

A Review of Transdisciplinary Relationship Between Teflon Cnc Machining and Robotics

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Keywords:

Teflon, CNC, robotics, machining, automation.

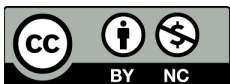
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Received: 6 October 2024

Revised: 12 November 2024

Accepted: 18 December 2024



ABSTRACT

This review work stemmed out of a quest to improve the machining efficiency of a Teflon material, aside the conventional method of machining a Teflon material, a CNC lathe is introduced as a means of overcoming the inherent challenges of conventional Teflon machining such as material wastage, time loss, noise pollution and so on. Numerous reviews of research outputs indicate that some of the identified challenges were overcome but more positive results are still desired. Impact of robotics and automation on Teflon machining also shows good improvement in speed, depth of cut, reduction in the amount of process heat generated, automatic adjustment of speed, high efficiency and precision. Future trends in Teflon machining shows that industry 4.0 and information technology plus artificial intelligence have big roles to play in the area of efficient machining, especially, of sensitive materials like Teflon.

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1. INTRODUCTION

In the ever-evolving landscape of modern manufacturing, the pursuit of precision, efficiency, and automation has driven the development of innovative techniques and technologies. Among the diverse range of materials used in industrial applications, Teflon, known scientifically as polytetrafluoroethylene (PTFE), stands as a remarkable exemplar due to its exceptional resistance to extreme temperatures, corrosive chemicals, and electrical insulating properties [1]. These distinctive

characteristics render Teflon indispensable for industries spanning aerospace, electronics, medical equipment, and more. However, the very attributes that make Teflon a highly sought-after material also contribute to the complexities inherent in its machining.

Machining Teflon is an intricate endeavour that poses formidable challenges due to its unique physical properties. With an extraordinarily low coefficient of friction and poor thermal conductivity, Teflon resists traditional machining methods, leading to issues such as excessive tool

wear, surface roughness, and inadequate surface finish. As industries strive for higher quality products and efficient processes, the quest to overcome these challenges has spurred the exploration of novel techniques that can unlock the full potential of Teflon's applications [2-4].

The advent of robotics and automation has heralded a new era in manufacturing, promising increased precision, consistency, and efficiency. The integration of these technologies into Computer Numerical Control (CNC) lathe processes offers a provocative solution to the intricacies of Teflon rod machining. By automating critical elements such as material handling, tool changes, and process control, robotics and automation hold the key to addressing the limitations of traditional machining methods for Teflon. The integration of robotics and automation in CNC lathe processes has been a topic of interest in recent years. This integration aims to enhance precision and efficiency in Teflon rod machining. CNC lathe machines have advantages in precision, turnaround time, and production capacity [5]. However, there is a need to optimize the machining parameters and improve the efficiency of the process. This can be achieved through the use of robotics and automation, which can provide better control and accuracy in the machining process through CNC machining process [6]. This integration offers improved control and accuracy during machining operations, leading to enhanced overall process performance. Studies have shown that optimizing cutting parameters in CNC machining can significantly impact sustainability, energy consumption, processing efficiency, and surface quality [7].

2. TEFLON MACHINING TECHNIQUES

2.1 Conventional technique in Teflon machining

Machining Teflon conventionally involves using coolant to address heat-related issues, but Teflon's low thermal conductivity may render this approach less effective, leading to heat build-up and problems like tool wear, poor surface finish, and dimensional inaccuracies. As an alternative, cryogenic coolants like liquid nitrogen and carbon dioxide have been proposed, especially for hard-to-cut materials such as

titanium and steel alloys. These coolants offer effective cooling due to their low temperatures, which can help reduce heat generation during machining. In a study focusing on drilling S2 glass fiber composite, liquid nitrogen as a coolant showed positive effects on hole quality, highlighting its potential benefits in machining processes [8].

Another alternative coolant is nanofluid, which has been shown to improve tool life and reduce tool wear. Nanofluid creates an artificial layer on top of the workpiece, reducing wear at the cutting tool. It has been suggested that nanofluid can be a potential alternative coolant in machining [3]. In a study on abrasive jet machining of Ti-6Al-4V ELI biomaterial, the use of nanofluid as a coolant resulted in a reduction in surface roughness and an improvement in tool life span [9].

Minimum Quantity Lubrication (MQL) is another alternative to conventional coolant that has been widely used in machining processes. MQL involves the application of a small amount of lubricant or coolant directly to the cutting zone [10]. It has been reported that MQL can improve machining performance, reduce environmental impact, and lower manufacturing costs. In a study on the performance evaluation of aluminum oxide nanoparticles in cutting fluid with MQL technique, MQL was found to be the most effective alternative in terms of minimizing health risks and machining costs [11].

In addition to alternative coolants, other methods have been proposed to improve the cooling efficiency during machining. One such method is the use of an automated coolant system that controls the amount of coolant supply. This can help reduce the environmental pollution and health problems associated with excessive coolant usage [12]. Another method is the use of a dual nozzle CO₂-based vortex tube cooling system, which has been shown to improve the machinability of Ti-6Al-4V. The system utilizes cold-compressed CO₂ gas as a coolant to produce a cooling effect in the machining zone [13]. Furthermore, advancements in machining techniques, tool optimization, and cutting parameter optimization have been explored to suppress damage during machining of carbon fiber reinforced composites in the work by [14] titled "Review on the Progress of Damage Suppression in Carbon Fiber Reinforced

Composites", 2022. Carbon fiber reinforced plastics (CFRP) are widely used in various industries due to their lightweight and high strength properties. However, it was discovered in the same work that the low interlaminar strength and poor thermal conductivity of CFRP can lead to defects such as delamination and matrix cracking during machining. Therefore, research has focused on developing methods to minimize damage and improve the machinability of CFRP.

The challenges posed by machining Teflon using traditional methods have prompted researchers and manufacturers to explore various techniques to overcome these obstacles. Conventional approaches, while offering some mitigation strategies, often fall short of providing comprehensive solutions. These methods typically involve the use of cutting fluids, tool coatings, and parameter adjustments to enhance the machining process. However, the inherent properties of Teflon continue to present difficulties that may impact the quality, efficiency, and cost-effectiveness of machining operations [15].

2.2 Cutting fluids

One common strategy to address heat-related issues in Teflon machining is the use of cutting fluids or coolants. These fluids are intended to dissipate the heat generated during machining and reduce the risk of material melting or thermal degradation. However, Teflon's low thermal conductivity limits the effectiveness of traditional coolant application, as heat transfer is hindered. As a result, excessive heat build-up can still occur, compromising the precision of machining and leading to issues such as surface roughness and poor dimensional accuracy [16, 17]. The author also mentioned that cutting fluids play a significant role in the machining process by providing cooling and lubrication to reduce heat generation and friction at the cutting zone. They also help in chip removal and protecting the workpiece and machine against. In the case of Teflon machining, the use of cutting fluids can help improve the surface quality of the machined part. Different types of cutting fluids can be used, including vegetable-based cutting fluids such as rice bran oil, almond oil, and sunflower oil. These bio-based cutting fluids have been found to increase tool life, reduce thermal deformation of the workpiece, and improve surface smoothness.

2.3 Tool coatings

In addition to cutting fluids, tool coatings can also enhance the machining process of Teflon. Coatings such as diamond-like carbon (DLC) and polycrystalline diamond (PCD) can improve the wear resistance of the cutting tool and reduce friction during machining [18]. These coatings can help prolong the tool life and improve the surface finish of the machined part. Applying specialized coatings to cutting tools is another avenue explored to enhance Teflon machining. Coatings with high wear resistance and low friction properties, such as diamond-like carbon (DLC) coatings, are utilized to extend tool life and improve surface finish. While these coatings can mitigate tool wear to some extent, they may not fully address the challenges associated with Teflon's stick-slip behaviour and poor thermal conductivity. As a result, tools may still experience adhesion and excessive wear, leading to the need for frequent tool changes and interruptions in the machining process [19, 20].

2.4 Parameter adjustments

Parameter adjustments are another way to optimize the machining process of Teflon. By adjusting parameters such as cutting speed, feed rate, and depth of cut, the cutting conditions can be optimized to achieve better surface quality and reduce tool wear [21, 22]. Adjusting machining parameters, such as cutting speed, feed rate, and depth of cut, is a common practice to optimize the machining process for different materials. However, Teflon's unique characteristics often require fine-tuning of these parameters to strike a balance between achieving the desired surface finish, preventing excessive tool wear, and minimizing heat-related issues. Achieving this balance can be challenging, as changes in parameters may lead to unintended consequences, such as increased tool wear or surface damage. For example, reducing the cutting speed can help reduce heat generation and minimize the risk of melting or deformation of the Teflon material [23]. Similarly, adjusting the feed rate and depth of cut can help control the chip formation and improve the surface finish [24].

2.5 Challenges in Teflon machining

According to [15], machining Teflon using traditional methods, such as turning, milling, and

drilling, poses several challenges. The low coefficient of friction leads to material adherence to cutting tools, resulting in poor chip evacuation and increased tool wear. Moreover, the material's low thermal conductivity makes it susceptible to heat build-up during machining which can cause melting and deformation. The delicate nature of Teflon also requires precise tool engagement to avoid surface damage and achieve the desired dimensional accuracy. Also, [25] mentioned that, machining Teflon, also known as polytetrafluoroethylene (PTFE), poses a series of intricate challenges due to its distinct mechanical and thermal properties. These challenges stem from its unique characteristics, which include an extremely low coefficient of friction, high chemical inertness, and low thermal conductivity. These attributes, while advantageous for various industrial applications, create hurdles during machining processes that demand careful consideration and innovative solutions.

Several studies have been conducted to investigate the properties and behaviour of PTFE. Fatti et al., [26] explored the structural and electronic properties of PTFE in its high-pressure phase. They highlighted the peculiar electronic, mechanical, and thermal properties of PTFE that make it an effective insulating polymer for various applications. Terwisscha-Dekker et al., [27], focused on the low friction properties of PTFE compared to other polymers. They found that PTFE has a coefficient of friction that is an order of magnitude lower than that of other polymers. This low friction behaviour is attributed to the weak internal interface of PTFE, which allows for easy transfer of the PTFE film to the substrate. Gaines [28] and Ayanleye et al., [29], discussed the broad industrial applications of PTFE and its unique properties. They highlighted its thermal stability, chemical inertness, and low dielectric constant, which make it suitable for use in various sectors such as building, automotive, and aerospace industries. Additionally, they mentioned that PTFE is known for its low friction, which is comparable to the friction coefficient of a skate on ice [30].

The use of PTFE coatings on different surfaces was also investigated. Yao et al., [31], studied the optimization of PTFE coating on PDMS surfaces to inhibit the absorption of hydrophobic molecules. They found that PTFE coating

effectively reduced the absorption of hydrophobic molecules, leading to increased optical detection sensitivity. Selvi [32] examined the effects of blade coatings on force demand when pruning grape branches. They found that PTFE-coated blades exhibited lower force demands compared to other blade coatings, indicating the low friction properties of PTFE. In terms of machining performance, Ni et al. [33] conducted drilling experiments on PTFE to evaluate the effect of cutting parameters on drilling performance. They found that higher spindle speeds with lower feed rates resulted in improved drilling performance and machining quality of PTFE. They also observed that the temperature differences due to different drilling depths were related to chip accumulation. Furthermore, the effect drilling parameters on machining performance in drilling PTFE was also investigated. They evaluated thrust, torque, surface roughness, and drilling temperature as indicators of drilling performance and found that cutting parameters significantly influenced these performance metrics.

The low coefficient of friction of Teflon is responsible for the phenomenon known as "stick-slip." Stick-slip occurs when Teflon adheres to cutting tools during machining, causing irregular cutting forces and surface imperfections [34]. Teflon, also known as polytetrafluoroethylene (PTFE), is known for its low friction coefficient, which is similar to that of a skate on ice. This low friction is due to the unique properties of PTFE, including its weak internal interface, which leads to low friction and enables the transfer of the PTFE film to the substrate even in the absence of strong adhesion [27]. The phenomenon of stick-slip can be inhibited or reduced through various methods. One approach is the use of laser-textured micro-dimples on the sliding surface. Laser-textured micro-dimples have been found to significantly inhibit stick-slip phenomenon, providing smoother sliding motion [35]. Another method is the use of lubricant-infused surfaces, which have been shown to reduce frictional drag. Infused Teflon surfaces induce an effective slip length that is much larger than expected based on the presence of the lubricant alone. The slip length increases with increasing air content in the water, but even in degassed and plain water, the slip length is much higher than expected, indicating the presence of other mechanisms contributing to the slip [34].

Coating the surfaces with Teflon can also reduce friction and inhibit stick-slip. Teflon-coated arch-wires in orthodontic brackets have been found to result in lower friction and resistance to sliding compared to uncoated arch-wires [36]. Teflon coating of stainless-steel wires has been shown to reduce frictional resistance compared to uncoated stainless-steel wires. However, it should be noted that the Teflon coating may increase surface roughness and lead to an increase in frictional resistance over time due to distortion of the coating during sliding [37]. The stick-slip phenomenon can also be influenced by external factors such as flow rates and shear rates. Higher flow rates increase the portions of exposed areas of the Teflon substrate to the water, which can increase nucleation site density and affect the slip behaviour [34]. The slip length values have been found to weakly increase with increasing shear rates, indicating that lubricant-infused surfaces are likely to reduce drag on length scales approaching macroscopic scales [38].

One of the most critical challenges in Teflon machining is its poor thermal conductivity. Teflon has a low thermal conductivity, which means it is not efficient at dissipating heat generated during the machining process. As heat builds up during machining, Teflon is prone to melting, deformation, and thermal degradation. This can result in dimensional inaccuracies, compromised surface finish, and a reduction in the mechanical properties of the machined components [39]. To address this challenge, researchers have explored various approaches. Wilke et al., [40], reported one approach as the use of polymer-infused porous surfaces (PIPS) to enhance the thermal conductivity of Teflon. PIPS utilize the large surface area of nanostructures to enhance polymer adhesion, while the nanostructures form a percolated network of high thermal conductivity material throughout the polymer, reducing the thermal resistance of the composite. This approach has shown promise in improving the thermal conductivity and heat dissipation of Teflon coatings.

Another approach is the use of vapor chamber cooling structures (VCCS) to enhance the effective thermal conductivity of Teflon. VCCS utilize the phase transition of a working fluid to transport heat more efficiently than pure thermal conduction. By incorporating VCCS inside the spindle shaft of a machining tool, the heat

generated during machining can be effectively dissipated, reducing the risk of thermal damage to Teflon components [40]. Coating the Teflon surface with other materials has also been explored in order to improve its thermal conductivity. For example, the use of Teflon coatings together with flow pulsing has been found to substantially enhance the chill down efficiency in microgravity conditions. Additionally, the use of Teflon coatings in cryogenic spray quenching has been shown to improve the efficiency of heat transfer [41].

Teflon's low hardness and brittleness make it susceptible to chipping and fracturing during machining. Conventional techniques can cause excessive cutting forces, leading to chipping and fracturing. To achieve desired dimensional accuracy and surface finish without causing damage, meticulous control over machining parameters and tool engagement is necessary. This is due to the material's delicate nature and the need for careful control over tool engagement and machining parameters to prevent surface damage [42].

In specific applications, the brittleness of Teflon can pose additional risks. For instance, when used in certain types of cells, Teflon increases the likelihood of breaking brittle Attenuated Total Reflectance (ATR) crystals. To mitigate this, the use of specialized gaskets is often necessary [43]. These gaskets are designed to protect the fragile nature of ATR crystals, reducing the risk of breakage during their application.

Furthermore, Teflon's chemical resistance can be utilized effectively with Teflon O-rings. These O-rings allow for the chemical resistance properties of Teflon to be exploited while avoiding mechanical stress on fragile windows [43]. The use of Teflon O-rings helps maintain the mechanical integrity of delicate components, leveraging Teflon's beneficial properties without exposing sensitive parts to the risks associated with its brittleness and damage susceptibility under mechanical stress.

2.6 Improving Teflon machining with CNC Lathe

Efficiency improvement is another important aspect of Teflon rod machining. Der et al., [44], conducted a study on the determination of optimal cutting parameters for machining

technical plastics. They performed experiments to optimize the cutting regime and improve the efficiency of CNC lathe machining. The study involved the programming of a fuzzy logic controller (FLC) to obtain the optimal factors of the cutting regime. This study can provide insights into improving the efficiency of Teflon rod machining by optimizing the cutting parameters [45].

3. PRECISION ENHANCEMENT IN CNC LATHE MACHINING

Precision is a critical factor in Teflon rod machining. proposed a method for fabricating micro rods by twin-mirroring-wire tangential feed micro electrical discharge grinding. This method aims to improve the machining efficiency and ensure high precision in the shaping process of cylindrical micro rods. The proposed method can be applied to enhance the precision of Teflon rod machining and achieve the desired dimensional accuracy [46].

3.1 Integration of robotics in CNC Lathe machining

The integration of robotics in CNC lathe machining processes can provide several benefits. It can enhance precision, improve efficiency, and reduce labour dependency. A study was conducted on vibration monitoring of the mechanical harvesting of citrus to improve fruit detachment efficiency. Although the author mentioned that this study focuses on the agricultural sector, it highlights the importance of integrating robotics to enhance efficiency in a specific process. The introduction of a mechanical harvesting process for oranges can contribute to enhancing farm profitability and reducing labour dependency. Similarly, the integration of robotics in Teflon rod machining can lead to improved precision and efficiency [47].

3.2 Robotics and automation in CNC machining

The integration of robotics and automation into CNC machining processes has been a topic of interest in recent years [48]). Industrial robots have been increasingly used in machining applications due to their advantages in processing large-scale components in industries such as aerospace. Compared to CNC machine tools, robot arms are cheaper and easier to

deploy. However, the integration of robots into machining processes presents challenges, particularly in terms of consistency and automation of robotic machining [49].

One approach to improving the integration of robotics and CNC machining is through the application of CAD/CAM/Robot integration technique. This method combines CAD/CAM technologies with robotic systems to enhance the intelligence and effectiveness of CNC machining. By integrating CAD/CAM systems with robots, various parameters can be automatically adjusted and compensated during the machining process, leading to improved online diagnosis and fault handling. Additionally, the integration of CAD/CAM and CNC systems allows for high-speed, high-precision, and efficient control of CNC machines [50]. To improve the motion accuracy of robots in machining applications, the use of a CNC controller has been proposed. Computer numerical control (CNC) systems have good performance in controlling motion accuracy in machine tools. By incorporating a CNC controller into an industrial robot, the motion accuracy of the robot can be improved. This integration of a CNC controller with an industrial robot can help overcome the low absolute position accuracy and low stiffness of robots, which can affect machining accuracy [51].

In addition to improving motion accuracy, the integration of robotics and CNC machining can also enhance the efficiency and accuracy of specific machining processes. For example, the integration of laser processing technology and numerical control technology can be achieved through the application of cooperative control solutions for electrical systems of laser CNC machines [52]. This integration allows for better machining efficiency and accuracy in laser CNC machining. Similarly, the integration of robotic milling and 3D point cloud technology has been explored for the welding pre-processing of large-scale components, demonstrating the feasibility of using robotic milling for such applications. Furthermore, the use of industrial robots in CNC machining processes can offer cost-efficiency and design freedom compared to traditional CNC machines. Industrial robots are flexible and reconfigurable, making them suitable for processing large workpieces and complex profile. By equipping industrial robots with milling end-effectors, researchers have explored the potential

of using robots for milling and electric discharge machining (EDM) processes. This approach allows for the use of small industrial robots for machining hard materials, while minimizing vibration and achieving dimensional accuracy [53]. However, the author further explained that there are still challenges to overcome in the integration of robotics and CNC machining. One major challenge is the difference in stiffness between CNC machines and industrial robots. CNC machines typically have higher stiffness than industrial robots, which can affect the stability and accuracy of the machining process when using robots. The low stiffness of industrial robots can result in unexpected deformation and vibration during machining. Additionally, the lack of stiffness combined with the flexibility of industrial robots can limit their performance in conventional machining processes.

To address these challenges, researchers have proposed various solutions. For example, the use of double encoders in the control system of industrial robots can improve position accuracy. The implementation of a secondary encoder in a CNC-based robotic system has been shown to enhance position accuracy. Moreover, the optimization of control schemes, hardware structures, and control software can contribute to the efficient integration of electrical systems in laser CNC machines [54]. By improving the collaborative control efficiency of the electrical system, the integration of laser processing technology and numerical control technology can be better achieved.

3.3 The Need for precision and consistency in Teflon machining

Robotic systems are designed to perform tasks with precision and repeatability [55]. These systems automate movements that would typically be performed manually by a physical therapist, minimizing therapist fatigue and increasing repeatability. The use of robotic systems in therapy has been shown to have comparable outcomes to traditional therapy methods [56]. In addition to therapy, robotic systems are also used in various other fields such as medicine, computer science, and physics. This level of accuracy is particularly beneficial for machining materials with intricate properties like Teflon. The robotic arms can precisely control tool engagement, ensuring consistent

cutting forces and minimizing the risk of surface damage. This is especially vital for Teflon, where even slight deviations in cutting forces can lead to stick-slip behaviour and compromised surface finish. The integration of robotics thus presents the opportunity to achieve the high degree of precision required for machining Teflon effectively [57, 58].

One important aspect of robotic systems is their ability to calibrate and position themselves accurately. While industrial robots generally have high-precision repeatability, their absolute position accuracy may not be as high due to kinematic errors. To compensate for this, calibration approaches based on neural networks and hand-eye vision have been proposed. These approaches aim to improve the absolute position accuracy of robots, making them suitable for applications that require small position errors [59]. Robotic systems are engineered to perform tasks with precision and repeatability. They automate movements that would typically be performed manually, minimizing fatigue and increasing repeatability. Calibration and positioning accuracy are important aspects of robotic systems, and various approaches have been proposed to improve their absolute position accuracy. Coordination strategies play a crucial role in multi-robot systems, allowing robots to collaborate and optimize their performance [60]. The accuracy and repeatability of robotic systems are important features, and studies have evaluated these characteristics in various applications. Robotic systems are used in a wide range of fields, including medicine, agriculture, and soft robotics. Further research is needed to explore the effectiveness of robot-assisted rehabilitation and to address challenges in the design and control of soft robots [61-63].

4. AUTOMATION OF COMPLEX TEFLON TASKS

In the realm of Teflon rod machining, automation significantly enhances efficiency by managing complex tasks that demand precise coordination, such as material handling and tool changes. Robotic systems, particularly valuable for their collaborative task execution capabilities, play a key role in this process. In systems involving multiple robots, coordination strategies are essential for effective task allocation and execution. Research by Gao et al., [64], highlights the effectiveness of reactive coordination

strategies in multi-robot systems, where robots collaborate and optimize performance. They also stated that these strategies include the creation of execution plans using genetic programming and the prioritization of urgent tasks, thereby reducing the need for manual intervention and limiting the risk of human errors. Additionally, automation introduces specialized mechanisms, such as robotic arms equipped with delicate grippers, that can handle Teflon rods with care, preventing damage or deformation. This automation not only ensures greater reliability in the machining process but also enhances productivity by reducing the downtime typically associated with tool changes.

4.2 Teflon real-time process optimization

The dynamic nature of machining Teflon demands real-time adjustments to optimize process parameters and ensure consistent quality. In the context of precision and consistency, the accuracy and repeatability of robotic systems are crucial. The accuracy refers to how closely the robot can achieve a desired position or perform a task, while repeatability refers to the consistency of the robot's performance over multiple repetitions. Studies have evaluated the accuracy and repeatability of various robotic systems. For example, a gantry robot used for welding applications demonstrated an average repeatability of 0.108 mm [65]. Also, in another study by Lehmann et al, [66], the 2-axis movement of a 5-axis gantry robot were evaluated and found that it had a repeatability of 96 μm and 108 μm for the X and Y axes, respectively. These results indicate that the gantry robot displayed good performance in terms of repeatability and accuracy. Robotic systems, when integrated with sensor technology, can provide real-time feedback on cutting forces, temperatures, and surface conditions. This data can be used to adapt machining parameters on the fly, maximizing efficiency and maintaining the desired surface finish. Automation enables the seamless adjustment of parameters, enhancing the overall quality of machined components and reducing scrap rates.

4.3 Future Trends

As industries continue to demand higher precision and efficiency, there is a growing emphasis on exploring innovative solutions for

machining challenging materials like Teflon. Overall, the future directions in machining challenging materials like Teflon involve the application of advanced algorithms and machine learning techniques to predict optimal machining parameters, the development of real-time monitoring systems for tool wear and process deviations, the advancement of metrological methods for assessing surface topography and machining accuracy, and the integration of information technology in CNC milling machines. These advancements will contribute to higher precision and efficiency in machining operations, meeting the demands of industries for precision and efficiency [66]. The application of advanced algorithms and machine learning techniques to predict optimal machining parameters holds promise for further enhancing process efficiency. Real-time monitoring systems can provide valuable insights into tool wear and process deviations, enabling proactive adjustments [67]. In the context of machining challenging materials like Teflon, there is a growing emphasis on exploring innovative solutions to improve precision and efficiency.

The author, [68], also mentioned that one promising approach is the application of advanced algorithms and machine learning techniques to predict optimal machining parameters. By using machine learning algorithms, it is possible to enhance process efficiency and achieve higher precision in machining operations. These algorithms have been successfully employed in various industries, such as aerospace and healthcare, to design lightweight materials for aircraft components and predict the toxicity of new drug candidates. Real-time monitoring systems play a crucial role in machining operations by providing valuable insights into tool wear and process deviations. These systems enable proactive adjustments to be made, ensuring that the machining process remains efficient and accurate [69]. For example, machine vision-based systems have been developed to monitor tool wear in turning and milling processes. These systems use computer vision techniques and machine learning methods to analyze images of the tool wear zone and predict tool life. The accuracy of these systems has been validated through experimental investigations, with prediction accuracies ranging from 96% to 97% [70].

5. CONCLUSION

This review work investigated the machining processes of Teflon material with the contribution of CNC machines. Observed challenges were overcome with the use of robotics and automation systems. This further improves the quality of the machining with reduction in the attendant material loss and time taken to complete the entire processes. In addition to machine learning and real-time monitoring, there are other areas of research that can contribute to the future directions of machining sensitive materials such as Teflon. One of such areas is the development of metrological methods for assessing surface topography and machining accuracy. In grinding processes, for example, the distribution of dimensional deviations is not the realization of stationary processes due to various factors such as deformation of the technological system, machining forces, temperature fields, and tool wear. Therefore, it is important to develop metrological techniques that can accurately evaluate the surface topography and machining accuracy in order to optimize the machining process [71]. Furthermore, the integration of information technology, such as Industry 4.0 concepts, can enhance the precision and reliability of CNC milling machines. Timely calibration and recalibration is also essential to achieve more accurate precision in CNC milling machines operation when handling sensitive materials. By improving the design of CNC milling machines and incorporating information technology, it is possible to enhance their precision and reliability [68].

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