A REVIEW ABOUT MACHINING OF COMPOSITIES MATERIALS TOWARDS MACHINING THE NEW A380/NBC COMPOSITE

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Abstract The use of metal matrix composites (MMC) has been highlighted due to industrial demands for better mechanical properties. MMCs of lightweight alloys such as aluminium and ceramic particles have been widely used in aerospace, marine, defense, and automotive industries. Niobium carbide (NbC) stands out as reinforcement due to its high hardness, good mechanical properties, and elevated Young's modulus. The advancement in manufacturing new composite materials leads to a further analysis of the process and parameters of machining these materials. The effects produced in the machining process of these materials are strongly influenced by the use of different amounts of reinforcement and its characteristics. Owing to the enormous heterogeneity of matrix alloys and reinforcements, machining CMMs left a challenging task. Several studies have been carried out in conventional and unconventional processes to optimize the machinability and characterize the processing quality of composites. The types of chips formed are related to some parameters like shear zone, material properties, and cutting conditions, which are influenced by the material. Surface integrity and quality are one of the most critical variables in its application. Different materials are expected to have different stresses in the piece, which could harm the piece's properties. The extremely high hardness of the most commonly used reinforcements, such as NbC, promotes relation to rapid tool wear; this condition could increase machining time and impair part quality. To reduce the problems of conventional machining, electric discharge machining (EDM) is the most used technique. This is mainly due to no direct contact between the instrument and the workpiece, avoiding mechanical forces and surface quality problems. However, there is a gap in studies to develop and characterize aluminum matrix composite reinforced with NBC. In this sense, an overview of some processes and parameters utilized to machining composite was presented. As conclusions form, the current work proposes some types of parameters which can be used in an optimized experimental matrix based on the Taguchi method to investigate the variables of different conventional machining (defined and non-defined tool geometry) and electrical discharge machining. This paper helps show some research on machining parameters and the challenges of the process on the composite.

Keywords: *aluminum matrix composite, niobium carbide, machining parameters, tool life*.

1. INTRODUCTION

The gradual increase in the research work associated with metal matrix composite is ostensible in the context of contemporary demand for advanced materials. Due to the high strength-to-weight ratio, MMCs are preferred in industrial applications (Sivakandhan *et al.*, 2019). MMC are materials typically ceramic-based materials acted as a reinforcement for lightweight matrix alloys. Aluminum alloys are highlighted as the most attention matrix due to excellent mechanical and corrosion properties, forming aluminum matrix composite (AMC) (Saini *et al.*, 2014).

The carbide class of ceramic materials has received great interest to be used in MMC, as reinforcement due to its mechanical, physical, and chemical properties. Carbides generally show high hardness, resistance to wear, and elastic modulus compared to high-strength steels (Dias *et al.*, 2017). Several materials can be used as reinforcement in the aluminum matrix; SiC is the most commonly used. However, it may present deleterious reactions to the matrix. Among these materials, niobium carbide (NbC), a refractory metal compound, exhibits high hardness around 20 GPa, the high melting point above 3000 °C, good chemical properties, elevated Young's modulus and Poisson's ratio (Subramanian *et al.*, 1996). The use of NbC as reinforcement is still not widely used in AMC; its use in other alloys and uses has already shown excellent results (Pizzatto *et al.*, 2021).

The composite production with NbC as reinforcement can be resumed in some works. In a previous work (Arendarchuck, 2022), the formation by stir casting process of A380 aluminum alloy reinforced up to 15wt% of NbC was analyzed, and subsequent thixoforming was applied. The results show that the technique is suitable to form composite fabrication, and the reinforcement level significantly influences grain size and hardness. In the Fig. 1, (a) it can be visualized a micrograph of A380/NbC composite, showing the presence of clusters of micrometric NbC particles, (b) energy dispersive spectroscopy (EDS) maps of Nb element.

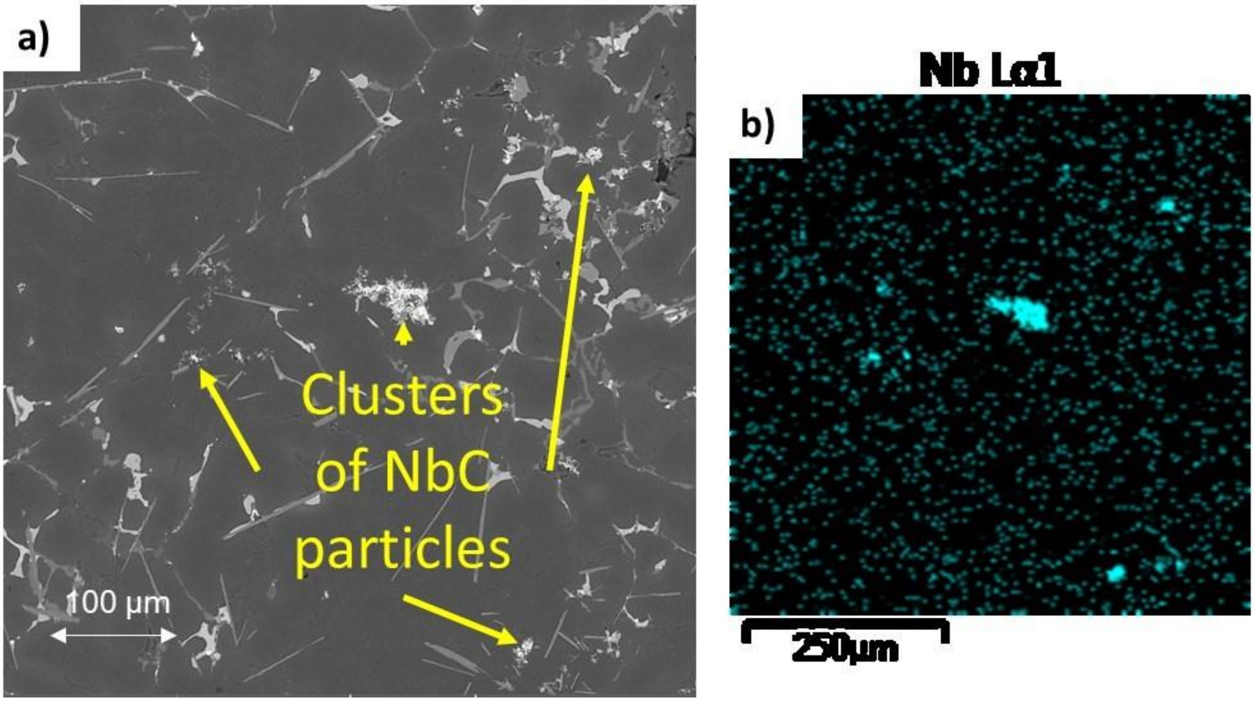

Figure 1. (a) Micrograph of A380 aluminum alloy reinforced with 5 wt.% of NbC particles and (b) EDS image of the micrograph showing the Nb distribution (Adapted from Arendarchuck, 2022)

Other methods have been used to obtain MMC with NbC as reinforcement. High-energy ball milling methods was used to synthesize a copper-based composite with Cu, Nb, and graphite powder mixture in situ (Zuhailawati and Mahani, 2009). Results by XRD show precipitation of NbC particle in the Cu–Nb–C after the sintering process. This particle improved the hardness of the *in-situ* composites.

The composite coating also was obtained, using an Fe50Mn30Co10Cr10 high entropy alloy with different NbC content, which were fabricated by laser cladding (Li *et al.*, 2021). After analysis, results show that the micro-hardness and wear resistance of the coatings significantly improved with the increase of NbC content.

The formation of W-NbC composites with up to 40 vol.% NbC was made, where the composites were prepared by hot-pressing at 2200 °C under a pressure of 30 MPa (Wei *et al.*, 2018). In that case, the properties have a peak. For example, composites' flexural strength and fracture toughness first increased and then decreased with NbC content increasing, reaching maximum values of 1050 MPa and 13.6 $MPa \cdot m^{1/2}$, respectively, at an NbC content of 20 vol.%.

The fabrication of AMC components can be realized with several manufacturing methods. However, to obtain a material with an exact shape, a subsequent machining process is required to size and shape for specific applications and with surface roughness quality (Srivastava *et al.*, 2018). Even though the AMC has excellent mechanical and thermal properties, its poor machinability and processing costs are major obstacles to its application and dissemination in several different areas (Laghari *et al.*, 2020). The principal effects of its characteristics are due to hard abrasive particles in the aluminum alloy that cause rapidly wear tool reducing its life, which can result in higher tool costs and surface roughness in the final component. This can be achieved by analyzing better machining parameters and understanding the influence of each one on the characteristics of the final part. The feed rate, cutting speed, amount of reinforcement, tool material, and others affect the surface quality and process (Rubi and Udaya Prakash, 2020).

Some statistical methods can be used to analyze and understand how each parameter influences the final part. The factorial design has been one of engineering experiments' most important statistical analyses. It is a statistical method for excellently evaluating and exploring the effect of factors on the response or output factor. In addition to factorial design, the Taguchi method is an approach to multi-response problems. It is designed to optimize process parameters and understand the combination of factors for an appropriate response. (Udaya Prakash *et al.*, 2018).

Some studies on the machining of AMCs have been reported in the literature over the years. In milling operations in composite behavior, a reduction in spindle speed can promote low cutting force. The machinability characteristics of end milling operation in aluminum 7075 metal matrix reinforced with Silicon Carbide (SiC-5wt%, 10wt%, 15wt%) and Alumina (Al_2O_3-5wt%) was studied by Rajeswari and Amirthagadeswaran (2017). The results show that between the spindle speeds tested a lower value of f 1000 rpm, depth of cut of 1 mm, 5% of SiC and medium feed of 0.03 mm/rev,) produces high material removal rate coupled with a fine surface finish, less tool wear, and low cutting force. With the analysis of the Taguchi method and ANOVA, the authors noted that spindle speed and weight percentage of SiC are the most significant factors affecting the machinability of hybrid composites.

In other machining processes, the results can be different. Pugazhenthi *et al.* (2018) investigate the machining characteristics of AA7075 / (0–12 wt.%) TiB2 during dry turning using a polycrystalline diamond cutting tool. The authors show that the increased cutting speed enhanced surface roughness due to reduced transferred material. In addition, the increased cutting speed increases the temperature, which destroys a portion of dislocations in the composite and causes thermal softening, reducing the machining force. Its results also were previously achieved by El-Gallab and Sklad (1998) when evaluating turning characteristics of 20%SiC/Al metal-matrix composites. On the other hand, cutting speed and TiB2 particles increased the tool wear respectively due to depletion of stable built-up edge (BUE), i.e., chips to adhere or locally weld to the tool's edge and abrasive action.

Among the machining universe, other methods are available to achieve an improved final surface with low roughness and better machinability. Unconventional machining, such as EDM, is currently being used to improve AMC machinability (Kar *et al.*, 2018). EDM process generated sparks that act in machining materials, producing complex shapes. Khajuria *et al.*, (2019) reported that an increase in the Al2O3 reinforcement weight in AA2014 alloy promoted a decrease in material removal rate (MRR) and surface roughness (SR), although there was an increase in tool wear rate (TWR), probably due to an increase in microhardness of composites.

A similar process of Wire-EDM is also available to produce accurate complex profiles with AMC. Recently Doreswamy *et al.* (2021) investigated the machinability of SiCp reinforced Al6061 composite by Wire-EDM. In the samples up to 8wt% of SiC, the three principals parameters influenced MRR: current (I) had the major influence (27.39%), followed by pulse-on time (Ton) (22.08%) and wire-speed (Ws) (21.32%). The authors also explain that adding SiC up to 8% in the Al6061 matrix did not significantly differ in MRR. However, a marginal decrease in MRR is observed with an increase in SiC content. These results are in accordance with Udaya Prakash *et al.* (2018); in their study, a hybrid MMC was fabricated by stir casting, reinforcing the A356 aluminum alloy with 1.5 wt%, 3wt% & 4.5wt% of 63 µm particles of B4C and fly ash of average particle size 12 µm. The results show a uniform distribution of reinforcement particles and that the proposed method can find the optimal process parameters. The analysis of the Wire-EDM process with 0.25 brass electrode shows that gap voltage (66.27%) has the most significant statistical influence on the MRR of composites, followed by Pulse on time (18.74%) and pulse-off-time (14.52%).

Although the process has a significant impact on the final surface quality of on machined part, tool selection also has an effective action in this situation. Tool geometry, like rake angle, edge geometry, and noise radius, in addition to tool wear in the finish machining, becomes an additional parameter affecting composites' surface quality. Therefore, it is possible to reduce these issues using the tool more effectively, like cemented carbide, coated carbide, and diamond in machining (Srinivasan *et al.*, 2012). This section shows the feasibility of high-speed steel (HSS) and ceramic tools unsuitable for MMC applications. On the other hand, Cubic Boron Nitride has been shown as a possible alternative in machining and diamond-coated PCD tools (Nicholls *et al.*, 2017).

The diamond tool was analyzed by Pugazhenthi *et al.* (2018), turning in a conventional lathe the composite of AA7075 aluminum alloy reinforced with 0wt%-12wt% of TiB2, using a PCD insert. The results show a formation of the BUE in the tool, and this phenomenon is desirable to delay the wear of the cutting tool. Nevertheless, the force required for cutting increases. In this study, in general form, the use of the PCD tool shows a satisfactory result with stable BUE observed on the tool face at lower TiB2 particle content. Therefore, in the paper, the increase in the content of TiB2 particles expedited the nose wear and removed the formation of BUE.

As can be observed from the literature survey, the formation of metal matrix composite reinforced with NbC is scarce, with a few papers only producing its composites with no machining analysis. This review aims to show some parameters and machining processes that can be used to understand the process of removing material from metal matrix composite with towards NbC as a reinforcement.

2. MACHINING PROCESS

In general, the composite can be machined by turning, drilling, or milling with proper tool design and operation conditions. Nevertheless, the reinforcement causes rapid abrasive wear of tool material, resulting in additional costs and prejudicial effects on the machined surface and material properties (Bains *et al.*, 2016). It is suggested that the different manufacturing processes are all affected by the composition of reinforcing particles in a composite material. Then on Tab. 1, it is possible to visualize the summary of some works related to different machining processes and their characteristics performed in composite materials.

Table 1. Process and tools utilized in machining composites

Material	Process	Tool	Results	Reference
Al520/ 10 wt% SiC/ 1 wt% Bi/ 1 wt % Sn	Milling	Physical vapor deposition (PVD) TiAlN coated carbide	Effect of cutting parameters and reinforcing particles on the surface quality attributes is not statistically significant	(Sougavabar *et al.*, 2022)
ZrO2/39.25 vol. % NbC/ 0.75 vol.% Al2O3	Rotary ultrasonic machining (RUM)	Sintered metallic diamond tools	The ductile fracture material removal mode	(Sandá and Sanz, 2020)
Alumina/ 17 vol.% Zirconia/ 25 vol.% - 32 vol.% NbC	Wire electoral discharge machining (WEDM)	Zinc coated brass	Higher contents of NbC lead a lower mean roughness	(Schmitt-Radloff *et al.*, 2017)
Al11Si/ 20 wt% Mg2Si/ 0.4 wt% Bi	Turning	Kennametal coated carbide	Bi presence, feed rate and cutting speed have an effect on cutting force, Bi reduce it and tendency to form BUE	(Razavykia *et al.*, 2015)
A380/ 20 vol% SiC	Turning	brazed polycrystalline diamond (PCD) and chemical vapor deposition (CVD) diamond coated	A faster rate of flank wear was observed on the CVD than PCD	(Andrewes *et al.*, 2000)

2.1. Conventional machining

Generally, there is no ordination in the particle's distribution of the composite. Therefore, considering the heterogeneous structure formation, the machined surface of MMC is dependent on particle position relative to the cutting edge. Ghandehariun *et al.* (2016) presented three cases of particle-tool interaction, which can be visualized in Fig. 2. In the first case, the particle is above the tool. The main phenomena are particle pullout related to cavities and tensile residual stress. On the other hand, no cavities were produced in two other cases, i.e., below or in the middle of the cutting plane/surface. It is probably due to the tool flank pushing the particles into the matrix, resulting in compressive residual stress. The relative position of particles in the material could also be linked to surface roughness since reinforcements can present different situations, such as being pushed, elongated, sheared, or pulled out during the machining process (Liao *et al.*, 2019).

An analytical model also was utilized to predict the too-particle behavior. Pramanik *et al.* (2007) conducted a FEM investigation into the behavior of metal matrix composites: tool-particle interaction during orthogonal cutting. They showed that the movement the tool performs significantly changes the state of stress in the particles and the matrix around them. Particles just above the cutting plane act as indenters and particles along the way are displaced, leaving voids, and are replaced elsewhere. In the case of particles below, the cutting plane moved along the chip and slid along the rake face to undergo a large plastic strain.

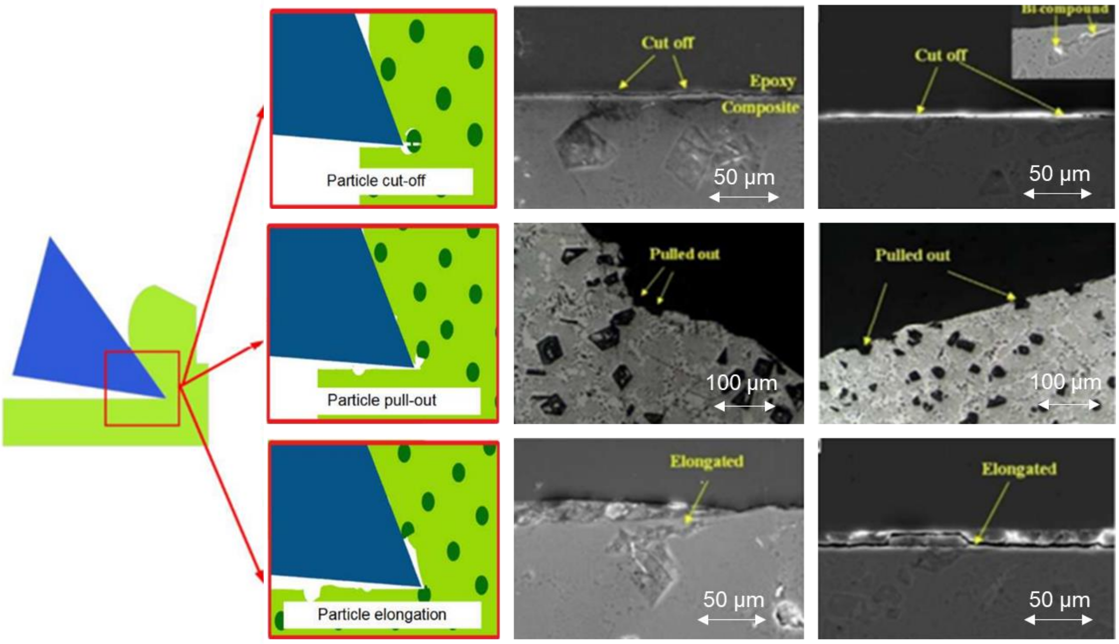

Figure 2 . A composition of probably scenarios of particle-tool interaction during the machining process with correspondent micrographs featuring particles shearing/ cut-off (top), pull-out (middle) and elongation/deformation (bottom). Micrographs correspond to turning of Al–20% Mg2Si (Adapted from Liao *et al.*, 2019; Ghandehariun *et al.*, 2016 and Razavykia *et al.*, 2015)

When multiple cutting tools are aggregated and sequentially forced on the workpiece, the heat generated tends to be higher if compared to a unique tuning process. In this situation, the built-up of the temperature or dynamic loads may affect the finished surface of the composite, for example, tool chattering marks, chip packing in tool flutes, and subsequent increased cutting forces and deteriorated surface integrity (Liao *et al.*, 2019).

The milling process was analyzed by in an investigation of the 2009Al/ 20 vol.% SiC surface integrity due to the intensive tool-particle interactions. The work evaluated two machining conditions with a very high feed rate (HFR) to promote displaying ductile milled marks and marginal subsurface damage. Meanwhile, very low feed rate (VLFR), the semi-brittle regime) induced intensive mechanical and thermal loads into the workpiece, leaving a layer of broken particles in the machined surface accompanied by the plastic flow of matrix material. The results show that machined samples with VLFR process lower surface roughness values and compressive residual stress. It also presents very low fatigue due to severe surface anomalies facilitating the formation and nucleation of cracks and reducing fatigue life. The machined surface under HFR surface pits caused by particle pull-outs, particle protrusion due to pushing the particles into the machined surface, and visible milling marks were identified as the main surface defects.

At this stage, different machined surfaces with the same material and tool function of machining parameters. In this fact, conventional machining of NbC-reinforcement composite would produce surfaces with contrasting results, so the choice and use of the appropriate parameters for the desired final surface are of great importance

2.2. Unconventional machining

New technologies applied to obtain of composite materials with high hardness and better distribution of particles reinforcement, lead to develop works focused on alternative methods to promote material removal, achieving good results in changing the form of composites (Sandá and Sanz, 2020). Usually, unconventional machining technology is a form of phase transformation that removes materials processed by high temperature, high pressure, or high-frequency vibration via special equipment. Current research focuses on methods to remove material without further damage to the final formation of the machined surface. Some processes are laser beam machining and/or laser-assisted machining, ultrasonic-assisted machining, electrical discharge machining (EDM), and high-pressure water jetting (Du *et al.*, 2019).

One of the methods most used for unconventional machining MMC is EDM. A technique in which material removal is provided by a succession of electrical discharges, which occur between the electrode and the workpiece. Material removal is proven by evaporation and melting from the electrode and the workpiece (Kathiresan and Sornakumar, 2010). The employee of this process in MMC already shows promising results with better precision and final quality surface. In the work of Gopalakannan and Senthilvelan, (2013) the EDM process in Al 707/ 0.5 wt% SiC composite was evaluated through the influence of process parameters and their interactions. The results could show an excellent final surface with low roughness and a lower crater height. The statistical analysis shows that the main significant factors that affect the MRR are pulse current, pulse-on-time, and pulse-off-time, whereas voltage remains insignificant.

Ultrasonic machining (USM) is marked as a process with lower material removal between unconventional machining methods. However, a great advantage, if compared to the conventional process, have a little or no heat produced in the machining and machining costs. To remove material, the principle of this method is based on using high-frequency oscillations of a shaped tool using abrasive slurry on the brittle work material (Li and Laghari, 2019). In most common unconventional machining processes like EDM, an electrically conductive material is required to be machined. In this sense, the USM process is highlighted; once in USM, nonconductive can be machined due to the vibrating frequency of the working tool (Dvivedi and Kumar, 2007).

With the mentioned factors, USM can be understood as an excellent process to machine MMC. With the mentioned factors, the USM can be understood as an excellent process to machine CMM. The optimization of the MRR from the parameters of the USM machining of Al/SiC composite was analyzed by Banerjee et al. (2021) using SiC as an abrasive slurry. The results show that to achieve the maximum value of MRR, both slurry concentration and tool feed rate are high. It is also observed that power rating is less significant during this process. Similar work was done by Saravanan *et al.*, (2021) when evaluating the USM machining process parameters in Cr/ 11 wt% Ni/ 1.5 wt% SiC. A constant tool feed rate promotes maintenance of the slurry concentration as an important parameter, but in this case, with process voltage.

Although there is no extensive research on unconventional machining methods applied to MMC, the already achieved results may indicate that the techniques can be applied and improved in composite materials. So, as NbC is similar to tested reinforcement materials, these techniques with appropriate values and parameters of composites formations can be used to machine composites with NbC reinforcements.

2.3. New prospects of machining composites

Although composite machining is a complex process involving several parameters and results, some new works show new machining methods. As noted through this review, some works emphasize processes to minimize tool wear and improve the machined surface quality. Recently Kim *et al.* (2022) presented a hybrid-hybrid (ultrasonic-assisted + laser-assisted) turning study of silicon carbide reinforced aluminum metal matrix composite. In a combination of methods with conventional turning (CT); (ii) ultrasonic-assisted turning (UAT); (iii) laser-assisted turning (LAT); and (iv) laser-ultrasonic-assisted turning (LUAT) with power of 60%, 80% and 100% were evaluated in cutting force.

Figure 3 (a) shows a schematic of the hybrid-hybrid process denominated by the authors. The results show that using only the ultrasonic process (UAT), an average reduction in cutting force and surface roughness was obtained. The separated use of laser (LUAT) promotes an increase in cutting force a poor surface quality due to the formation of BUE in the cutting tool. However, the authors show that in combination with ultrasonic machining (i.e., LUAT), there is a significant reduction in machining forces, and probably, the insertion of rapid vibrations prevents the formation of BUE and, in this case, improves the results.

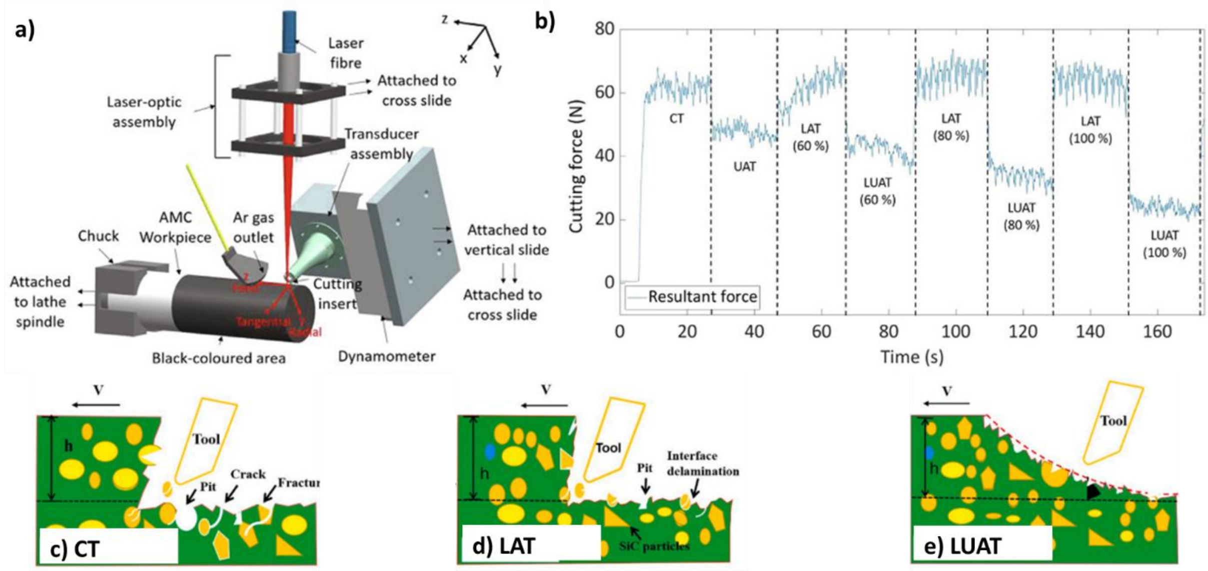

Figure 3. (a)A 3D schematic showing the hybrid-hybrid turning setup, (b) real-time cutting force in the different process of machining composites (Adapted from Kim *et al*. 2022 and Peng *et al.* 2022)

Similar results were obtained by Peng *et al.*, (2022) in the analysis of Al/ 70 vol% SiC by conventional turning using a PCD tool assisted with only laser and together with an ultrasonic process. The results also show that under appropriate conditions, the LUAT process can effectively improve the processing surface quality and effectively inhibit surface damage such as holes and thermal cracks. The material removal process could explain these phenomena. In LUAT, the material is in the form of small particle crushing (Fig. 3 (d)). While the case of LAT is dominated by extensive particle extraction (Fig. 3 (e)), both differ from conventional turning, presenting brittle removal, containing many particle breaks, extraction, large cracks, and matrix tears.

Therefore, new technologies were proposed and can be used together to possibly machine MMC with a high and low level of brittle particles. In this way, future uses in machining NbC-based composites can be made to achieve low cutting force and improve the surface of machined composites.

3. TOOL PROPERTIES

Machining hard-soft composite materials is a complex mechanism. Inside it is a tool selection, and properties are the areas of primary importance.

3.1. Tool selection

The MMCs are typically characterized by inhomogeneous microstructure and high abrasiveness with hard particles. In this sense, the tools used to remove material should ensure it has an adequate hardness, strength, and toughness levels. Concomitant with these factors, the thermal conductivity, and resistance to thermal shock should also be analyzed when cutting intermittently or at high cutting speeds, where the thermal load applied is significant (Sheikh-Ahmad and Davim, 2012).

Many types of tools can be used in machining composites: uncoated tungsten carbide (WC), polycrystalline diamond (PCD) (Pugazhenthi *et al.*, 2018), single crystal diamond (SCD) (Yingfei *et al.*, 2010), chemical vapor deposition (CVD) (Andrewes *et al.*, 2000), physical vapor deposition (PVD) (Sougavabar *et al.*, 2022), coated carbide tool (Rajeswari and Amirthagadeswaran, 2017), cubic boron nitrate (CBN) (Dabade *et al.*, 2007).

Among all processes, the cutting show should be analyzed by the workpiece characteristics and be chosen by its characteristics to make it possible to cut the composite material. Tab. 2 presents the main properties of some cutting tool materials. It can be seen from almost all attributes that the PCD tool shows better values highlighting its heat conductivity, a crucial parameter as it has a direct influence on tool wear due to the high heat generated during machining. In addition, the carbide presents a significant fracture toughness, and CBN an e highest bulk modulus.

Table 2. Properties of some cutting materials used to machining composites (Adapted from Asgari, 2015 and Heath, 1986)

Properties	WC (k10)	Al_2O_3 + TiC	CBN (Low %)	CBN (Low %)	PCD (Syndite10)
ρ (g/cm^3).	14.7	4.28	3.12	4.28	4.12
Y (GPa.)	4.50	4.50	3.80	3.55	7.60
HK (GPa.)	13	17	31.6	27.5	50
K_{IC} (MPa.m$^{1/2}$)	10.8	3.31	6.30	3.70	8.80
E (GPa.)	620	370	680	587	776
G (GPa.)	258	160	279	284	363
B (GPa.)	375	232	405	254	301
υ	0.22	0.22	0.22	0.15	0.07
C (10^{-6} /K.)	5.00	7.80	4.90	4.70	4.20
k (W/m K.)	100	16.7	100	44	560

P (Density), Y (Yield Strength), HK (Knoop Hardness), K_{IC} (Fracture Toughness), E (Elasticity Modulus), G (Shear Modulus), B (Bulk Modulus), υ (Poisson Ratio), C (Coefficient Thermal Expansion), k (Heat Conductivity)

3.2. Tool wear

Severe pressure and temperature conditions are achieved at tool surfaces during contact with the workpiece. Due to these conditions, the wear of work tools is inevitable, and this process can occur prematurely and on a large scale or gradually, leading to the end of tool life (Sheikh-Ahmad and Davim, 2012).

Different tools may present alternative wear mechanisms, although the basic is the same, degrading the tool material, which promotes the worst surface of the finished machined material. As mentioned in section 3.1, the use of PCD tools is very well seen because, in addition to their long useful life simply compared to other cut tools, they tend not to present deep crater wear on the face of the rake. This effect may be related to the lower frictional friction and higher thermal conductivity of PCD inserts (Pugazhenthi *et al.*, 2018). In these tools, the wear occurs similarly to conventional machining of other materials with surface fatigue and microfracture. For example, this process can be exacerbated by adhesion between the tool and the machining material as a BUE (Hooper *et al.*, 1999).

In the tool with smooth coatings, the failure occurs by a process in which welding machining material in the tool surface and then, as added in, new layers form a BUE. As this is a cycling process of formation and removal, the trend is for the particle pull-out mechanism to occur, leaving the soft subtract of the tool to the abrasive wear caused by the composite reinforcement particles (Kremer *et al.*, 2008).

In general, the processes related to tool wear are: cutting speed, depth cutting speed, feed rate, and nose radius, and it can be improved according to operating conditions (Bhushan, 2013). In this sense, these process act by some wear mechanism in the tool material. The most commonly reported in the literature are edge chipping, crater wear, notch wear, flank wear, and abrasive wear (Sekhar and Singh, 2015). Some of the mechanisms can be observed in Fig. 4.

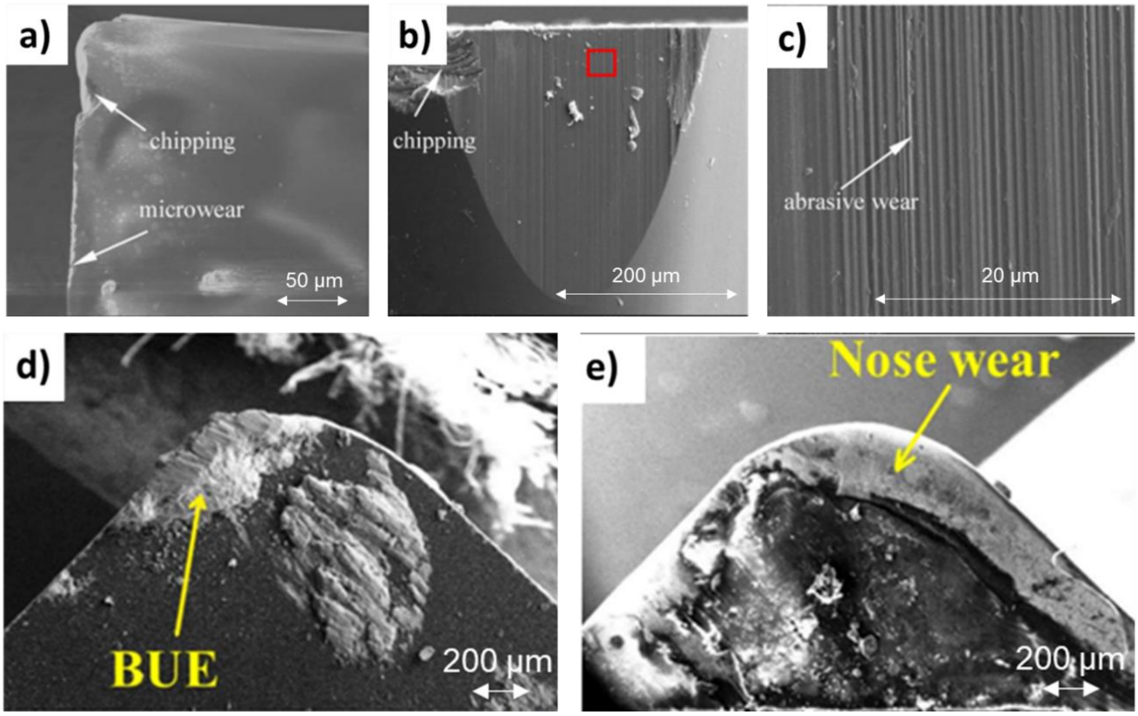

Figure 4. Micrographs of 2009Al/ 15 vol.% SiC showing the tool wear in the round edge SCD (a) flank face (b) flank fase on tool nose (c) higher magnification of rectangle in (b) showing abrasive wear, (d) BUE formation in the PCD tool, (e) tool nose wear in the PCD tool (Adapted from Yingfei *et al.*, 2010 and Pugazhenthi *et al.*, 2018)

El-Gallab and Sklad, (1998) when evaluating the turning of A356/ 20wt% SiC with PCD and Al2O3/TiC coated inserts, it shows a presence of excessive edge chipping probably caused by the Al2O3 particles being pulled out by the abrading workpiece particles. In addition, crater wear was obtained, which is due to the widening of grooves that were caused by abrasion. Machining pieces with NbC as reinforcement and using similar tools could be expected for similar mechanisms to occur due to the high hardness of NbC near 3000 HV (Muchiri *et al.*, 2019).

Notch wear is another process that can be visualized in the series of undulating ridges in the workpiece. The wet condition is more favorable for this mechanism due to the increased hardness of the workpiece caused by reduced cutting temperatures brought down by the application of coolant. This wear mechanism is more pronounced at lower cutting speeds. Once at high speeds, the coolant could not efficiently absorb heat from the machined surface, and thus, the hardness of the work matrix did not increase (Ding *et al.*, 2005).

Flank wear is commonly caused by abrasion caused by friction between the underside of the tool (clearance face) and the workpiece. It can be visualized in the machined surface as a parallel groove to the cutting direction (Sheikh-Ahmad and Davim, 2012).

Another type of tool wear is abrasion, one of the dominant wear mechanisms, due to hard inclusions in the workpiece material (Park and Kwon, 2011). In their work, (Seeman *et al.*, 2010) evaluated the tool wear process in the turning LM25/ 20 vol.% SiC composite with an uncoated carbide tool insert. From the results, abrasive and adhesive wear is the primary mechanism in tool wear. It was related that hard particles in the workpiece are responsible for abrasion. On the other hand, a simultaneous formation of the BUE could protect the tool flank face against further abrasion.

Since NbC has physical characteristics, such as hardness, similar to SiC analyzed in most articles, all of the mentioned tool wear mechanisms could be presented in different tools when machining NbC composite. The tool wear mainly related to abrasive could present different wear rate levels in machining material function. Although in comparison with MMC with Ti matrices, using Al matrices with NbC will probably present lower abrasive wear. This effect is due to the very low thermal conductivity of Ti-MMCs compared to the Al matrix. In the cutting zone, there is a high level of generated temperature, which leads to the rapid abrasion of the cutting tool in a tiny area around the cutting edge (Asgari, 2015). Thus, highlighting as possibly lower the wear rate observed in the machining of composites with NbC reinforcing an Al matrix.

4. CONCLUSIONS

The use of MMCs has grown rapidly, with it the need to shape parts through different processes such as machining. In this process, the non-homogenous material promotes a series of different material removal mechanisms linked to results, such as quality machined surface, tool wear, surface tensions, and surface particle distribution. The review shows different processes utilized in composite machining and its significance or not parameters in the characteristics of MRR and surface quality. Along with this information, the working tool properties and selection also present the possibility of obtaining better results, following tool life, removal rate, and mainly tool wear and its mechanisms.

Based on this factor in the conventional machining process, feed rate, depth of cut, and type of tool can be used in the analysis as variable inputs with response factor as surface quality roughness. This parameter tends to satisfy the subsequent necessities by using materials in specific functions in their various areas. Meanwhile, an unconventional process has its own parameters. In the EDM process, the current, gap tension, and time pulse-on and off also could be related to roughness. As the current or gap increases, there is a tendency to increase the removal rate, which is related to the surface quality of the material.

News methods lead to an investigation of new parameters and correlate to mechanical properties to understand the best combination for each situation and requirement. Hybrid processes are on the top of the edge in machining composites, with new parameters and machine construction adequate for each process. In this scenario, a combination, in principle, of basic parameters of laser power with a depth of cut and cutting speed can be related to surface roughness. An analysis could provide some base results to understand the alterations and the results promoted in the workpiece. In the sequence, it is possible to analyze the parameters of more significant influence to place the alteration of other parameters in comparison with those that most cause changes in the parts.

In short new materials already have a big challenge to be analyzed; the details make a big difference when adding the variation in manufacturing processes. Machining composites reinforced with has several properties related to the material and thus to the process parameters. However, machining can be done and still in order to understand the influence of some factors on its behavior.

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