Also, the cutting fluid considerably reduced the amount of adhered materials on the flank face.

Keywords

MMC, AZ91/SiC composite, cutting fluid, machinability, wear, surface roughness

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Introduction

High demands for new materials made the opportunity available for researchers to improve and develop the materials like metal matrix composites (MMC). MMCs are being increasingly used in industries because of having the properties like excellent strength to weight ratio, resistance to wear and creep.[1–3] These features made them unique to be utilized in some industries such as automotive, medical, and aerospace. Among all the MMCs, Mg-based composites have taken attractions as superlight materials. For instance, they revealed some particular applications in diesel pistons[4] and turbocharger impellers.[5,6]

In MMCs, mainly there is a soft base material reinforced with hard phases. Although presence of reinforcements like SiC, Al_2O_3, B_4C improve the mechanical properties, these ceramic particles make the MMCs hard enough to be categorized as difficult-to-cut materials.[7] There are many methods to fabricate MMCs, but they are being fabricated mainly by stir casting process due to its low costs compared to other ways. Basically, obtaining a desired final shape through casting process would be difficult and somehow impossible, according to the complexity of shape. In this case, machining process would be a promising way to get the MMCs sized and remove the unwanted or extra parts.

Magnesium and its alloys found themselves many areas of uses particularly in automotive and medical industries and aviation thanks to their low density.[8] Magnesium alloys due to its hexagonal crystal lattice, does not show a great plasticity at low temperatures

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and its deformation is limited to elevated temperatures ($>200°C$).[9,10] AZ91, with general composition Mg-9Al-1Zn, is one of the most widely used Mg alloys which is ideal for lightweight constructions. AZ91 alloy showed a better combination of castability, plasticity, and cost compared to conventional wrought magnesium alloys such as AZ31 and AZ61.[11] Generally it also presents a great machinability specifically in terms of surface integrity although at low cutting speeds build-up edge is formed reducing the quality of finished surface.[12]

Machining of MMCs, regardless of the base material type, faces many difficulties such as short cutting tool life,[13] low quality finished surface caused by pulled out particles, micro cracks and so forth.[14] That is why many researchers have investigated the machining of such challenging materials. For instances, in the machinability of aluminum based composites reinforced with 5% Safill and 15% SiC particles, it was observed by Chambers[15] that K10 cemented carbide inserts are not proper as they were worn out shortly. Sahoo et al.[16] utilized Taguchi method, as a statistical approach, to assess machinability of Al/SiCp composite in turning process by considering cutting speed and feed rate. Manna and Bhattacharayya investigated temperature and built-up-edge (BUE) roles on wear in machining of the Al/SiCp15% at high cutting speeds. Kılıckap et al.[17] found that TiN-coated cutting tools indicated better performance compared with uncoated cemented carbide tools during turning of Al-based MMCs containing 5% SiC particles. Sahin[18] reported that presence of TiN as top layer of multi-layer coated carbide tools resulted in the best performance among various multi-layer coated cemented carbide tools in machining of Al-based composites reinforced with 10 and 20 vol% SiC. Ozben et al.[19] mentioned increasing the amount of reinforcement, volume fraction, decreased the tool life significantly when machining of Al-based MMCs with SiC, particulate composites. Devaraj et al.[20] applied some texture on the tool surface to explore its effect on the tool wear, surface roughness and power consumed during machining of an Al-based composite. Ciftci et al.[21] analyzed the CBN tool wear and surface roughness of aluminum based metal matrix composites with particle sizes 30,45, and 110 μm. Kannan and Kishawy[22] observed that using cutting fluid makes a lubricant layer affecting the coated tungsten carbide wear in machining of A356/SiCp composites with volume fraction 20% reinforcement. Bhushan et al.[23] TiN-coated cutting tool provided better results in terms of tool wear and surface finish in machining of an Al-based composite reinforced with 10% SiCp. Additionally, PCD tools were recommended for machining of Al-based composites for cutting speeds higher than 220 m/min. Han et al.[24] studied the surface integrity mechanisms in machining of MMCs. They pointed out that semi-brittle and ductile cutting happen during the MMCs machining. Davim and Baptista and Baptista[25] mentioned abrasion wear as dominated mechanism during drilling and turning of an A356/ SiCp 20vol% composites using PCD tools while adhesion was believed to have the secondary effects. Sankhla et al.[26] investigated tool wear when machining of an aluminum-based composite reinforced by SiC particles. They showed that increase in the volume fraction of SiC particles detrimentally affects the tool surface. Bushlya et al.[27] observed build-up layers formed on the tool surface and these layers protected the diamond and CBN grains against both diffusional and abrasive wear in machining of Al-20 vol% SiCp composite. Liu and Zong[28] found that grades containing fine diamond grains showed less wear resistance and tool life when machining of Al/ 45vol% SiCp composite. El-Gallab and Sklad and Sklad[29] pointed out abrasion and micro-cutting of tool material grains were the main mechanisms during machining of Al/SiCp20% composite with PCD tools. Muthukrishnan et al.[30] observed severe wear on the primary and secondary flank surfaces at the high cutting speeds when machining an Al/SiCp10% using PCD tools. Bai et al.[31] could obtain a significant reduction of cutting forces along with a slight increase of cutting temperature by ultrasonic-assisted machining of Al/SiC-25%. Dabade et al.[32] pointed out feed rate and preheating temperature have a considerable effect on the surface roughness and micro-hardness when hot machining of Al/SiCp MMCs so that some defects like pit, crack, and porosity on the surface of machined samples were reduced. Xiong et al.[33] assessed the surface quality of a machined particulate aluminum based composite reinforced by TiB_2 and they faced different defects such as micro cracks, tearing in matrix and formation of voids. Szaloki et al.[34] pointed out that BUE formation reduces the surface quality when machining of aluminum based composites reinforced by SiC fibers. Kilickap et al.[17] investigated tool wear and surface quality of aluminum based composites reinforced by SiC particles. They indicated that increase in the cutting speed would improve the surface quality because less build up edge was formed. Marousi et al.[35] pointed out that initial wear affects the process significantly. They reported that abrasion, adhesion cracking considered as the critical morphological changes during machining of titanium metal matrix composite. Davim et al.[36] studied effect of MQL on the power consumption and surface quality of machined Al-based metal matrix composite A356/20/SiCp-T6. Hung et al.[37] used pressurized cutting fluid when machining of aluminum-based matrix composites reinforced with SiC or Al_2O_3 particles. They pointed out that pressurized cutting fluid does not influence the tool life significantly because of either effective flushing of the cutting chips or limitation of lubricating film.

When it comes to machinability of magnesium-based composites, there are limited number of

Table 1. AZ91 elements composition, 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

published references. For example, Pedersen and Ramulu[38] found that abrasive SiC particles made the TiCN/TiN coatings worn away during facing of ZK60A/SiCp20% in a short machining distance. Also, it was pointed out that SiC particles were not met fracture during machining and applied a severe abrasion on the flank face of the tool. Asgari and Sedighi[39] showed that increasing the volume fraction of composite materials would induce severe wear onto the surface of carbide tools. They optimized the machining to reduce the wear, improve the surface quality, and enhance the productivity. In another research, Asgari and Sedighi[14] presented a study about surface integrity of machined AZ91/SiC composites to evaluate how SiC particles become pulled-out in the machining and how surface and subsurface features get affected by machining due to presence of reinforcements. Weinert and Lange and Lange[40] presented a study in which the same tool life for cemented carbide tools and TiAlN-Coating tools when drilling of AZ91 composite reinforced with Al_2O_3-Vol.5% and SiC-Vol. 15% reported.

According to the researches done in machining of MMCs and usage of cutting fluids, it can be concluded that there is very limited investigation on the effect of cutting fluid on machinability of MMCs and, in particular, Mg-based composites with high potential to chemical reactions. Hence, the current research is going to bridge some of the existing gaps in machining of Mg-based composites when using cutting fluid is concerned.

In the current study, effect of the industrial cutting fluid emulsion 5% on the machinability of AZ91/SiC composite is evaluated as a novel work. To this end, one of the widely used carbides in industries, cemented carbide, when turning process is taken into account to assess the tool wear and surface quality. Machining process is accomplished in both conditions of dry and wet. In wet condition, a suspension 5% as cutting fluid is used. Then, the most important cutting parameters such as cutting speed, feed rate and side cutting edge angle are varied in both dry and wet machining to compare the tool life in those different conditions. Also, the surface roughness of machined samples are measured to analyze the effect of the fluid on the quality of samples. Additionally, scanning electron microscopic (SEM) images and energy-dispersive X-ray spectroscopy (EDS) are utilized to realize which wear mechanisms when machining of the composites exist. Moreover, a 3D surface topography is utilized to analyze the surface defects formed during machining.

Experimental procedure

Samples are made of AZ91 composites considering magnesium alloy AZ91 was the matrix material and SiC particles were reinforcements, volume fraction 5%. This volume fraction is chosen since more clusters of SiC particles are seen in high fractions and 5% has been mentioned in different references.[14,17,41] Composites were fabricated by stir casting process because of simplicity and lower costs.[42] Chemical composition of AZ91 material is shown in Table 1. In order to fabricate the metal matrix composites, some pieces of magnesium alloy AZ91 are put into the crucible and is melted while argon gas is continuously blowing into the furnace. At temperature about 776°C, SiC particles with mesh size 320, meaning average particle size 45 μm, are added to the molten materials. Then, the mechanical stirrer is applied to blend it for nearly 10 min, with rotational speed 2600 rpm, and then magnet stirrer is turned on and works for 3 min. Afterward, composite materials are cooled down to reach the ambient temperature.[41] Composites are machined to reach a cylindrical shape 50 mm in diameter and 60 mm in length. Fabricated composites and the used set-up are illustrated in Figure 1.

Carbide inserts CNMA1202404-WK20CT are used for machining of the Mg-based composites. Also, tool holders TCMNN-2525-M12 and MCBNR-2525-M12 provided two different lead angles 75° and 55° for tool life tests. All the experiments were performed in longitudinal direction on a Newaycnc-NL251H CNC turning machine. In wet machining, cutting fluid emulsion 5%, due to wide use in industries, is taken into consideration to explore its effects on the machinability of Mg-based composites. Specific features of the cutting oil used in cutting fluid is presented in Table 2.

General view of machining in both dry and wet conditions are shown in Figure 2. Different cutting speeds, feed rates, and side cutting edge angles are set on the CNC machine at a constant depth of cut 0.5 mm to investigate their effect on the machinability of Mg-based composites. Generally, depth of cut is not considered as a machining parameter in the current study since depth of cut mostly does not have a considerable effect on wear.[39] Instead, side cutting edge angle was chosen since it directly affects the chip thickness and force acting on the tool.

One of the paper aims would be analyzing the wear with a focus on the flank wear. The flank wear width is measured by using an optical microscope (euroscope) after each machining pass to measure the wear over machining time. Later, the tool inserts are

Figure 1. AZ91/SiC composites fabrication through stir casting: (a) AZ91/SiC composites and (b) stir casting set-up.

Table 2. Characteristics of the cutting oil used for machining.

Density at 15°C (Kg/m^3)	Kinematic viscosity at 40°C (cSt)	Flash point (°C)
895	34.5	210

analyzed using scanning electron microscope (SEM), TESCAN VEGA//XMU. The microscope equipped with Energy-dispersive X-ray spectroscopy (EDX) to analysis the worn surfaces. Then, surface roughness of samples are measured by tester TIME-T200. The profilometer moves with speed 1 mm/s and sense the roughness over length 4 mm.

As mentioned, to analysis the effect of machining parameters, different cutting conditions are considered. Cutting speed, feed rate and side cutting edge angle are three important cutting parameters will be varied to discover their influence on the machinability of AZ91/SiC composite. Also, machining is accomplished in both dry and wet condition. Table 2 presents the cutting conditions and their variations. Range of cutting speeds and feed rates matches with literature[39] and some pre-testing in which severe wear occurred for higher values of parameters. Number of 12 experiments were chosen based on modified response surface method (RSM) shown in Table 3.

Results and discussion

In this section, cutting fluid effects on the tool wear considering the cutting parameters such as cutting speed, feed rate and side cutting edge angle is presented. Also, influence of cutting fluid on the roughness and surface quality of finished samples will be analyzed.

Effect of cutting fluid on the tool wear

Before analyzing the tool wear, material characterization is done to get a sense about the probable reasons behind of the wear. Figure 3 shows the microstructure of the AZ91 composite reinforced by SiC particles, vol. 5%. Also, EDS analysis of phases formed during composite fabrication can be seen in the figure.

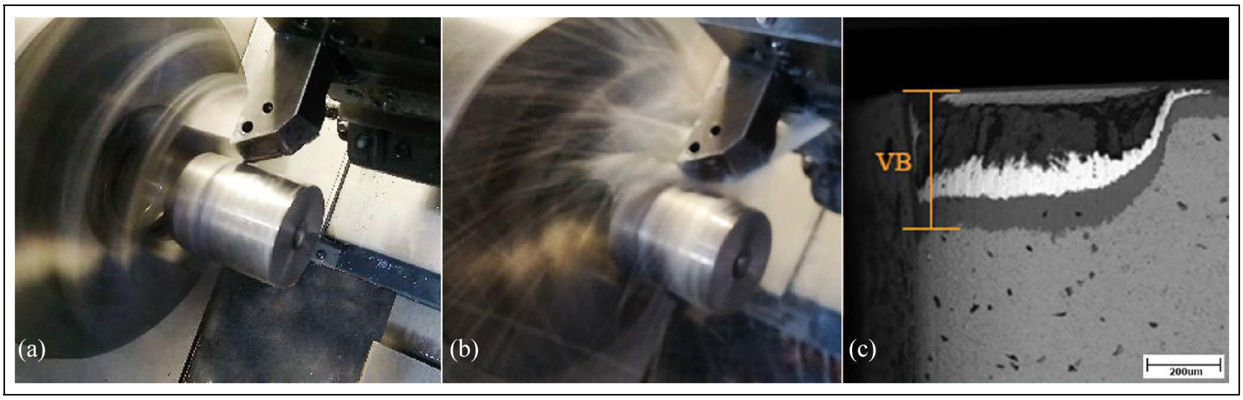

Figure 2. View of AZ91/SiC machining under different conditions: (a) dry machining, (b) wet machining, and (c) flank wear measurement.

Table 3. Cutting conditions designed for machining of AZ91/SiC composite.

Number	Feed rate (mm/rev)	Cutting speed (m/min)	Side cutting edge angle (degree)	Machining condition
1	0.1	30	35	Dry
2	0.1	70	35	Dry
3	0.1	30	35	Wet
4	0.1	70	35	Wet
5	0.2	30	35	Dry
6	0.2	70	35	Dry
7	0.2	30	35	Wet
8	0.2	70	35	Wet
9	0.15	50	35	Dry
10	0.15	50	35	Wet
11	0.15	50	15	Dry
12	0.15	50	15	Wet

Magnesium matrix is the main and softer part of the composite. During fabricating the composites around the melting temperature, a secondary phase Mg_2Si could be formed[43] caused by the reactions as follows:

$$4Al + 3SiC \rightarrow Al_4C_3 \quad 3Si + 2Mg \rightarrow Mg_2Si \tag{1}$$

Mg_2Si secondary phase is also hard but not as much as SiC particles. Hence, SiC mainly affects the cutting insert surface in terms of wear. Mg_2Si phase is distributed throughout the composite materials. Also, from the figure it is indicated that interface of the SiC particles and matrix has a small boundary less than 5 μm. Additionally, some particles are clustered increasing the chance of particles pulled out during the machining.

Cutting speed and feed rate are two important parameters in machining affecting the tool wear directly. In machining of MMCs, wear occurs in a short time as reinforcements are considerably much harder than the matrix materials like magnesium in this case. Figure 4 illustrates the cutting fluid effect on the tool life. As seen, using fluid with emulsion 5% results in improving the tool life nearly 50% at cutting speed 30 m/min and feed rate 0.1 mm/rev. In the machining of magnesium matrix composites, both roles of cooling and lubricating of cutting fluid can affect the tool life. Specially lubrication from 5% percent of oil make the movement of hard particles and their interaction with tool surface easier and reduces scratching the surfaces. At low cutting speeds, temperature rise is not concerned, but abrasion wear reduces the tool life. Abrasion wear during usage of cutting fluid is controlled compared to dry machining since the oil in the cutting fluid reduced the friction coefficient and in turn wear.

According to the figure, increasing the cutting speed from 30 to 70 m/min reduces the tool life. It could be attributed to the contact length between tool and work piece for a certain period of time that cutting speed defines when machining. The cutting fluid at higher cutting speeds show better performance as wet condition improved tool life about 110% compared to the dry machining. It is associated to the role of cooling since main part of the fluid was made of water. At high cutting speeds, temperature rise wears the tool surface. In other words, at high cutting speeds, because of high temperature, composite materials are adhered and detached frequently weakening the surface of tool since tool surface can be plucked out. When cutting fluid is used, coolant part of the fluid limits the wear and improves the tool life in return. But, at low cutting speeds, build-up edge formation can protect the tool surface from being worn-out improving the tool life. That is why emulsion 5% showed better performance at high cutting speeds

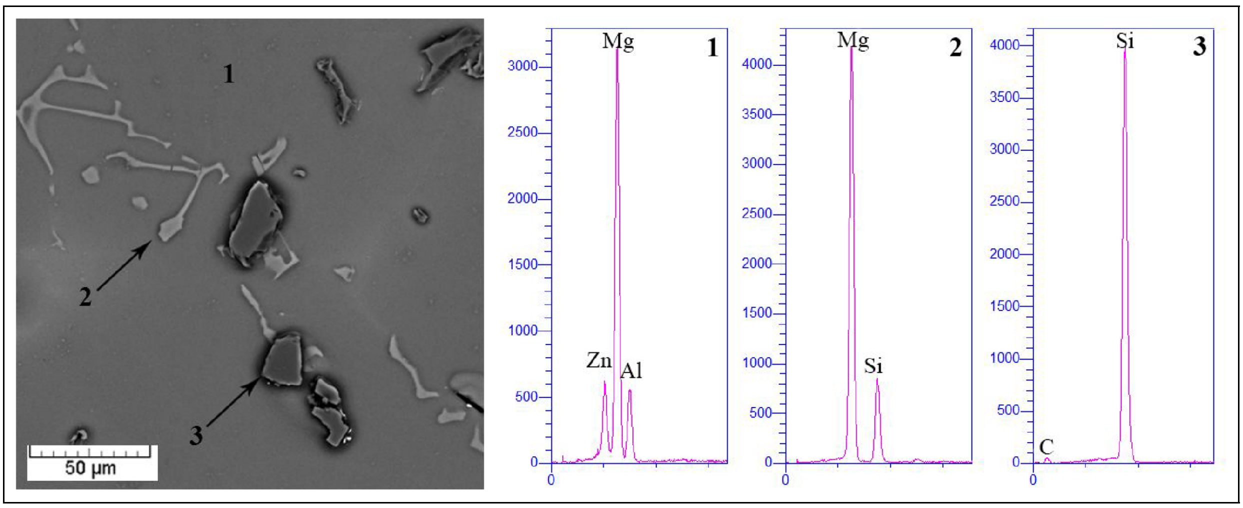

Figure 3. Microstructure and EDS analysis of AZ91/SiC composite, vol. 5%.

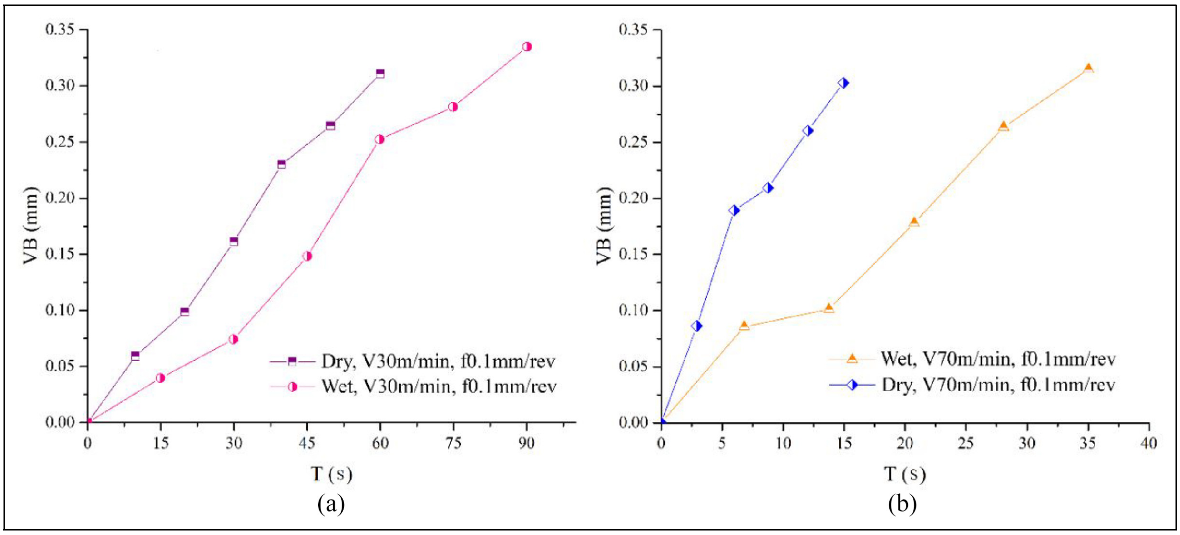

Figure 4. Effect of cutting fluid on the tool wear at feed rate 0.1 mm/rev and side cutting edge angle 35°: (a) cutting speed 30 m/min and (b) cutting speed 70 m/min.

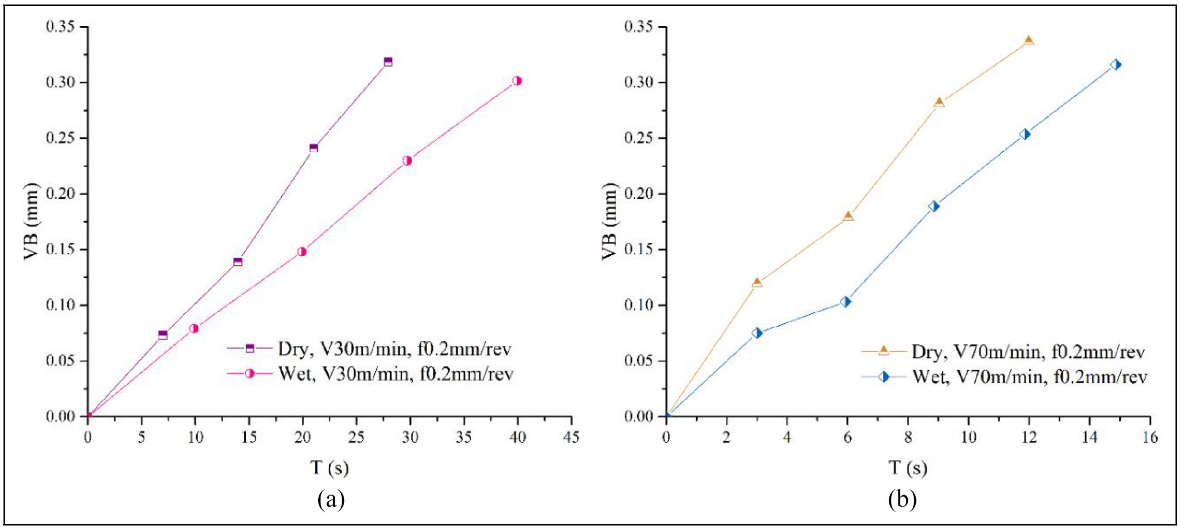

Figure 5. Effect of cutting fluid on the tool wear at feed rate 0.2 mm/rev and side cutting edge angle 35°: (a) cutting speed 30 m/min and (b) cutting speed 70 m/min.

rather than low speeds. Figure 5 shows the cutting fluid effect on the tool wear at feed rate 0.2 mm/rev. Comparing the results of the tool life which shown in Figures 4 and 5, makes this conclusion that enhancing the feed rate reduces the tool life. Increasing the feed rate leads to increase in the chip thickness and in turn machining force since more volume of materials will be removed. When the force increases, it would enforce the particles to apply more pressure on the tool surface leading to wear. The correlation of force and wear rate is presented in Archard[44] wear model as follows:

$$W = \frac{K}{H}.F.V.t \tag{2}$$

Where W is the volume of worn out materials, K is the wear constant, H is the material hardness, F is the normal force, V is the cutting speed, t is the machining time.

Side cutting edge angle is another parameter affecting the tool wear. This angle affects the chip thickness and the cutting force when machining. Figure 6 illustrates its effect in dry and wet machining conditions. As shown, lower angles lead to more intense wear rate as chips thickness enhances and act somehow like feed rate role meaning more machining force.[45] Also, when angles become small, machining force is distributed in a smaller length.[45]

Figure 7 indicates severe wear on the tool surface when machining of AZ91/SiC composite. As it is

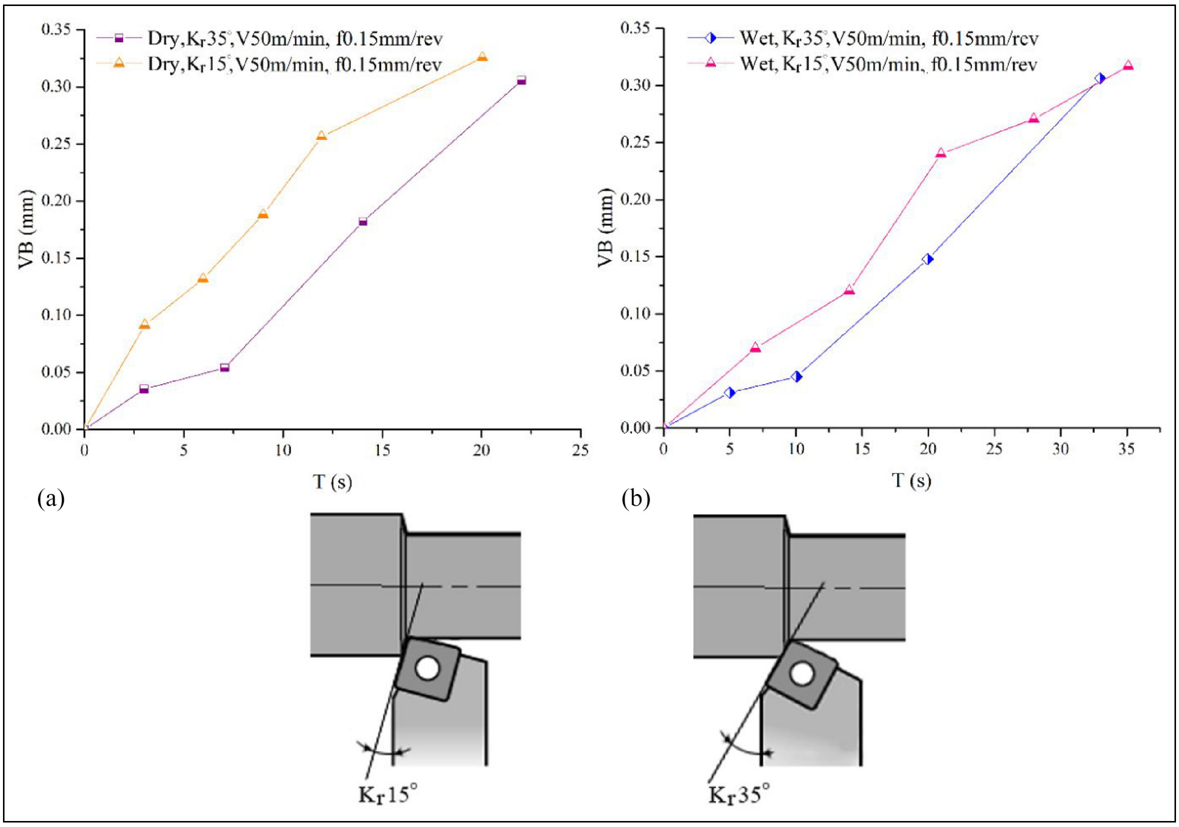

Figure 6. Effect of side cutting edge angle on the tool wear at feed rate 0.15 mm/rev, cutting speed 50 m/min: (a) dry condition and (b) wet condition.

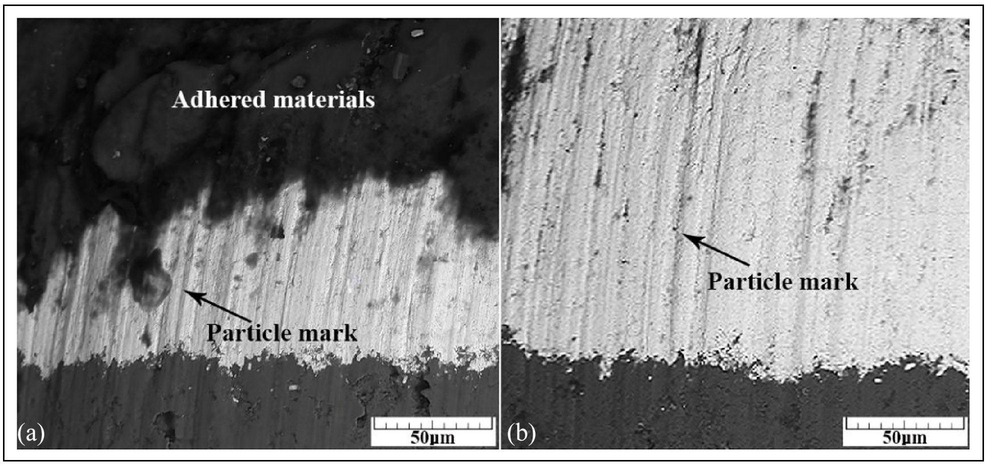

Figure 7. Wear in machining of AZ91/SiC composite at cutting speed 70 m/min, feed rate 0.2 mm/rev and angle 35 for two cases of dry and wet: (a) dry and (b) wet.

shown, in both dry and wet conditions, some grooves caused by particles movements are emerged on the flank surface. In the dry machining, some parts of composite adheres on the flank side and at first glance, it comes to the mind that adhered materials protects the tool from being worn out and this idea is correct, but machining condition like particle hardness, machining time, feed rate and so forth finally overcome to the stuck materials and make insert surface worn out. Regarding the results presented in Figures 4 and 5, it is indicated that using emulsion 5% provides a proper lubrication so that SiC particles included in the composite slip on the flank side and machining time until wear criterion VB 0.3 mm, is improved. Also, from Figure 7, it is realized that in wet condition, number and depth of grooves are less than what is seen in dry condition. It could be attributed to the role of machining liquid in reducing the friction

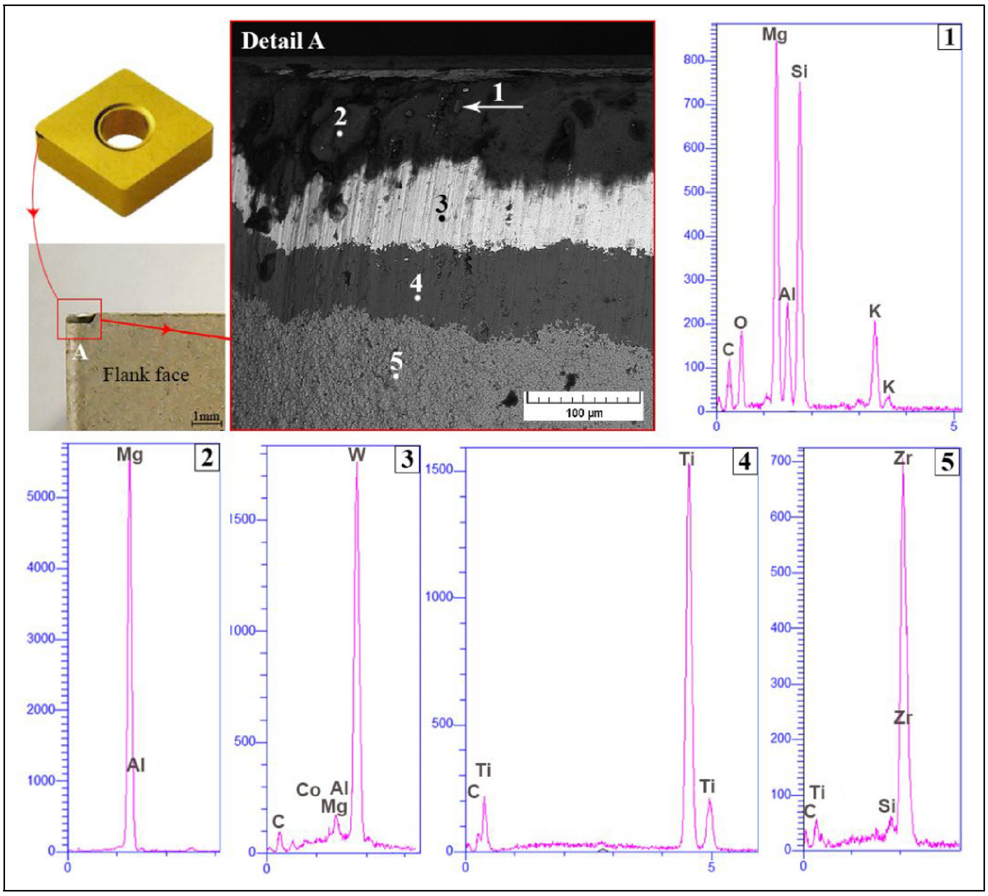

Figure 8. EDS analysis of the tool flank face when it is worn out in dry machining of AZ91/SiC composites.

coefficient between SiC particles and making the slippage easier. Change in the die geometry due to the wear induced when machining, affects the surface quality. As tools get worn out quickly, if the samples get machined further, low surface quality will be reached.

Figure 8 shows EDS analysis of the worn out tool when dry machining of AZ91/SiC composite. As seen, there are two coatings on the tungsten carbide layer including Ti and Zr as the most dominant elements. Also, on the flank face, SiC particles included in the composite materials along with magnesium adhered to the insert. Clearly adhered materials keep the tool surface safe from wear although during the machining they might get attached and detached frequently. Moreover, tungsten carbide shown with number 3, tolerate the wear resulted from SiCs. Some parts of the coatings are scratched and subsequently broken because of severe wear caused by SiC particles.

To better characterize the insert coating, EDS map is used shown in Figure 9 in which each element illustrated with a specific color. As seen, after machining of AZ91/SiC composites, some composites materials are adhered on the flank face of the tool. Also, the main element of top layer is Zr while the second layer is Ti. Under the coatings, tungsten carbide with small amount of cobalt can be found. Hard SiC particles existed in the composite materials, easily removed some of the layers of tools.

Figure 10 illustrate the effect of cutting fluid on the build-up edge (BUE) formation and adhered materials beside the cutting edge on the flank side. As seen, using cutting fluid intensively prevent sticking composite materials to the inserts that could be one reason of improving the surface quality will be explained later in the next sub-section.

Effect of cutting fluid on the surface quality

Reaching a high quality finished surface has been one of the major problems when machining of MMCs since some of the reinforcement particles might get pulled-out during the machining from the surface and some cracks and defects are formed. According to Figure 11, some defects are formed after machining of Mg-based composites. Some of the defects are formed during machining while some others are made after machining since some particles can gradually move out from the surface because of releasing the residual stress around the particles.[14] SiC particles, due to being very hard, cannot get deformed by cutting tools and they are susceptible to breakage or making unwanted deformations. Also, some SiC particles can be pushed into the surface of specimens leading to cracks and holes. Moreover, as in boundary of SiC particles and magnesium materials, there

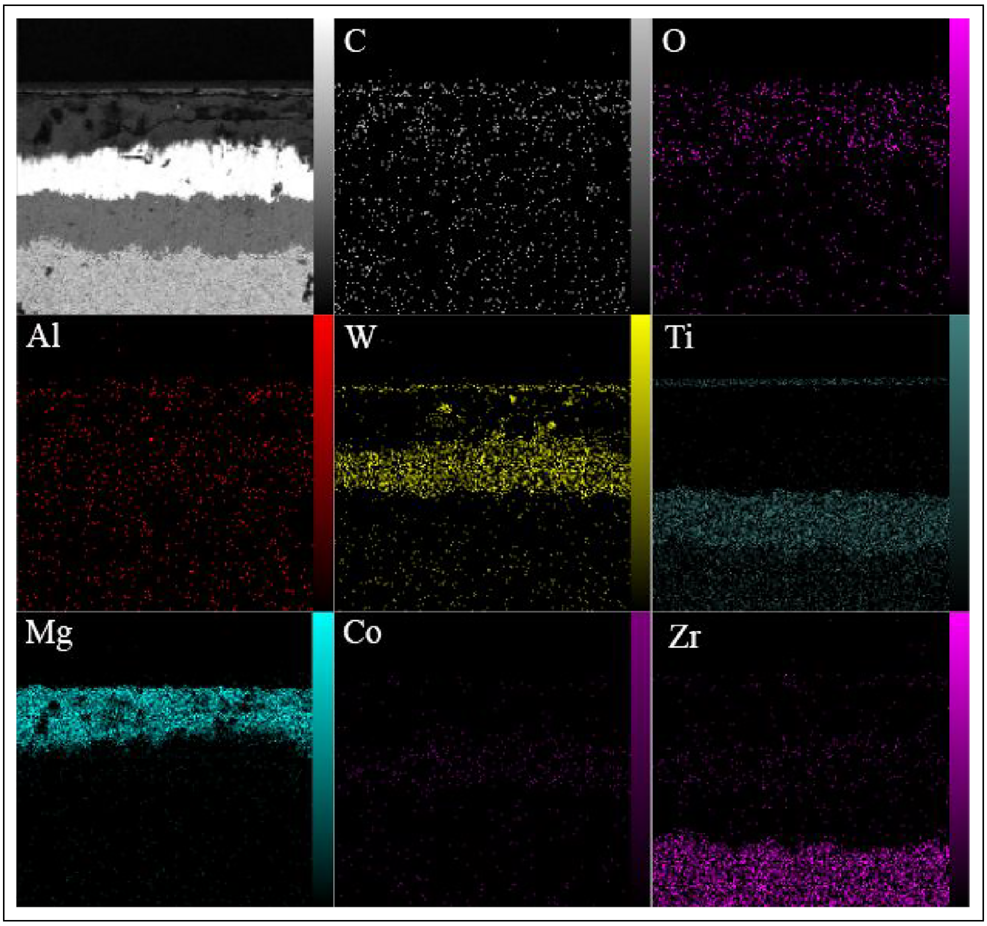

Figure 9. EDS map of the worn out tool.

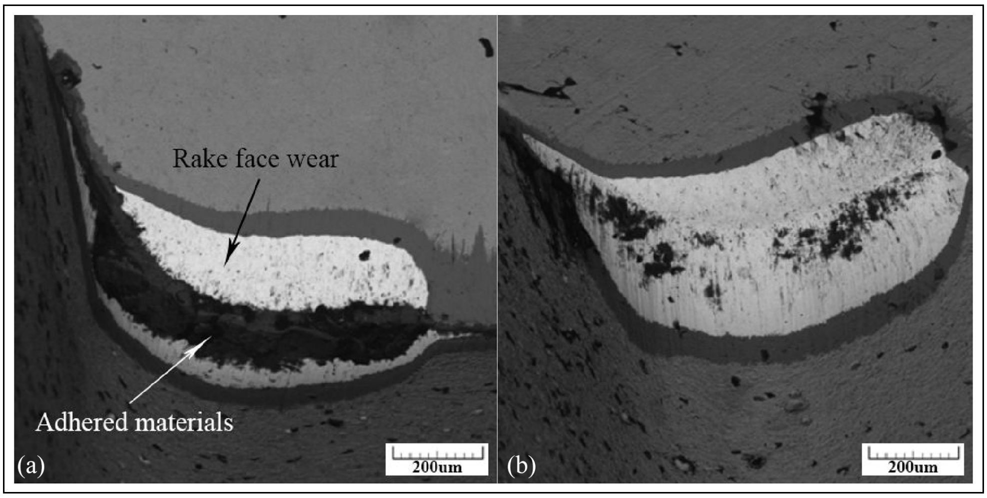

Figure 10. Effect of machining fluid on the adhered composites materials close to the cutting edge: (a) dry and (b) wet.

are brittle phases, micro cracks might propagate facilitating pulling out process. In Figure 11, 3D topography of machined surface shows how SiC particles can be pulled out. In some areas, build-up formation and adhering composite materials onto the surface of tools can make the finished surface weak in terms of quality. Reduction in the quality of surface becomes important when it comes to fatigue life since holes and undesired deformation coming from the pulled out particles could be a potential place for crack propagation.

Here, effect of used cutting fluid on the surface roughness is evaluated. Additionally, roughness evolution versus machining length due to the wear is

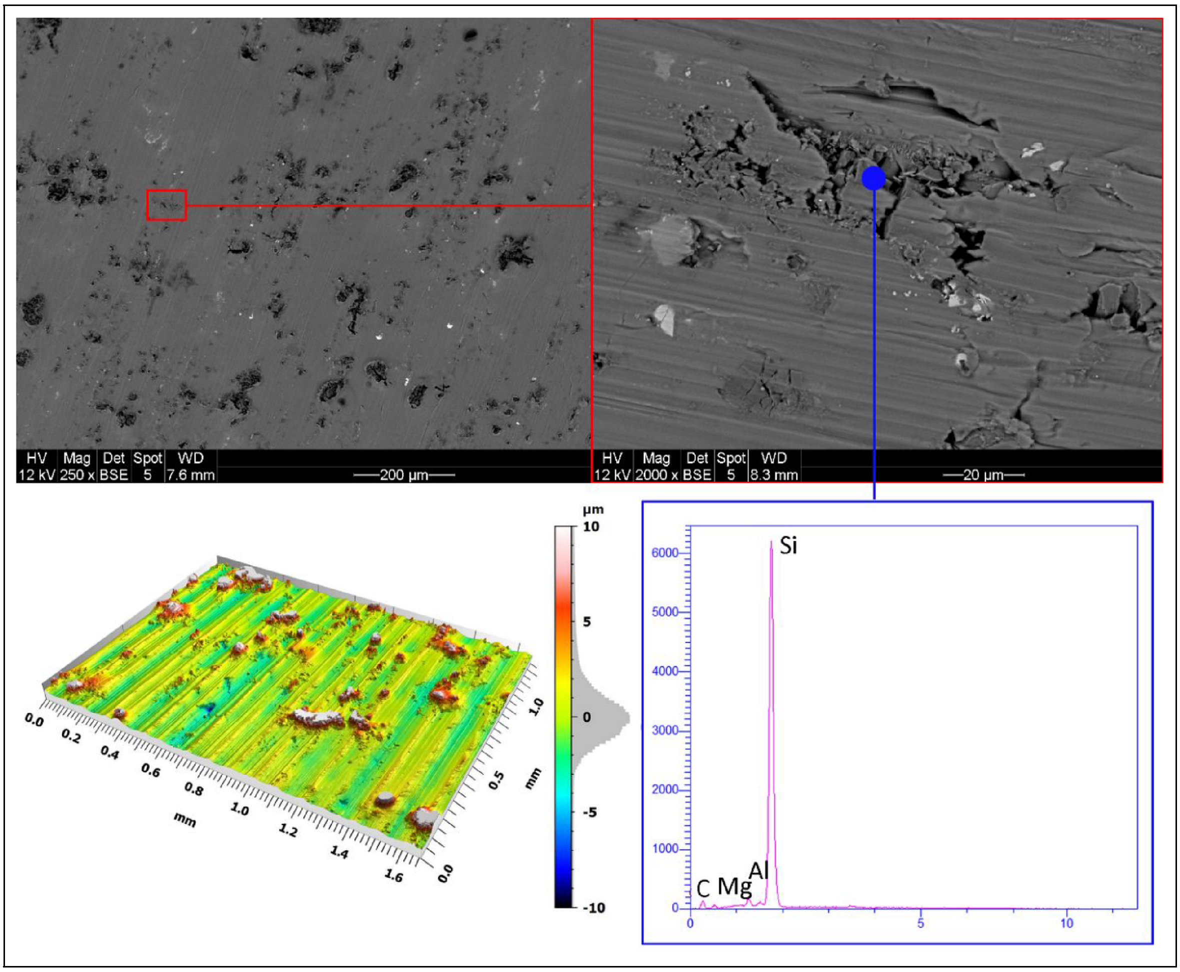

Figure 11. Surface defects of machined Mg-based composites.

presented. Figure 11 shows the surface features of machined samples. According to Figure 12(a), it is seen that in dry machining, profile of roughness is rougher than the wet one. Also, deviation of surface ups and downs in presences of cutting fluid is much lower than the dry machining. Regarding Figure 12(b), using cutting fluid improves the quality if machined samples considerably and machining roughness evolution when wet cutting is limited as the tool life is improved.

Also, according to Figure 12(c), it clearly is shown that emulsion 5% oxidize the surface and specimen surface color is changed. It can be attributed to the amount of water in the cutting fluid leading to a chemical reaction with magnesium as follow:

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2 \qquad (3)$$

This reaction would lead to magnesium oxidization and changes the surface color. Hence, although using cutting fluid improves the surface roughness, it oxidizes the surface of specimens clearly. It seems that a compatible cutting fluid which does not react chemically with the magnesium should be developed in future to have both features of tool life surface quality improvement. Proportion of water and oil in a way that less water included in the fluid could a promising step to reduce the amount of surface oxidization. Also, more oil could help the lubrication role as hard SiC particles might be able to move smoothly on the tool face where they have some contacts.

Conclusion

In this study, machining of AZ91/SiC composite with approach of assessing the effect of using cutting fluid is investigated. Important machining parameters such as cutting speed, feed rate and side cutting edge angle effect on the wear in both dry and wet machining are analyzed. Also, effect of cutting fluid on the surface quality of machined sample is evaluated. According to the achieved results the following conclusion can be drawn:

- Increasing cutting speed and feed rate accelerate the wear rate. Also, higher side cutting edge angle leads to higher wear rate as chip formation is concentrated on a shorter cutting edge.

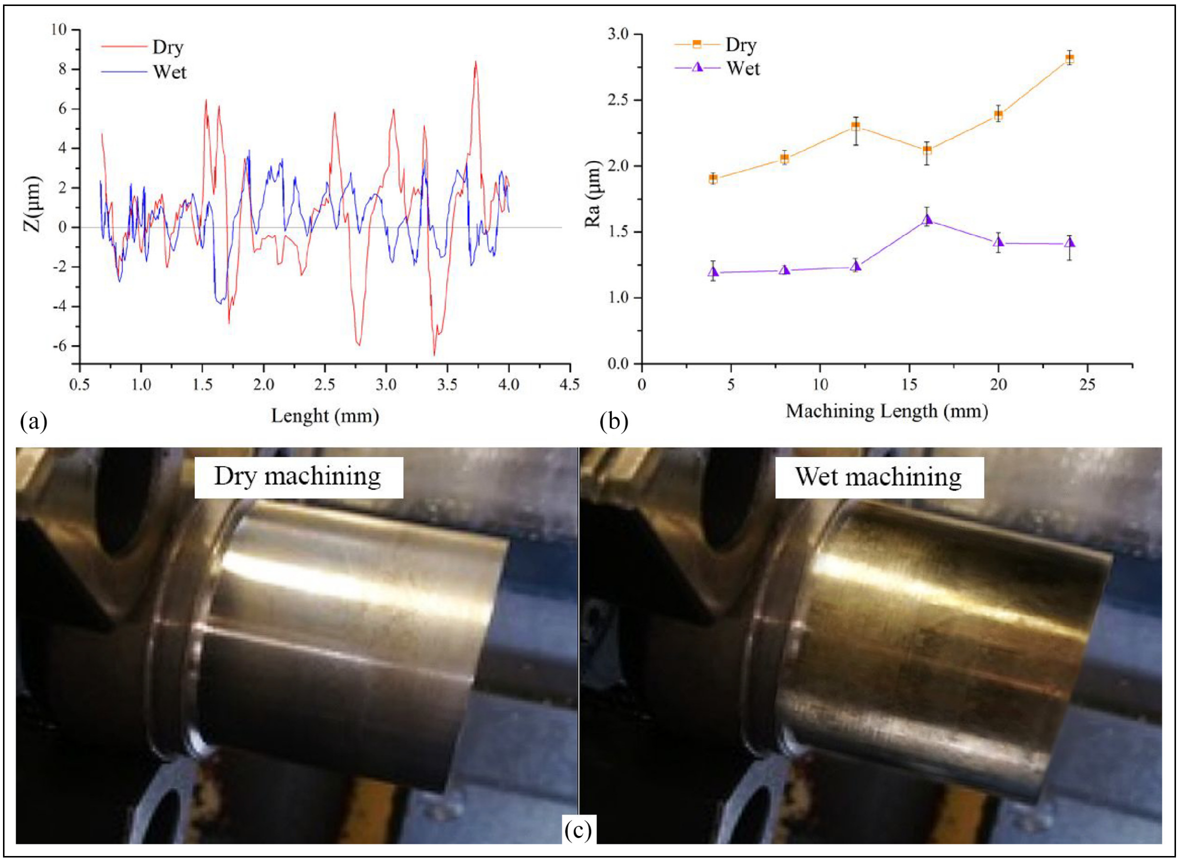

Figure 12. Surface quality of machined AZ91/SiC composites at cutting speed 70 m/min, feed rate 0.2 mm/rev and angle 35: (a) roughness profile, (b) surface roughness, and (c) surface oxidization of samples for different conditions.

- Using cutting fluid emulsion 5% improved the tool life considerably so that at cutting speed 70 m/min, feed rate 0.1, depth of cut 0.5 mm and side cutting edge angle 55°, tool life improvement is nearly 110%. It is attributed to the role of coolant part of the cutting fluid controlled the temperature rise as well as the oil reduced friction coefficient between hard SiC particles and tool surface.
- Abrasion is the main mechanisms when machining AZ91/SiC in both dry and wet conditions regarding the SEM images and the tool surface analysis.
- Using the machining fluid limits the formation of BUE as well as adhered composite materials on the flank side compared to dry condition.
- The cutting fluid used when machining of AZ91/SiC improved the surface roughness compared to dry machining. Also, profilometer of machined surface at wet condition showed a smoother ups and downs with more reliability.
- Emulsion 5% due to having water, as ingredient, oxidized the surface and changes the composite color. Hence, other combinations of oil and water are suggested.

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