Proceedings in Manufacturing Systems, Volume 21, Issue 2, 2026, pp. 79-90 ISSN 2067-9238

CUTTING TOOL PROCESSING METHODS TO IMPROVE DRY AND NEAR-DRY METALWORKING – A REVIEW ON MACHINING PERFORMANCE

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https://doi.org/10.5281/zenodo.21873522

Abstract: *Metal cutting is still one of the most commonly used machining method, but it comes with some drawbacks such as the negative impact on the environment by producing hazardous emissions into air, water and soil. The studied literature has shown that the researchers' efforts were directed towards finding solutions to obtain a sustainable metal cutting process and their results are considering reducing energy consumption and waste, increasing the amount of reusable or recycling waste, limiting resource consumption and choosing alternative options for lubricating and cooling the tool and part during the machining process. Among these methods, dry and near-dry machining were found to be most environmentally friendly solutions as there is no more or very little contamination with cutting fluids. Nevertheless, these methods come with several disadvantages such as increased heat generation and frictional forces, rapid tool wear and inefficient chips removal but the researchers in this domain were investigating different methods and strategies to address these challenges, such as new materials for cutting tools, coatings, surface texturing of cutting tools, hybrid processes that combine dry machining with laser, ultrasonic, vibrations etc. The current review focuses on the following developments in cutting tool processing methods as a strategy to improve dry and near-dry machining performance: cutting tools cryogenic treatment; coated cutting tools; textured cutting tools and coated and textured cutting tools. For these methods, based on the studied literature, some conclusions are formulated on how they influence the cutting process in dry and near-dry machining.*

Key words: *sustainable production, dry and near-dry machining, coated, textured, cryo-processed cutting tools, machining performance.*

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1. INTRODUCTION [1]

All the charts with data on energy consumption, global temperatures, levels of CO_2 in atmosphere and other data on the polluting potential of industrialization, to which one add population growth, indicate a continuous increase in these values, meaning things are heading towards a less sustainable future. At a global level, this situation has imposed the emergence of rigorous regulations and laws that lead to the reduction of the impact that industrialization has on the environment and human health and wellbeing. The literature in this field, consisting of scientific articles, manuscripts, press articles, conferences of companies and organizations in the field of ecological manufacturing, articles of the companies producing vehicles, machine tools, tools etc., abounds with solutions regarding the achievement of sustainable manufacturing processes and their practical usefulness will be seen over time.

As it was depicted from the studied literature, sustainable manufacturing or production refers to a manufacturing system or process that takes into account the three key factors, namely the impact on the environment, economy and society. In a broader definition, sustainable manufacturing includes minimizing negative environmental impacts, conserving energy and natural resources, safety for employees, community and consumers and economic efficiency. Thus, considering the green/ clean metalworking, it can be said that ecological manufacturing is an important part of sustainable production. The efforts of the researchers were directed towards finding solutions to obtain a sustainable metal cutting process and the results are considering reducing energy consumption and using renewable energy resources, reducing waste and increasing the amount of reusable or recycling waste, limiting resource consumption by identifying solutions to extend cutting tools lifespan, or choosing alternative options for lubricating and cooling the tool and part during the machining process.

During the cutting process, 99.5% of the mechanical work is converted into heat, the rest being stored in the part as potential energy in the superficial layer of the machined surface. The cutting heat is accumulated into workpiece, tool, chips, and environment. The heat is released within the cutting area from various sources which are based on both plastic deformations of the machined material and friction at the interfaces cutting

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tool – chips and cutting tool – workpiece. The most effective method to remove heat from the elements that store it is the use of coolant-lubricant which, properly applied, can absorb and remove over 50% of the heat.

The use of cutting fluids within the cutting process extends to three directions of action, namely: cooling and lubricating the active surface or edge of the tool, as well as the material of the workpiece, and transporting chips from the cutting area. Depending on the surface quality to be achieved, the cutting fluid used may require better cooling, lubrication, or both characteristics [1, 2].

The efficiency of the cutting fluids depends on several factors, including the type of cutting operation, cutting conditions, and the method of coolant application.

During machining, the cooling-lubrication fluid enters the cutting area due to the vacuum effect that occurs at the intersection point between the cutting tool, workpiece, and chip [3, 4]. Thus, the chip is removed more efficiently due to the lubricating qualities of the cutting fluid reaching the cutting area. An oil film occurs at the contact between the cutting edge and the chip when, due to the wetting capacity of the liquid, the adhesion forces become greater than the cohesive forces. The oil film obtained helps to reduce the friction between the cutting edge and the chip, which leads to a decrease in the shear plane length resulting in less plastic deformation and therefore less heat created [5].

The lubricating effect of the cutting fluids used in the cutting process leads to a decrease in the friction forces on the cutting area and therefore to a decrease in the total cutting force. This will contribute to reducing the power consumption, decreasing process vibrations, and therefore increasing the quality of the machined part.

It is also known that metals and alloys subjected to machining tend to rust quickly when exposed to moisture and oxidation due to the removal of the protective layer from the machined surface. Cooling-lubricating fluids form a thin, non-porous layer on the surface of the part, preventing wear through corrosion [6].

Another important role of coolants is transporting the chips from the cutting area, chips that can scratch the machined surface when detached or could accumulate between the cutting tool and the workpiece, leading to a decrease in the quality of the workpiece surface or damaging the cutting tool. This cutting fluid's role is more important when the cutting area is not open, as it is the case with drilling, deep drilling, broaching, etc. If we consider the durability of the cutting tool, coolants contribute to increasing the lifespan of the cutting tools used within the process by reducing and preventing heating, friction, and overall wear.

However, it is well known that the petroleum-based coolants have a major negative impact on the environment and human health and wellbeing and thereby, the majority of research in this field aimed at finding alternative options for lubricating and cooling the tool and part during the metalworking process.

An ecological solution is the use of water, but water is highly corrosive, although it cools the cutting area very well and is ecological; therefore, commercial fluids with lubricating properties are used in order to ensure the desired quality for the machined surface, simultaneously with the decrease in the power consumption [7].

The studied literature has divided cooling-lubrication methods into two categories, namely conventional and alternative, where the former refers to the continuous flow of oil-based fluid and additives into the cutting zone to improve certain properties, and alternative methods refer to different cooling and lubrication options during the cutting process with the aim of obtaining a sustainable and environmentally friendly process [8].

Efforts were made by the researchers in this area of interest to achieve a cleaner cutting process and safer for the human's health, and several alternative methods for cooling and lubricating were investigated (Fig. 1) [9].

Although the essential role of cutting fluids during metalworking is well known, in recent decades the problem of their negative effects has become increasingly pressing, such as environmental pollution through chemical dissociation of the cutting fluids at very high temperatures, water pollution and soil contamination during their final disposal, biological threat to the operator's health coming from vapors, smoke, physical contact, bacteria and odors, the need for additional space and additional systems for storage, pumping, filtration, recycling etc. This has determined the development of solutions that aim to partially or totally eliminate these fluids from the process or to use substitutes that aim to ensure completing the same role, namely lubrication, cooling and transporting the chips and heat from the cutting area.

Two alternative methods are accepted by researchers as the most suitable from the point of view of a cleaner machining – dry and near dry cutting. As the name suggests, dry cutting means that no fluid is used in the cutting process, which will lead to some deficiencies such as: increased heat generation and frictional forces, build-up edge, rapid tool wear and inefficient chip removal from the working area. Thus, it becomes necessary the use of a cutting material with high levels of resistance to breakage, pressure and temperature, high hardness, chemical stability and resistance to thermal fatigue [10–14].

In addition, there are some benefits of this method, namely:

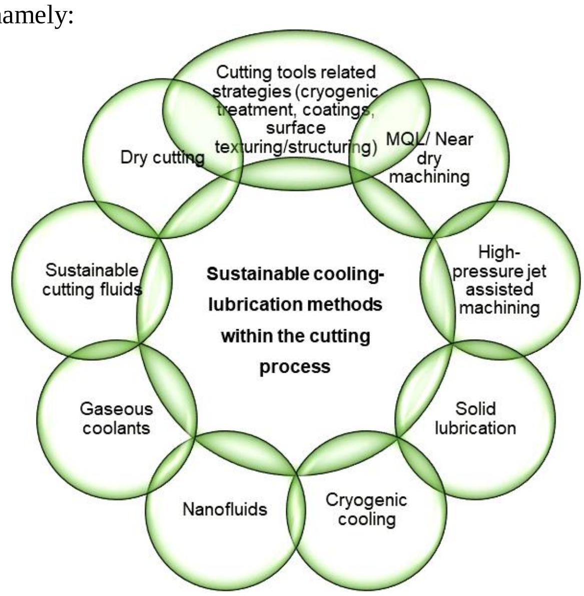

Fig. 1. Ecological solutions for a sustainable metalcutting process.

- no more contamination with coolant and therefore no negative impact on the environment, water and employee health;
- no more residual fluid on the chips and the finished part, so cleaning procedures are eliminated;
- the need for coolant treatment is eliminated and therefore recycling costs are reduced.

Machining without cutting fluids is usually used when it is found that the same quality and productivity can be achieved as when using fluids. In fact, dry-cutting is often used when there are no requirements for higher precision and quality of the machined surface, using lower cutting speeds. However, the use of dry cutting has proven to be beneficial in machining magnesium and aluminum parts, as well as titanium [12, 14, 15-19].

The minimum quantity of liquid method (MQL), also known as near dry machining (NDM), micro-lubrication (ML) or green manufacturing (GM) could eliminate some of the dry cutting disadvantages. In this method the cutting fluid is sprayed into the cutting area in the form of aerosols, and it uses approximately 10.000 times less amount of cutting fluids than conventional machining.

With the MQL method, the coolant-lubricant is sprayed into the contact area between the cutting tool and the workpiece with a pressure of approximately 5 – 6.5 bar, and the amount of liquid differs depending on the type of operation, the workpiece material, the cutting material, the quality and precision to be obtained and can take values between 10 ml/hour and 300 ml/hour. The coolant-lubricant can be applied from the outside or from the inside of the cutting tool. Spraying coolant-lubricant on the outside of the cutting tool is often used in turning, milling, and drilling when the ratio $l / d < 3$ (l = hole length, d = hole diameter). Application from the inside of the tool is more suitable for drilling, threading, reaming when the ratio $l / d > 3$.

The cooling-lubricating liquids combined with compressed air are sprayed into the cutting area by two methods, namely: through a nozzle provided with a single channel to transport the mixture of liquid and air, and from outside the nozzle, through two channels, one for air and the other for liquid. Spraying from within the nozzle has been shown to offer superior performance by eliminating the adverse effects associated with vapor emissions into the environment [20–22].

The fluids used in this method could be based on pure oil, synthetic oils, or emulsions with different water concentrations, but there are alternative methods where the agent used can be cryogenic, biodegradable liquids, nanofluids, etc. This ensures cutting efficiency by reducing frictional forces and heat and increasing the cutting tool lifespan, while obtaining the desired quality for the machined surface. In addition, this method has a minimal impact on the environment and the operator's health and the small amount of liquid used in the cutting process leads to lower costs with chips and used liquid disposal, therefore a lower cost with recycling.

2. METHODS FOR ENHANCING CUTTING TOOL PERFORMANCE

Sustainable machining can be achieved by completelyor partially eliminating cutting fluids from the process, which means, as previously shown, that several challenges may occur such as reduced surface quality, increased friction between the cutting edge and chip/workpiece, thus increasing temperature with consequences on the durability of cutting tools, increased energy consumption and difficulties in chips evacuation. The main advantage of these methods is that there is no longer cutting fluid contamination that would require processing and treatment, and chip recycling is easier and less costly. Thus, it is necessary to maximize the advantages of dry and near-dry machining and aim to reduce or eliminate the drawbacks of these methods by using suitable cutting tools.

To enhance the cutting tools performance in order to overcome the problem of friction during machining, and also to prolong their lifespan and improve the quality of the machined surface, several methods of processing cutting tools have been developed, namely: cryogenic treatment of the cutting tools, coatings, surface structuring/texturing (micro-texturing) of cutting tools and combining coating and texturing the cutting tools [23, 24].

This review aims to investigate these cutting tool processing methods and identify the advantages and disadvantages of using processed tools in dry and near-dry cutting. Finally, a summary of the results regarding the performance of processed cutting tools will be made, depending on the machined surface quality, elimination of friction in the cutting process, achieving cooling, ease of chip evacuation, costs, and waste management.

2.1. Cryogenic Treatment of Cutting Tools

With the cryogenic treatment or cryo-processing of the cutting tools, significant improvements in their durability and performance can be achieved, and machining conditions can be brought to a more optimum level which will be reflected in lower production costs and higher productivity. It is a heat treatment below 0°C that affects cutting tools across their entire cross-section and leads to changes in their microstructure. This advanced process will lead to increased tool life, dimensional stability, reduced wear, improved hardness and microstructure of cutting tools [25-29].

There are two types of treatment, namely superficial treatment which takes place between – 80 and – 145°C and deep treatment which takes place at temperatures lower than – 145°C. Also, the result of cryogenic treatment depends on the cutting material, high-speed steel and tungsten carbide tools often being studied [30, 31].

Cryogenic treatment of the new inserts helps to significantly relieve the residual stresses. Cryo-processing cycle typically involves several parameters: cooling rate, soaking temperature, soaking time period, heating rate, tempering temperature and tempering time period [31, 32].

The researches in the field have led to some conclusions, namely: the first three parameters have a 98% contribution to improving the mechanical properties of the cutting tool [33], the mechanical properties of cooling must be slow enough to avoid thermal shocks and cracking [34], [35] suggested that in order to avoid rupture of tool the rate of cooling should not exceed

30 °C/h and likewise for the soaking period and it recommended that soaking period should not be greater than 35 h, soaking temperature has an important influence on the wear resistance of the tool, in the case of high-speed steel showing an increase in wear resistance of 315%–382% [36], during turning of Impax supreme alloy with both cryogenically treated and untreated tools showed that the cutting tool wear, cutting tool tip temperature, surface roughness, vibration and noise values decreased after the deep cryogenic treatment applied to the cutting tool and enhance cutting tool life by up to 150% [37]. However, it was suggested that at very high cutting speeds and temperatures, cryo-processed cutting tools did not perform better than conventional ones [30, 38, 39].

Cryogenic processing is a treatment for the cutting tools, which is relatively less costly as compared to several other techniques. This treatment has significantly improved the efficacy of dry machining by increasing the tool life. In some case, the increase in the wear resistance, toughness and hardness of cutting tool has improved the cutting tool life up to 343% [31, 40].

2.2. Coated Cutting Tools

Several properties are desirable in cutting tools, some referring to the tool's active surfaces and some to the tool's core. The tool surface has to be hard, smooth, wear-resistant, and inert, while the tool core has to be strong, heat-resistant, tough, and thermally conductive. These properties are hard to achieve in a single material, so coatings are used to enhance the tool surface. Coatings consist of a few micrometers or nanometers thick layer (single or multi-layers) of chemically inert, hard, anti-friction, and thermally isolating material deposited on the tool surface to improve its performance [10, 41–43].

A single layer of refractory or composite material is superior to uncoated cutting material in terms of hardness, fracture toughness and surface inertness, but the low wear resistance and high friction usually cause mechanical and chemical damage. Therefore, multi-layer coating can improve the tribological properties as it prevents crack propagation and hence improves the fracture and wear resistances, extending tool life and achieving machining accuracy and a high-quality machined surface. In addition, the number of coating layers acts as a thermal shield against conductive heat transfer through the cutting tool, which increases its life. However, the total thickness of layers must be controlled and optimized to avoid any counterproductive effects on wear resistance and tool life [44–47].

Latest researches in coated cutting tools have focused on improving the coating preparation process, increasing the bond strength between coating and substrate, increasing the coating hardness and toughness, improving oxidation resistance at very high temperatures, increasing wear resistance and reducing friction, so that the coated tools could be used in various situations, including machining under very hard conditions [48–50].

There are two widely used methods for preparing coatings for cutting tools, namely chemical vapor deposition (CVD) and physical vapor deposition (PVD). In Fig. 2, two types of CVD and PVD coated tools are depicted.

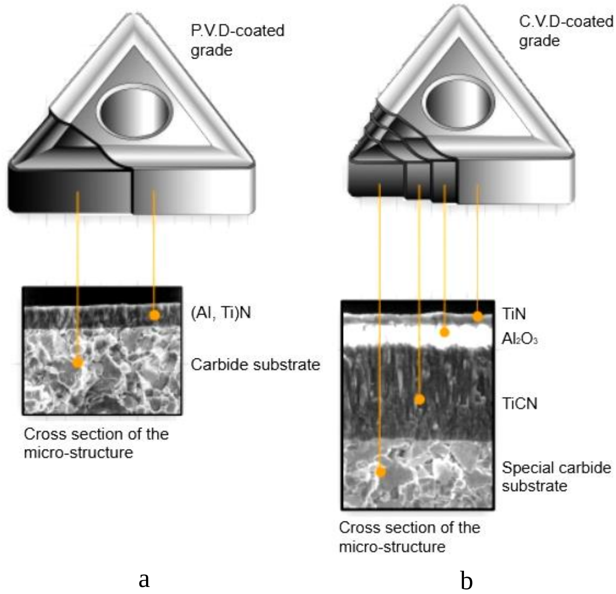

Fig. 2. Types of coated inserts: *a* – PVD -coated insert [51]; *b* – CVD-coated insert [52].

In the chemical vapor deposition process, one or more gaseous substances containing the desired coating elements are used to chemically treat the surface of the cutting tool in a reaction chamber, forming a coating layer on the surface of the cutting tool substrate. The chemical vapor deposition process is divided into three important stages: diffusion of the reactive gas to the substrate surface, adsorption of the reactive gas on the substrate surface, chemical reaction on the substrate surface to form solid deposits, and removal of gas-phase byproducts from the substrate surface [53].

There are many chemical vapor deposition methods, including atmospheric pressure chemical vapor deposition, low-pressure chemical vapor deposition, ultra-high vacuum chemical vapor deposition, laser chemical vapor deposition, metal–organic chemical vapor deposition, plasma-enhanced chemical vapor deposition, etc. [48, 54–56].

In the physical vapor deposition process, physical methods such as evaporation or sputtering are used to vaporize the coating material and then deposit a film on the surface of the substrate. PVD (physical vapor deposition) coating technology is mainly divided into three categories: vacuum evaporation coating, vacuum sputter coating and vacuum ion coating. Each of them has advantages and disadvantages as following: in vacuum evaporation coating, deposition speed is fast and it can be mass-produced, but the structure is not easy to control and the bonding strength of is not high; in vacuum sputter coating, target materials are in a wide range, deformation of the coated workpiece is small, film quality is high and thickness is relatively uniform, it is easier to realize large area and rapid deposition of material surface, but diffraction performance of deposition technology is poor; in vacuum ion coating, bonding strength is high, the diffraction property is good, coating materials are relatively wide, the deposition rate is fast. The main physical vapor deposition methods are: multi-arc ion plating, vacuum cathodic ion plating, magnetron sputtering, cathodic arc evaporation and so on, but there are other emerging PVD methods such as plasma-assisted cathodic arc evaporation technology, high-power pulsed magnetron sputtering (HiPIMS), plasma spray physical vapor deposition (PS-PVD), electron beam physical vapor deposition (EB-PVD), ion-assisted evaporation technology (IVD), plasma-enhanced magnetron sputtering, arc plasma accelerated PVD which were developed in order to avoid the inherent defects of conventional physical vapor deposition and improve the coating quality [48, 57–61].

Composite coating preparation technologies have been developed to overcome the shortcomings of individual coating processes and to improve the performance of coated cutting tools. Methods such as PCVD, ion beam assisted deposition, cold spraying, thermal spraying and sol-gel method have been proposed [62–67].

There are two main categories of coating materials, namely „hard” and „soft”, where each one depicts a different impact on the cutting tool performance. The ‘‘hard’’ materials have higher hardness and wear resistance, while the ‘‘soft’’ materials depict a lower friction coefficient. The ‘‘hard’’ coating materials can be divided into the following categories: Ti-based coating materials, Cr-based coating materials, ceramic materials, superhard coatings, and solid lubricant coatings [48, 66].

Titanium-based coating materials are the most widely used coating materials for cutting tools, with a highly developed preparation technology. Initially, Ti-based coating materials were TiC and TiN, and TiCN was later developed to overcome the shortcomings of the first two. Cr-based coating materials were originally composed of CrN, with high hardness, thermal stability, anti-wear, anti-sticking, and anti-corrosion properties. However, CrN coating is resistant to oxidation at high temperatures up to 800°C (temperatures higher than 800°C intensify oxidation, and hardness is increased). To further optimize their performance, coating materials such as AlCrN, CrSiN and AlCrSiN have emerged, as the addition of Al and Si elements improves the hardness and oxidation resistance of the coating.

The most commonly used ceramic coating material is Al2O3, which has strong heat and oxidation resistance. It can isolate the heat generated by the active surface of the cutting tool and the deformation caused by cutting.

The typical representative of superhard coating materials is diamond coating. Diamond coating is often applied to the substrates of cemented carbide cutting tools, which will not only lead to high hardness, good wear resistance, and thermal conductivity, but also has good impact resistance and toughness.

Solid lubricants are represented by cubic boron nitride (CBN), which comes second after diamond in terms of hardness and thermal conductivity. It has optimal thermal stability and does not oxidize easily; therefore, it is widely used in the machining of steel parts [66, 68-70].

Thus, there is currently a wide variety of hard coating materials that are wear-resistant and can be used with very good results in high-speed cutting without the need for cutting fluids. Although they have many advantages, at very high cutting temperatures, these materials are subject to oxidation and changes in softening and friction coefficient. This will cause a decrease of the hard coating, as well as the performance of the coated cutting tool.

This drawback can be overcome by using "soft" coating materials based on solid lubricants with a low friction coefficient such as soft metals (zinc, lead, tin, indium, etc.), metal compounds (metal sulfides, fluorides, selenides, borates, phosphates, etc.), organic substances (various polymer materials, thermoplastic materials and resin materials) and mineral substances [71-73].

The pure soft coating has limited application scope due to its low hardness, rapid performance degradation in high temperature, humidity and other environments, therefore, currently, attempts are being made to organically combine hard coating with soft coating, adding alloying elements that can form lubricating oxides in the existing coating, which can improve the machining performance of the cutting tool.

Of particular importance is the coating structure which has evolved over time from single to multilayer coatings, composite coatings, gradient coatings, multilayer composite coatings, smart coatings, etc. [48, 74-76], Fig. 3.

A single layer is a form of solid coating made of a compound consisting of metallic or non-metallic particles combined with gas molecules in single or multi-gas environment. A monolayer is easy to prepare and is stable in long-term use.

Multiple layers of coatings have been developed to improve the performance and protective effect of coatings. The number of layers should not be excessive as the bonding force between the coating and cutting tool base becomes weak if the number of layers is too large and the coating could easily fall off. Multi-component coating refers to the composition of two or more components in the form of grains, particles or fibers.

Gradual coating refers to the introduction of gradual changes in the chemical composition and microstructure of the coating on the basis of the multi-layer coating.

Nanostructured coatings include nanogranular films as well as nanocomposite films.

Superlattice multi-layer coating refers to a multi-layer coating with a single layer thickness in the range of 5-50 nm. This type of coating holds high hardness, high tear strength, good bonding properties and strong wear resistance.

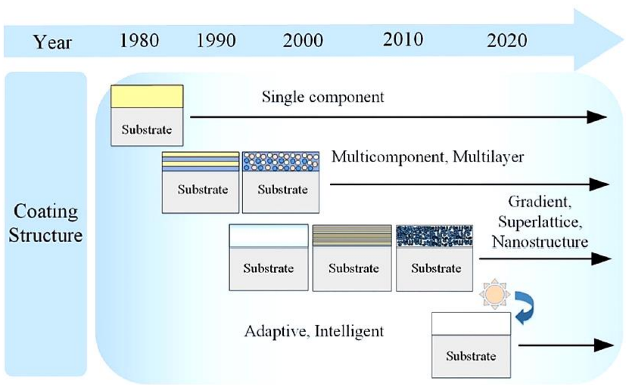

Fig. 3. The evolution of coating structures [48, 74–76].

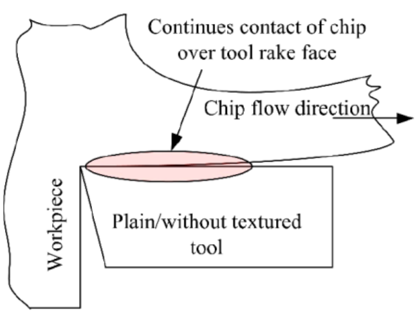

Fig. 4. The interface between tool rake face and chip in textured tools comparing to conventional ones [10].

Smart coatings are generally coatings that can change their tribological properties according to changes in the working environment. This type of coating usually consists of a wear-resistant phase and a lubricating phase and can achieve adaptive changes in different environments by adjusting the surface morphology, chemical composition and structure to reduce wear. The complex structure and chemical properties of such coatings can be reversibly transformed in the friction contact area to generate a lubricating phase suitable for the working environment. This is the main research direction of cutting tool coatings in the future [48, 75, 76].

The studied literature has shown that researchers have investigated the performance of various kinds of coatings for machining different materials, such as conventional, nanocomposites and self-lubricative coatings [77-82] and they concluded that the performance depends on several factors, such as layer ordering in multilayer coatings, coating thickness, composition ratio and deposition method.

Although the results have shown improved cutting performance when using coated tools compared to uncoated tools by increasing the tool lifespan, decreasing of cutting temperature, diminishing friction coefficient at the cutting zone which reduces the cutting force and energy consumption as well [83, 84], improved wear resistance and quality of machined surface [85, 86], it is necessary for different workpiece materials to identify the suitable coating cutting tools so as to improve the machining quality but also their efficiency has been proven under certain cutting conditions (at higher cutting speeds, higher feeds, etc.).

2.3. Textured Cutting Tools

The textured active surfaces of cutting tools were developed as a necessity to eliminate the inconveniences that arise due to friction at the contact between the cutting edge and workpiece, under dry cutting conditions or with a minimum amount of coolant-lubricant. The textured surface is a surface designed with a specific pattern or texture to provide a certain machining performance or to control the tribological, optical and mechanical properties of the cutting tool surface [87-89]. Because of the advances in micro and nano technologies, surface texturing can be achieved under conditions of high control and precision. The mechanism of surface texture on cutting tools mainly includes three stages (Fig. 4) [90]:

- reducing the contact length of the chip and so reducing the friction as well as the cutting temperature,
- storing lubricant to increase its retention,
- capturing debris and reduce the furrow and adhesion between the cutting tool and workpiece.

Thus, the placement of the texture reduces the contact length between chip and cutting edge which lead to decreasing friction coefficient and cutting force, improving temperature distribution, increasing chip breaking capacity and prolonging the tool lifespan. In addition, the overall quality of the finished workpiece surface can be enhanced.

The researches in this field have focused on studying the effects of different textures placed on the clearance/ rake surface [91–93], on the flank surface [94, 95] or on both active surfaces of the cutting tool [96, 97] have on the cutting performance (Fig. 5).

Different textures styles were designed for both active surfaces of the cutting tool (rake and flank surfaces) including grooves [98, 99], pits [89, 100], waves [101], grids [102], ovals [103, 104], diamonds

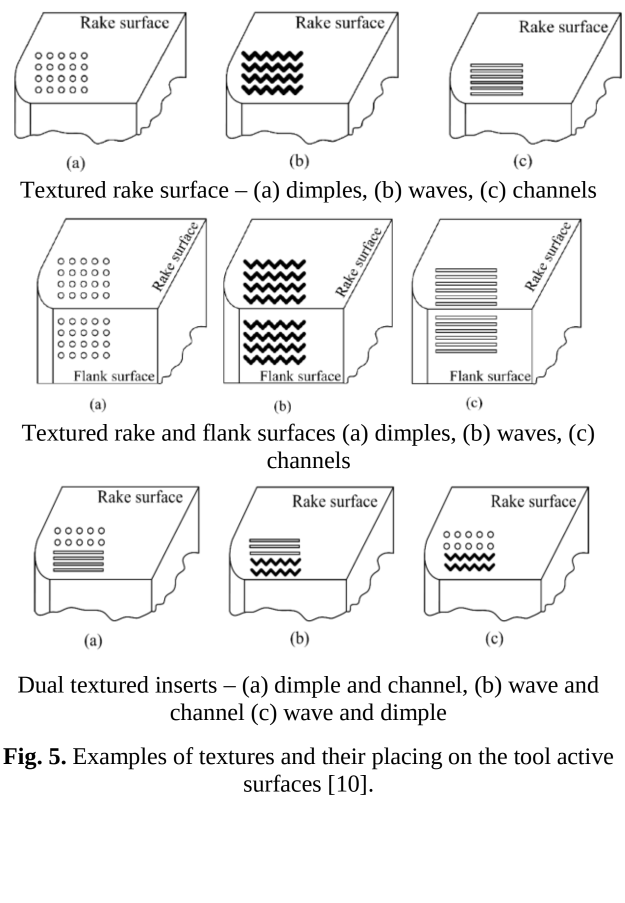

Fig. 5. Examples of textures and their placing on the tool active surfaces [10].

[105], zigzags [106], and mixed textures [107, 108]. These patterns have their own characteristics and are designed to meet different machining needs and performance requirements [109].

Various techniques are used to produce micro-textures, which can be achieved by different methods. With the continuous deepening of research on micro-textured cutting tools, micro-texture processing technology has been continuously developed, so that in addition to traditional processing methods, new technologies have emerged, including laser, micro-grinding, photolithography, electric discharge, electron beam, focused ion beam, chemical etching processing, ultrasonic, abrasive jet, electrochemical machining and surface shot peening [110, 111].

Among these methods, laser machining and electrical discharge machining are currently the most commonly implemented approaches in texture processing, and the size of the micro texture can reach micro or even nanometric level. At this stage, research on micro-texturing technology was mainly focused in two directions: (1) preparing micro-textured cutting tools in order to study their machining performance and (2) optimizing the parameters of the micro-texturing process in order to obtain a high-quality micro-texture. Regarding the research on the performance of microtextured cutting tools, two directions were pursued, namely the analysis of micro-texture parameters on cutting tool performance, cutting temperature and force, cutting tool wear and machined surface quality, and the optimization of micro-texture parameters to obtain the best cutting conditions.

Various studies have shown that the performance of textured cutting tools depends on the shape and dimensions of the textures [112-115]. It is recommended that the textures on the cutting tools have mixed sizes, both micro and nano scale, which will lead to better coolant retention. In order to maintain the integrity of the cutting edge, it is necessary for the textures to be placed at an optimal distance, although this distance also depends on the thickness of the uncut chip.

Moreover, the way the textures are aligned with the cutting edge is very important and, in this regard, it has been shown that in the case of grooved textures on the rake surface, it is necessary to be placed parallel and not in the direction of chip flow, which will lead to reduced edge wear and better orientation of the coolant-lubricant in the contact area between tool and workpiece.

Also, grooves orthogonal to chip flow direction prevent chips from penetrating into textures, which results in enhancing effects of micro-pool, micro-pocket and reducing contact area [116]. Therefore, the grooves orthogonal to chip flow direction show better overall cutting performance in terms of reduced cutting force [89, 117-119], improved anti adhesion [120-122], and lowered tool wear [114, 117, 123, 124].

Cutting force and temperature are among the most important physical phenomena in the metal cutting process, which directly influence the quality of the machined part, the cutting tool lifespan and energy consumption. Also, choosing the cutting regime and optimal geometry of the cutting tool depends on the magnitude of cutting forces.

In one of the first studies on this concept, textured cemented carbide tools at the microscopic or nanoscale using a laser beam were presented [89]. The textured tools showed a decrease in cutting force and the direction of the texture had a great influence. Also, placing textures on both active surfaces of cutting tools can significantly reduce friction, by ~13–26%, during machining processes [125, 126].

2.4. Textured Coated Cutting Tools

Based on the available studies, it can be suggested that the current research on the textured coated cutting tools focuses on the analysis of the cutting performance and some results are as follows: compared to the textured cutting tools, the tribological properties of the textured coated cutting tools were superior, the wear mechanism was characterized by the brittle peeling of the coating film and the anti-adhesion and anti-wear properties of the cutting tool surface were improved [127]; the texture could slow down the degree of wear of the coating by capturing and storing the wear particles, enhanced the bonding strength of the coating and substrate, maintained the surface integrity of the coating and synergistically improved the cutting and anti-wear properties of the textured coated cutting tools [128, 129]; compared with the pure coating cutting tool, applying texture enhanced the cutting performance in terms of cutting force and friction coefficient [130]; the cutting force were significantly reduced and so the friction coefficient and cutting tool wear, whereas the cutting tool life and workpiece quality were improved [131, 132]; in the case of highspeed cutting (250 m/min) in dry machining, the cutting forces of the textured tool were reduced by 13–22% compared with that of the conventional tool, and the cutting forces of the both textured and WS_2 coated tool were reduced by 25–44% compared with that of the conventional one and also it showed the smallest cutting temperature and friction coefficient at the tool–chip interface among all the tools tested [133]; when the cutting performance of the three kinds of coated nano-textured tools was studied, it was found that the average cutting forces were lower, as well as the friction coefficient and the cutting temperatures at the tool–chip interface compared with the conventional tool and the coated tool without nano-textures [134]; the coating enhanced the wear resistance of the tool and combined with the texture, an optimal sliding-rolling compound friction was formed on the rake face of the cutting tool which effectively reduced the friction coefficient along with diminishing the occurrence of adhesive wear on the cutting tool surface [135, 136].

In [137] the cutting performance of TiN-WS2 coated and textured tool in dry machining of Ti-6Al-4V was investigated compared to a coated tool, a textured tool and a conventional tool and, and the following results were obtained: the cutting force generated during machining was reduced by 14 % for coated-textured tool the coefficient of friction was reduced by 47 %, the tool-chip contact length was reduced by 13 % , the tool life was improved by 43 % when compared to commercial tools and overall the performance of the cutting tools in terms of the assessed parameters could be rated as TiN-

Table 1

Machining performance and sustainability of the processed cutting tools

	Processing cost	Tool wear	Cutting forces	Cutting temperature	Quality of the finished part	Sustainability
Cryogenic treatment of CT	*	***	**	**	***	****
Coated CT	***	**	**	***	**	**
Textured CT	***	***	***	**	**	**
Coated and textured CT	****	**	**	**	****	**

WS2 coated textured tool > TiN-WS2 coated tool > Textured tool > Commercial tool.

Four strategies for improving machining performance in dry and near-dry metal-cutting were reviewed and some advantages and challenges were depicted. In terms of the influence that these strategies have on the machining process, it can be appreciated that the cutting results are conditioned not only by the type of cutting tool, but also by other cutting process parameters such as cutting regime, type of operation and workpiece material and by the specific parameters of the tool processing method.

Table 1 depicts an overview of the influences that these four cutting tool processing methods have on dry and near-dry machining, and the following are considered: processing costs, tool wear, finished surface quality and accuracy, cutting performance (with regard to forces and temperature, lubrication and cooling of the cutting area, chips removal ease) and sustainability (where * = low, **** = high).

3. CONCLUSIONS

This paper presents a review of the most common cutting tool processing methods used for enhancing performance in dry or near-dry machining in order to achieve sustainable and environmentally friendly manufacturing. The results of the study have highlighted the following:

- from an economic, social, and environmental point of view, sustainable cutting processes are a necessity of the moment to meet environmental regulations and eliminate or reduce health hazards for operators, maximize productivity, and make competitive products;
- dry cutting is an environmentally friendly machining method, but in the absence of cooling and lubrication fluids, it will lead to rapid wear of cutting tools, lower quality of machined surfaces, and higher tool costs;
- MQL or NDM is an intermediate solution between dry and conventional cutting in terms of processing cost and quality of machined surfaces; in this case, both lubrication and cooling of the cutting area are ensured, and the use of ecological liquids can increase the sustainability of the technique; however, there are disadvantages such as vapor formation and the problem of chip evacuation in the case of some operations; also, a continuous supply of compressed air is required throughout the cutting process;
- in cryogenic treatment of cutting tools, machinability increases, and due to good thermal conductivity, the cutting temperature decreases; also it enhances machining performance by improving the tool's wear resistance; the liquid nitrogen used for treatment is nontoxic, easily disposable and leaves no residue; the cryo-processed cutting tools provide better performance for low cutting speeds; this type of processed tool is not suitable for interrupted cutting because rapid wear can occur; this treatment is equally effective for HSS and carbide tools; additional supply of coolant and lubricant is needed during the machining process;
- coating the surface of the cutting tool base can effectively improve the hardness, bonding force, chemical stability of the cutting tool surface, along with improving the cutting and wear resistance of the tool; tool coating is a viable option for reducing the cost of tools in dry machining and can provide the desired functionality for the cutting tool without compromising its core properties.
- texturing of cutting tool surfaces is an environmentally friendly technique that can be used in dry cutting; it also improves machinability by effectively controlling the chip flow direction, reduces the build-up edge formation, also cutting forces, friction coefficient and diffusion wear are reduced; as disadvantages of the technique: special machines are required to create the textures, which involves higher costs; it might be necessary to use an alternative cooling option for cutting in difficult conditions and it is not a suitable method for small-scale production;
- the geometric attributes of the tool surface texture, such as the shape, layout, and size, play crucial roles in determining cutting efficiency. Compared with a single texture, a composite texture with appropriate shape, distribution, and size parameters can more effectively enhance the cutting characteristics of the tool (such as by reducing the cutting temperature, increasing the wear resistance, optimizing the surface quality, and extending the lifespan of the tool;
- combining two different cutting tool processing methods, such as texturing and coating, texturing and self-lubricating coating, or texturing on advanced tool material in dry machining, may offer advantages in terms of obtaining friction reduction, improved wear resistance and surface quality, while machining various difficult-to-machine materials; the coated micro-textured cutting tools represent a new technology that combines the surface micro-texture and coating technologies.

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