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Review Article

Cutting tool selection for machining metal matrix composites

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ABSTRACT

Metal-based composites (MMCs) have been a major material widely used in aerospace, automotive, and other machinery industries that require low weight and high performance for the last 50 years. Machining of metal matrix composites is quite difficult due to discontinuities in the structure of the material. As a result, it is important to understand all the factors that affect tool wear. Appropriate tool selection is one of the most important parameters to improve process quality and extend tool utilization time. The tool materials are ranging from tool steel to carbide cutters and other coating materials. This study aims to investigate various cutting tools for machining metal matrix composite in a conventional machining process. The effect of cutting tool selection on process parameters is determined in the processing of composite and microstructure, as well as on surface finishing fluid, cutting force, tool life, and tool wear.

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INTRODUCTION

Metal matrix composites (MMCs) are materials reinforced with fiber, particles, or whiskers [1]. The most commonly used materials as matrix materials are cobalt, titanium, aluminum, magnesium, copper, and their alloys. The reinforcement materials are alumina (Al_2O_3), boron carbide (B4C), and silicon carbide (SiC) are the most commonly used materials [2]. The materials of MMCs are classified into two parts, continuous and discontinuous reinforced [3]. In MMCs, the matrix material gives the composite toughness and ductility, while the reinforcing element adds properties that will increase the hardness and strength of the structure [4]. MMCs have been frequently used in recent years in industries where high performance, lightness, and durability have come to the fore. These sectors are; aerospace, cutting tool manufacturing, automotive, marine vehicles, etc. Proper processing of MMCs used in critical parts specifically used in the aerospace and automotive industries is crucial. However, a larger crop using MMCs has been reduced due to the difficulty associated with the machinability of the material [1]. MMCs parts are generally fabricated in near-net shapes; on the other hand, conventional machining is necessary for complex features. However, MMCs have discontinuous structures that make the machining of materials difficult. “The considerable tool wear and quality surface machined finish can be introduced by abrasive particles with tool-like hardness” [5]. Due to this, the machining process of MMCs is limited due to the properties of the reinforcing material. Considering

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Table 1. Physical characteristics of various cutting tool materials

Property	AJ1O$_3$	AJ1O$_3$+TiC	Sialon	Hard metal	PCD	CBN	MCD
Density (g/cm)	3.91	4.28	3.20	14.7	4.12	4.28	3.52
Compressive strength (GPa)	4.00	4.50	3.50	4.44	7.60	3.552	8.68
Fracture toughness (MPa m^{05})	2.33	2.94	5.00	10.48	8.81	3.7	3.4
Knoop hardness (GPA)	16	17	13	17	50	27.5	57–104
Young's modulus (GPa)	380	390	300	593	776	587	1141
Thermal expansion (10–6/°K)	8.5	7.8	3.2	5.4	4.2	4.7	1.5–4.8
Thermal conductivity (W/m/°K)	8.4	9.0	20–25	100	540	44	500–2000
Wear coefficient	0.76	0.92	0.91	1.15	3.89	1.34	2.14–5.49

PCD: Poly-crystalline diamond; CBN: Cubic boron nitride; MCD: Mono-crystalline diamond.

the wide range of uses and potential applications of MMCs, it is understood that extensive research has been conducted on these materials. To optimize machining and improve the machinability of MMCs; Many experiments and modeling studies have been carried out to examine the effects of reinforcement shape, tool materials, and tool geometry on the process. The processing of MMCs differs in many respects compared to metals. Composites have lower machinability than matrix materials.

However, machining composite materials have some problems such as excessive tool wear. This causes problems such as reduced tool life and high tool costs. This is a major problem, such as low surface quality and sub-surface damage. For this reason, selecting a cutting tool suitable for machining MMCs is the most important factor in determining the quality of the part. A cutting tool suitable for machining the material will be considered cutting forces, surface temperature, roughness, and BUE are reduced and less friction is achieved by reducing the mating time of the composite material and the cutter tool, thus extending the tool life. High-speed steel (HSS) tools, which are common and cheaper to use, are inadequate because tool wear is fast in the machining of MMCs [6]. Therefore, advanced features must be added to the cutting tools to machine the metal matrix materials such as a carbide cutter or a diamond-coated cutter. Generally, machinability depends on tool materials, workpieces materials, cutting conditions, and tool geometry. The machining of metal-based composite materials with shavings differs significantly from the machining of traditional and alloy metals. The composite processing is also dependent on the matrix material, the reinforcement element, and the volume fraction of the matrix and reinforcement [7]. The cutting tool encounters at least two distinct phases that have completely different responses to machining. For this reason, cutting tools with high abrasion resistance and special geometry are needed for machining MMCs with shavings.

Within the scope of the study, the effects of cutting tool coating and the effect of cutting tool tip angle on the machining parameters of metal matrix materials were investigated in recent years. In the study, the effect of the coating material on the process parameters was discussed in a wider scope. In the next sections, cutting tools coated with different materials are divided into categories and their advantages and disadvantages are discussed.

This study is a summary of recent studies investigating the effects of coating properties and process parameters of cutting tools presented in the literature on the machining of MMCs materials.

Conventional Machining

Conventional machining is a common technique used to engineer components. Cutting tools are used to give the material its final shape. In the machining of MMCs, it has been observed that the reinforcement material is harder than most cutters. Therefore, the machining of MMCs with shavings is very difficult with conventional cutting tools [8]. In general, MMCs can be machined with cutting tools with the appropriate design and by turning, drilling, and milling in operation conditions. The reinforcement material in the matrix causes wear on the cutter due to friction during cutting, the tool cost increases, and the machine cannot operate at high performance. Therefore, studies are mostly focused on cutting tools that have the same hardness or higher hardness as the material to be machined. Table 1 shows the various physical characteristics of the cutting tools [3].

Recently, cutting tools are produced from many materials, from high-speed steel (HSS) to polycrystalline diamond.

Classification of Cutting Tools

Cutting tools are classified according to the materials from which they are made. Table 2. shows the abrasive cutting tools' properties.

Chip Removal Mechanism

MMCs include reinforcement particles and matrix phases. Chip structures depend on the matrix, reinforcement, and interactions. Although the chip removal mechanism is similar to the monolithic lifting mechanism, there

Table 2. Physical characteristics of various cutting tool materials

Tools materials	Description
High-speed steel (HSS)	• Largest single-tool materials
	• Include W, Cr, V, and Mo alloys
	• Used for drills, hobs, shaping tools, broaches, and some milling cutters
	• Its difficulty in hardening has proved to be a good substitute
Cemented carbides (Hard metal)	• Rigid materials
	• It is an excellent tool where wear resistance and toughness
	• Surface can be coated by TiC, TiN, and A_2O_3 using the CVD process.
Cermets	• Titanium carbonitride cermets are used mostly
	• This tool be able to perform as the cemented carbides
Ceramics	• These tools are more stable than cemented carbides at high temperatures
	• Fraction toughness is less than half cermets
	• Tools materials are Al_2O_3, TiC, Si_3N_4, SiC
	• These tools have excellent hot hardness and thermal shock resistance,
Polycrystalline cubic boron nitride (CBN)	• Hardest materials
	• High temperatures and pressures resistance
Polycrystalline diamond (PCD)	• This material is hardest than CBN
	• Higher temperature and tool wear resistance
Diamond-coated (DC)	• It is the process of coating the substrate with the CVD method.
	• The cutting strength is increased by coating the substrate with carbide.
Monocrystalline diamond (MCD)	• Mono crystal diamond tools can achieve a perfect cutting edge with grinding.
	• The surface finish can reach 0.025 microns or higher.
	• It exhibits superior performance in the machining of MMCs.

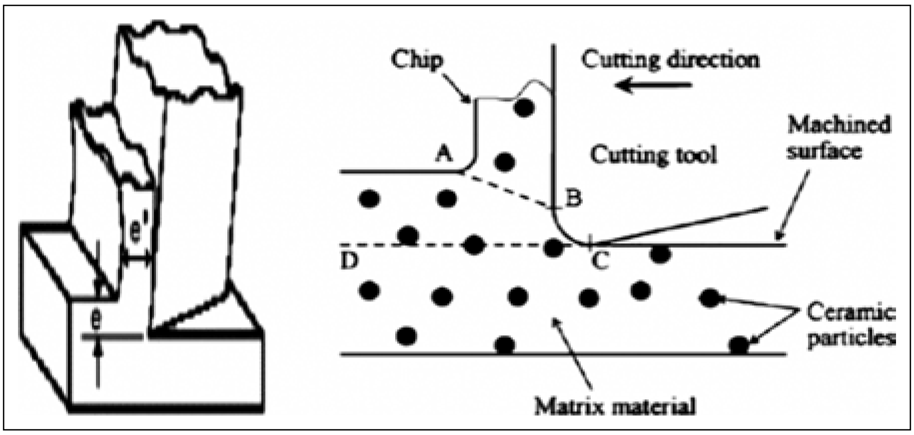

Figure 1. Machining of particulate-reinforced MMCs.

are differences in terms of cutting forces, cutting tool materials, and machining stages. The cutting process of MMCs is typically shown in Figure 1.

Chip formation due to cutting in the AB cutting plane is shown in Figure 1. However, the cutting tool edge Radius will be a plowing region BC around the cutting edge, in there plastic deformation occurs with no chips formed. Therefore, this process shows similar properties to the machining of monolithic metals. In the processing of MMCs, propagation along the CD line, particle breakage, and displacement occur [9]. Chip formation can be affected by factors such as cutting tool properties, cutting progress, the microstructure of the material being machined, and machine characteristics. The effect of cutting feed on the chip formation mechanism is shown in Figure 2.

At a cutting feed of 0.05 to 0.1 mm/rev, the chip has a spiral shape. With the increase of the feed rate (0.4 mm/rev), there is a change from the pillar to the C shape. On the other

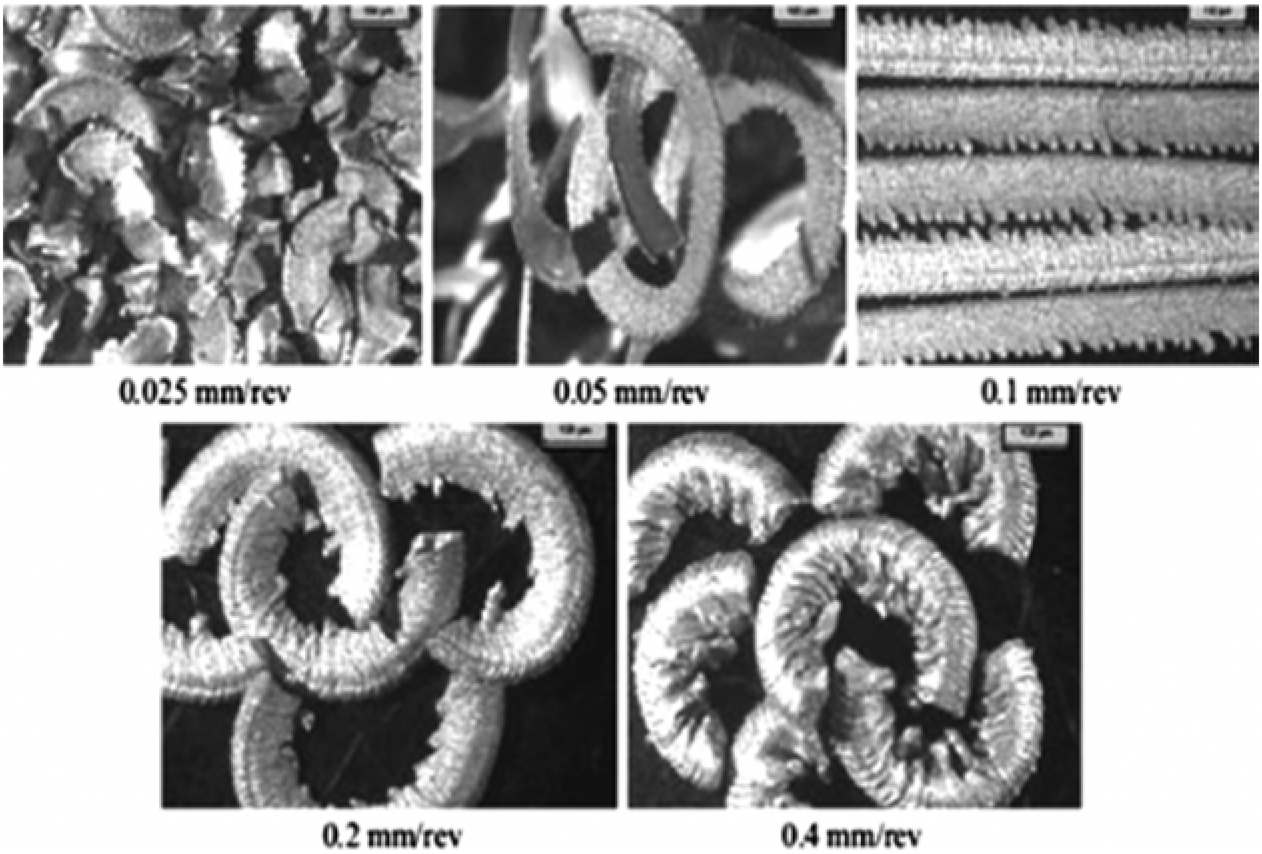

Figure 2. MMC chip shapes at different feeds (speed 400 m/min and depth of cut 1 mm).

side, compared to the alloy, the shape did not change with the cutting progress. At a high feed rate, the cutter has less contact with the material and a short chip is formed. At low feed, the cutter creates longer contact with the material. Thus, a more homogeneous cutting process takes place and long chips are formed [10]. In addition, the tool feed rate is an important factor that directly affects the surface quality. Considering the effect of cutter feed, depth of cut, and tool geometry on chip formation mechanism, reinforcement element size, and matrix material size; It was observed that the continuity of the chip increased with the cutting speed. It is concluded that this is due to the transition effect from brittle fracture to ductile fracture with the effect of temperature on the surface. This trend is more pronounced for fine particles [11].

BUILT-UP EDGE AND EFFECTS OF CUTTING PARAMETERS

Built-up Edge (BUE)

The tool life is usually measured by the amount of cutting tool wear [12]. Cutting tool wear is caused by the combination of loads (Mechanical, Thermal, Chemical, and Abrasive) on the cutting edge. The combination of loads increases synergistically as the stock removal continues [13]. Adhesion and diffusion wear are mechanisms that affect cutting tool wear [14]. The material of the workpiece adheres to the cutting tool surface simultaneously and in two different ways [13]. Built-up edge (BUE) is defined as the adhesion of the workpiece material to the cutting edge of the cutting tool [15]. The reason for the formation of blue is the increase in temperature and pressure during the cutting progress. Another reason for BUE formation is the chemical structure of the workpiece material. The workpiece material adhering to the cutting tool accumulates during the ongoing machining process and is not able to withstand the excessive stresses and separates from the cutting tool. In the machining process, the adhesion of the main material to the cutting surface of the cutting tool is called BUE. This is one of the factors that shorten the wear of the cutters and shorten the tool life. BUE usually occurs in the machining of ductile materials. With the BUE rupture that occurs on the cutting tool and hardens over time, the parts from the cutting tool also begin to break. Therefore, fractures occur through the adhesion wear mechanism. Figure 3 shows the BUE mechanism.

The BUE formation is caused by the effect of the cutting speed. Therefore, studies have shown that the BUE formation is reduced or eliminated by increasing the cutting speed. In a study, the cutting speed rate was increased by 200%, and the BUE formation was reduced by 50% [16].

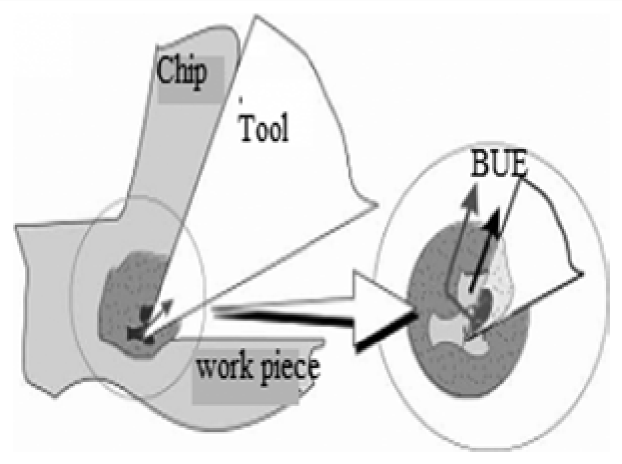

Figure 3. BUE formation and wear by adhesion.

When the cutting speed reaches high values and the cutting depth decreases, the BUE build-up is not visible [17]. However, another study investigated BUE formation in MMC machining of poly-crystalline diamond (PCD) cutting tools. No BUE formation was observed at the high cutting speeds achieved with the PCD cutting tool. This is due to the decrease in the tendency of the material to stick to the cutting tool with the increase in temperature. In addition, longer tool life was obtained at low cutting speeds. The reason for this is considered the BUE formation of the material accumulated on the cutting edge, which protects the cutting edge against abrasive wear [18]. The chemical affinity between the workpiece material and the cutting tool coating material is important for the formation of the BUE formation mechanism.

Many studies have reported that BUE formation negatively affects surface quality [19–21]. BUE becomes unstable as material accumulates continuously. The unstable material falls from the cutting tool to the workpiece and thus the material surface becomes rough.

Effects of Cutting Parameters

Cutting feed and cutting speed is effective on many parameters from tool wear to surface quality when machining the workpiece In a study examining the parameters affecting the cutting force and surface quality of Al/SIC-based MMC material in turning, it was concluded that the surface roughness decreased with the increase in cutting speed [22]. For achieving good surface quality; high cutting speed, low feed rate, and low depth of cut were suggested by the researcher.

In another study focusing on surface roughness in machining 20% ceramic reinforced MMC, they investigated the effect of cutting parameters on surface roughness in turning without using coolant at variable cutting parameters. As a result of their study, it was observed that the cutting tool wear and surface roughness increased with the increase in the reinforcement ratio at constant cutting speed and constant feed values [23]. The amount of reinforcement material is one of the most important factors affecting tool wear. Therefore, tool wear accelerates when the reinforcement ratio in the composite exceeds a certain level [24]. In the research, three parameters that affect the surface quality and cutting tool life come to the fore. These parameters are feed, depth, and cutting speed. It has been observed that the effect of cutting speed on the cutting edge wear is reduced to a minimum with the optimization of the cutting speed [1]. In the turning process with a machine speed of 0.12 mm/rev and a depth of cut of 1 mm, the part was processed with more than one cutting speed. It has been shown that the process performed at a cutting speed of 150 mm/min performs less tool wear than the processes at cutting speeds of 100 mm/min and 200 mm/min [20]. It was determined that the surface roughness decreased at average cutting speeds [25]. Figure 4 shows the effect of variable speeds on the surface [26].

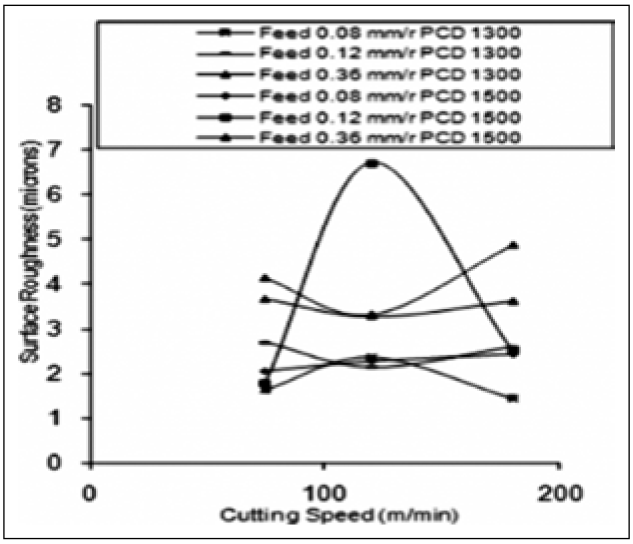

Figure 4. Cutting speed versus surface roughness.

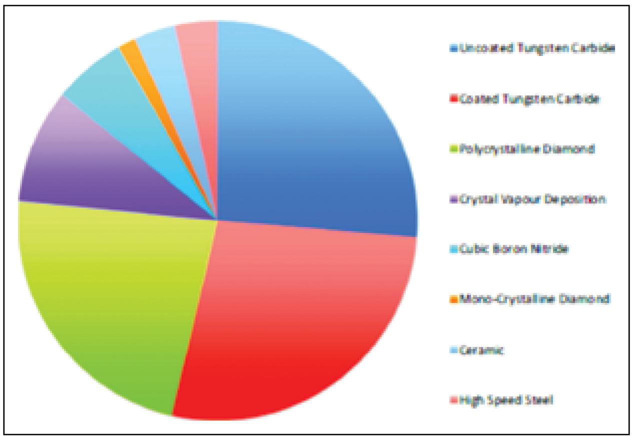

Figure 5. Tool type used in the machining MMCs.

In other studies, it has been claimed that the surface quality improves with the increase in cutting speed [22]. Many studies have suggested that low cutting speed will produce less tool wear by diffusion during the machining or MMCs [27, 28]. Diffusion wear is a problem that causes softening of the tool material when cutting at high temperatures [29]. Research has shown that the primary parameter affecting the required machining power is the cutting speed [30–32]. Cutting speed has been defined as the primary effect of cutting on the wear mechanisms [33]. The size BUE has been found to depend upon cutting speed. BUE formation is inversely proportional to cutting speed [34]. As a result of some studies, it has been argued that BUE formation damages the surface quality of the workpiece and the cutting speed should be increased to prevent poor surface quality. Cutting speed selection is determined by considering 3 factors. These; are BUE formation, surface quality, and tool life. These research seems to have BUE formation occurs at low cutting speeds and tool life is improved; However, the higher the cutting speed, the higher the surface quality of the workpiece. Studies have shown that there is less wear on the cutting tool at high feed rates [35, 36]. The reason for the decrease in tool wear was attributed to the thermal softening of the material with the increase of the contact temperature between the workpiece and the tool interface [37]. In another study, it was attributed to the decrease in the contact time of the cutting tool with the reinforcement material in the matrix with the increase in the feed rate [38]. Studies have shown that feed rate (mm/rev) is less effective than cutting speed (mm/min) on tool life [39, 40]. A study using a lathe found that the primary influence on surface quality was feed rate [41]. In another study, in the fuzzy logic analysis used; It has been suggested that feed rate is the most important factor affecting surface quality and should be minimized to improve surface grinding quality [42]. However, a study on sustainable machining of MMC material using milling tests concluded that feed rate is the most important parameter of surface quality. However, in the experiments, they concluded that, contrary to the known opinions, the surface quality improved with the increase in feed rate [30]. Another study states that the surface roughness depends on the cutting progress. However, it was observed that the roughness of the surface increased as the cutting progress decreased. It has been observed that the cutting and friction angles are significantly dependent on the feed during chip removal. However, it is concluded that the surface roughness is almost independent of the cutting speed [10]. The depth of cut is an important factor in machining MMCs. Many studies show that with increasing depth of cut, a significant increase in cutting force occurs [43]. Considering the results obtained in the studies, it was observed that the surface quality increased as the depth of the cut decreased. In addition, it was stated that the depth of the cut is an effective parameter of the cutting force [30, 44]. It has been observed in the studies that the tool wear increases with the increase of the depth of cut in the turning machining [45]. Considering the literature, it is recommended to increase the depth of the cut if the cutting tool needs to be used economically. If surface quality is a priority, the depth of cut needs to be reduced. Another problem in machining MMCs is that the change in dislocation density affects the shear force. Therefore, the length and volume ratios of the reinforcement material are among the factors affecting the cutting progress and cutting speed [46].

TOOL SELECTION FOR MACHINING MMCS

Reinforcement particles dispersed in the matrix are one of the most important factors that shorten tool life in machining composite material. The reinforcing element, which is separated from the sheet during the cutting process, slides on the tip of the cutting tool during machining. The direct contact between the cutting tool tip and the particles, and thus the friction, causes severe tool wear and material loss [47]. Tool wear mechanisms can be classified as abrasive wear, BUE formation, fractures, and fatigue due to thermal and mechanical loads, which affect machining performance [47, 48]. Studies have shown that carbide-coated inserts are the most preferred cutting tools in the machining of MMCs [49]. Although PCD is the recommended cutting tool for machining MMCs, most studies claim that carbide-cutting tools are an important alternative. Coated and uncoated carbide cutters were investigated in more than half of the studies [1]. Studies on ceramic cutting tools and high-speed steel (HHS) have shown that they are not suitable for machining MMCs due to the brittleness of ceramic and rapid wear of HSS [37, 49]. However, in other studies, However, other studies have shown that coated HSS tools are suitable for use in small numbers of machining and drills [50]. Apart from coated and uncoated carbide and PCD cutting tools, cubic boron nitride (CBN) has also been investigated as a viable cutting tool for machining MMCs. However, studies show that the PCD cutting tool has a higher performance and is a more suitable tool for manufacturing [20, 51]. The cutting tool distribution used in the cutting process is shown in Figure 5. In this study, four commonly used cutting tools are discussed.

Cemented Carbide Tools

It is an ongoing debate in the scientific world whether sintered carbide cutting tools are suitable for machining MMCs. Many researchers have argued that carbide-coated cutting tools are not suitable for machining MMCs [52, 53]. In the machining of MMCs, the use of carbide tools is beneficial after certain conditions are met [33, 54]. Carbide tools are effective in machining or roughing a small number of workpieces [55–57]. However, low cutting speed and high feed rate are suggested to improve tool life

[40]. In a study, the effect of cutting speed on the tool life of a ceramic particle-reinforced composite on a lathe in a certain time was investigated [58]. In the study on different cutting tools, it was concluded that carbide cutters are the most economical cutting tool for machining MMCs [59]. It has been observed that the coating has little effect on tool life during the machining of MMCs [60, 61]. It has been observed that the surface quality of the MMCs increases when the carbide-coated tool is used instead of the uncoated cutting tool [62].

Polycrystalline Diamond (PCD) Tools

PCD tools have long been used successfully to machine MMCs [63, 64]. The success of PCD tools is attributed to the fact that the tool insert hardness is greater than the hardness of the grains that make up the reinforcement phase [65, 66]. It has been observed that high surface quality is obtained with low cutting force with the PCD tool. Researchers agree that PCD cutting tools have a longer life than carbide tools. This makes PCD cutters the ideal tool for machining MMCs [1]. PCD tools provide admirable performance in machining MMCs; however, the processing cost is also significantly higher due to production costs and consequently limits their use [40]. Rapid tool wear was found on the cutting edges of PCD cutters used in a study in which hole drilling was performed on MMC material with a high particle reinforcement rate. However, considering the machining performance of the material, it has been observed that these tools are suitable for machining composites with high volumes and large grain sizes [67]. Results from their research showed that the PCD tool exhibited 30 times longer tool life than a carbide tool with the same cutting parameters. In another study, he machined particle-reinforced MMCs using PCD tools and found that wear was the primary wear mechanism confirmed by the flank with grooves parallel to the chip flow direction [68].

Chemical Vapor Deposition Tools

The usability of diamond-coated tools produced using the chemical vapor deposition (CVD) method as a suitable tool-tip for machining MMCs was also investigated. In a study comparing the CVD cutting tool and the PCD cutting tool, the CVD tool was found to be insufficient [69]. In another study, it was observed that the use of rough or multi-layer CVD coatings provides lower machining strength when machining SiC-reinforced aluminum than using smooth coatings [70]. However, during additional studies, coating defect was identified as a major issue for wear when machining MMCs with CVD tools [71]. In a study examining the effect of SiC additive ratio on the machinability of MMCs, it was concluded that tool life shortens as SiC additive amount increases [72]. In another study comparing the performance of CVD diamond coated and PCD tools in machining A356/SiC MMCs, the time it took for side wear to become visible on CVD tools was 10 times faster than with PCD [73]. Figure 4 shows a comparison between side tool wear on a coated carbide tool and a CVD tooltip. A study of the behavior of CVD tools when machining MMCs showed that at low cutting speeds the primary failure mode is coating failure, while at high speeds the primary failure mode is edge chipping [74]. Due to the difficulty of controlling the coating parameters, CVD tools are considered to perform poorly in the machining of MMCs.

Cubic Boron Nitride Tools

Although not as hard as PCD cutting tools, CBN cutting tools are much harder than conventional carbide tools [75]. CBN and PCD cutting tools were used in a turning experiment at low depth of cut, feed rate, and cutting speeds. In the study, it was seen that the amount of BUE formed in CBN tools was higher than in PCD tooling. However, it was concluded that CBN tools exhibited shorter life performance [67]. A study on an aluminum MMC machined with 110 μm and 16% SiC reinforcement particle sizes identified tool breakage as the primary wear mode in CBN tooling [20]. During the same study, abrasive side wear was detected as the primary wear mode when machining the material with reinforcement particles of 30 and 45 μm. In a study investigating the machining of ceramic particle-reinforced composites, tungsten carbide, PCD, and CBN cutting tools were investigated. It was observed that PCD and CBN cutting tools caused the least subsurface damage by breaking the ceramic particles along their crystallographic planes. In a study, it has been shown that the PCD cutting tool has a five times longer life than the CBN cutting tool at optimum cutting and feed rates and a certain depth of cut [60]. However, it was concluded that the CBN cutting tool is not suitable for cutting MMCs with larger particles.

Machining Performance of Cutting Tools

Table 3 show thats In the machining of MMC materials, the effect of the cutting tool coating material on the process parameters and the surface in turning, milling and drilling processes.

The main obstacle to the processing of MMCs with traditional methods is the presence of two or more different phase materials in the internal structure of the material. Since the ceramic materials dispersed in the metal material are very hard, they cause the wear of the cutting tools. Therefore, both the cutting tools wear out and the surface quality of the material deteriorates during the machining of MMCs. Therefore, it is very important to use the correct cutting tool when machining MMCs. As indicated in Table 3, it is seen that the coating process has made serious changes on the performance of the cutting tools.

Uncoated HSS cutters have been found to wear quickly when machining MMCs. Therefore, it has been observed that these cutters cannot meet the desired cutting performance in the processing of MMCs.

Table 3. Table 3. Performance of the cutting tools used in the machining of MMCs

Cutting tools	Workpiece machining methods		
	Turning	**Milling**	**Drilling**
CT	• In ceramic tools, wear increases as the cutting speed increases, but wear in carbide or diamond tools is independent of the cutting speed [64]. Wear in ceramic cutting tools completely depends on the reinforcement geometry. • Cutting speed and depth of cut were not found to have much effect on surface roughness. However, as the cutting speed increases, the surface quality decreases.	• PCD inserts generated higher cutting forces. The cutting forces are also higher during milling with PCD tools because the cutting edge is slightly honed before the deposition of the diamond film [76]. • In the study, although CT cutters outperform PCD cutters in terms of productivity, PCD tools have a longer lifespan [77].	• Considering the surface roughness parameter, the efficiency of CTs is low at high cutting speeds [17]. • In drilling MMCs, the number of holes remains almost stationary until it reaches a certain number. Therefore, the performance of carbide-cutting tools is higher than CVD cutting tools [17].
PCD	• Surface quality is high at high feed rates [64]. • As the reinforcement ratio increases in MMCs, CVD inserts cannot meet the expected cutting performance. Therefore, PCD-cutting tools are preferred in such cases [78]. • PCD cutting tools outperform carbide tools in turning MMCs with different geometries and reinforcement ratios [79].	• BUE is observed at high feed rates. BUE is observed at high feed rates. Therefore, the coolant should be used where the amount of advance is high [62]. • As the chip removal rate increases, the surface roughness increases. As the chip removal rate increases, the surface roughness increases. The most efficient chip removal rate is between 250 and 1000 m/min [62].	• The cutting tool performance is high against the increase in cutting speed in the drilling of MMCs [80]. • Considering the surface roughness parameter, the productivity of PCDs is low at high cutting speeds [81]. • PCD cutting tools show high performance in drilling.
CVD (WC, TiC, etc.)	• In MMCs, tool wear increases as the reınforcement ratio increases [40]. • Cutting speed and temperature have little effect on WC tool wear [82]. • It is not suitable for MMCs with high reinforcement ratios because of its high wear rate.	• Carbide tools have low tool life even at low cutting speeds. However, coating carbide tools offer little advantage [83]. • The CN coated carbide cutting tool showed a tendency to wear at a cutting speed of 61 m/min in dry chip removal [84].	• The performance of CVD-coated cutting tools is remarkable in MMCs where the hardness of the reinforcement is reasonable. However, tool wear is low in graphite-reinforced MMCs because the additive is a lubricant [85].
CBN	• In silicon carbidereinforced MMCs; The CBN tool performed best compared to the silicon nitride tool, while the carbide tools were found to wear significantly [20]. • Machining SiC particle-reinforced MMCs, the CBN cutting tool wears less than the PCD cutting tool because it is harder than the reinforcement material [62].	• Milling of MMCs it has been determined that the forces decrease with the increasing cutting speed in milling operations with the CBN tool [77]. • Surface roughness decreases with the increasing cutting speed in the milling process with the CBN cutting tool. • CBN cutting tools are highly resistant to milling operations at high temperatures.	• CBN shows high performance in drilling hard particle-reinforced MMCs. Surface quality is good and tool wear is less than other cutting tools [86]. • CBN cutting tools are tools with high hardness. However, production costs are high.

CT: Cemented carbide tools; PCD: Poly-crystalline diamond; CVD: Chemical vapor deposition; CBN: CBN: Cubic boron nitride.

It has been observed that the cutting performance of ceramic coated cutting tools has increased compared to HSS. However, it has been reported that the wear behavior of ceramic tools changes with the cutting speed. However, although the production performance of ceramic coated cutters is high, their lifetime is shorter than PCD cutters. However, the performance of CT cutters decreases at high cutting speeds. Therefore, CT cutters should not be preferred if surface quality and cutting tool life are important in the machining of MMCs.

PCD cutting tools outperform carbide cutting tools in machining MMCs. Material surface quality is good at high feed rates. However, PCD tools show very high performance in drilling.

WC cutting tools are not affected much by cutting speed and temperature increase. Their wear is very less compared to carbide tools.

Due to their high hardness, CBN tools have less wear behavior in machining of MMCs compared to other cutters. Therefore, in MMCs where reinforcement ratios are high, CBN tools show superior performance compared to PCD and other cutting tools.

The study shows that choosing the right tool is vital to meeting the challenges of machining MMCs. Coated cutting tools are very useful in the efficient machining of MMCs. One of the most important criteria in the selection of cutting tools is the economic reason. High performance cutters are costly and this is the case in many applications. In applications where surface quality and cutting tool life come to the fore, PCD and CBN cutters are recommended to be preferred. HSS or carbide tools can be preferred in machining where surface quality and tool wear are not important.

Even if the applications of non-traditional processing methods increase in the coming years, traditional processing methods will still be at the forefront in terms of ease of processing, accessibility and economy. Therefore, with the developments in materials science, the properties of composites change and accordingly, the performance of cutting tools should be increased.

In the current studies, it is seen that the materials used in the cutting tools, the coating material, the coating thickness and the coating method are the most important parameters in the processing of MMCs. Choosing the right cutter for the right workpiece and determining the features of the cutter are still among the intense research topics.

While research is still ongoing for super-cutting tools that will process MMCs without any problems, it seems possible that a super-coated cutting tool will emerge in the near future, with developments in nanotechnology and coating engineering.

CONCLUSIONS

According to the literature study provides some conclusion on follow;

- In the machining of MMCs, the slope of cutting speed versus tool life is independent of cutting parameters and secondary manufacturing processes. However, the slope is affected by tool geometry, tool material and workpiece material.
- The matrix hardness affects MMC machinability. As matrix hardness increases, tool life is shortened.
- CBN and PCD cutting tools are one and two times greater than a WC tools in terms of wear resistance. A WC tool can be used economically for roughing. However, PCD tools should be used for finishing as they minimize subsurface damage.
- Water-based coolant helps reduce built-up edge formation but fails to improve tool life. Insufficient flushing of chips can reduce tool life as a tool has to re-cut abrasive chips.
- Broken and delaminated particles in part-reinforced MMCs are unavoidable in conventional machining. Most MMCs, with care, can be processed by suitable conventional processes. Polycrystalline diamond tools can be effectively used to machine MMCs in turning, milling, surface finishing, drilling, reaming, threading, tapping, and grinding. Once adequate adhesion of the coating is achieved, cheaper diamond-coated tools can emerge as an alternative to solid diamond tools.

As a result, In MMCs, the size and properties of the reinforcement material, as well as the matrix material, are among the factors affecting tool wear. In MMCs, the size and properties of the reinforcement material, as well as the matrix material, are among the factors affecting tool wear. However, cutting speed and depth are other factors that affect both tool performance and surface quality.

WC tools are generally preferred for economical machining; however, diamond cutting tools are preferred where the efficiency of WC is low. PCD and CBN cutting tools show superior performance in machining MMCs due to their high hardness. Therefore, these cutting tools should be preferred in processes that require good cutting performance rather than cost.

Data Availability Statement

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics

There are no ethical issues with the publication of this manuscript.

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