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Review

State of the art of tool texturing in machining

Alisson R. Machado[a,b,*], Leonardo R.R. da Silva[a,b], Felipe C.R. de Souza[b], Rahul Davis[c], Leandro C. Pereira[b], Wisley F. Sales[a,1], Wagner de Rossi[d], Emmanuel O. Ezugwu[e,1]

[a] Mechanical Engineering Graduate Program, Pontifícia Universidade Católica do Paraná – PUC-PR, CEP 80215-901, Curitiba, PR, Brazil
[b] Federal University of Uberlandia, School of Mechanical Engineering, Av. João Naves de Ávila, 2121, Bloco 1M, 38400-902, Uberlândia, MG, Brazil
[c] Department of Mechanical Engineering, National Institute of Technology Patna, Patna, 800005, India
[d] Centro de Lasers e Aplicações, Instituto de Pesquisas Energéticas e Nucleares - IPEN, São Paulo 05508-000, Brazil
[e] AFIT – Air Force Institute of Technology, Kaduna, Nigeria

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ABSTRACT

In most of the machining processes, the application of surface texturing is one of the most remarkable and promising research fronts in relation to the use of tribological concepts for improving machinability. This paper aims to review the most recent articles on this theme (from 2016 to date) to assist the researchers in the state of the art of this technology, guide the forthcoming related investigations, and thus, fill the identified research gaps. The texture effect in machining was comprehensively reviewed considering chip formation, cutting forces, cutting temperature, lubrication, surface integrity, and tool life. The present review highlights and summarizes the major findings with emphasis on the influencing parameters, such as workpiece and tool material, cutting process, lubri-cooling condition, texture geometry, and texture manufacturing technique. The overwhelming majority of the studies presented tool surface textures manufactured by laser ablation on the rake face of uncoated WC-Co tools. In this relation, turning was identified as mostly used machining process and dry condition as the chiefly implemented lubri-cooling environment. Moreover, most of the textures were noticed with linear grooves and dimple geometries, whereas the work materials mostly investigated were the hardened/high alloy steels and titanium alloys.

1. Introduction

The technological development of humanity is inevitably linked to its ability to advance the tooling system. It is interesting to know that the historical periods were divided based on materials used in tool production, such as stone, bronze, and iron ages. Even in the contemporary era, this remains valid where the emergence of more technologically intricate devices occurs concurrently with the development and advancement of more complex materials.

Interactions at chip/tool/workpiece interfaces adversely affect the machining tribosystem since in relatively closer surfaces (such as the primary and secondary shear planes), the mechanical and thermal stresses exhibit huge differences, thus, give rise to entirely different tribological interactions, tool wear mechanisms, and machining performances (Astakhov, 2006). The tribosystem is further aggravated by the growing demand for materials with higher mechanical, thermal, and tribological properties, such as nickel (Thellaputta et al., 2017) and titanium alloys (Gupta and Laubscher, 2017). This further increases the already-high complexity of the interactions at the cutting interfaces. In addition to the utilization of more sustainable cooling techniques (Debnath et al., 2014), the most advanced research fronts are getting focused on the development of tools and coatings (with an ever-increasing combination of hardness and toughness) (Favero Filho et al., 2019) for improving efficiency and environmental impact of the machining processes.

Cutting fluids are another front of research that has called attention in recent years because, on the one hand, they may be indispensable from the technical point of view; on the other hand, they usually cause adverse environmental impact. Therefore, the interaction of textured tools and the use of cutting fluids is another interesting matter to consider.

The assertive given by Moore (1969) that the surface texture is the most crucial variable regarding the magnitude of frictional interactions between coupled surfaces remains as relevant as ever. Despite its

* Corresponding author at: Mechanical Engineering Graduate Program, Pontifícia Universidade Católica do Paraná – PUC-PR, CEP 80215-901, Curitiba, PR, Brazil.
E-mail address: alisson.rocha@pucpr.br (A.R. Machado).

[1] In memoriam.

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implementation and evaluation in ancient times (Gachot et al., 2017) by historical figures such as Leonardo Da Vinci (Hutchings, 2016), the modern approach to implement surface textures in engineering was driven by pioneer studies which involved the evaluation of the so-called micro-asperities in mechanical seals and bearings, such as the works conducted by Hamilton et al. (1966) on the theory of lubrication under micro-asperities, Anno et al. (1969) studies about the effect of micro-asperities in load-support and fluid leakage and Etsion and Burstein (1996) model for mechanical seal under the effect of micro-asperities.

With the advent and popularization of surface engineering techniques, the investigation of surface texture's significance on cutting tool performance amid machining processes has gained immense attention (Sharma and Pandey, 2016b). Surface texture fabrication techniques in cutting tools do not differ much from those commonly applied ones used for texturing other components such as pistons/cylinders (Da Silva and Costa, 2017a,b), mechanical seals (Wang et al., 2019), bearings (Vlădescu et al., 2019), and prostheses (Baino et al., 2019) with the most common methods such as laser, electrical discharge, and electron beam texturing (Arslan et al., 2016). The relatively lower understanding of the effects of surface texturing of cutting tools on the various factors affecting machinability still hinders applying this technique on a larger scale (Ranjan and Hiremath, 2019).

Most published research addressing various insights of surface texturing of cutting tools are focused on the surface manufacturing techniques (Ranjan and Hiremath, 2019) and tribological effects of the texture (Chen et al., 2019b). Moreover, some related researches are covered by a relatively smaller number of articles consisting of the actual state of the art (Gajrani and Ravi Sankar, 2016), and most of them applied in areas other than machining. The machining tribosystem has contact pressures of the orders of magnitude higher than those found in most mechanical systems such as sliding and rolling bearings (Rosenkranz et al., 2019) and even higher than those found in forming processes (Shimizu et al., 2019). This happens because in machining the pressures at the chip-tool-workpiece interfaces must be high enough to allow shearing of the work material to form the chip properly.

Such high pressures make it impossible to apply hydrodynamic models such as those described by Gropper et al. (2016) or elasto-hydrodinamic as described by Marian et al. (2019). Despite the recent advances in surface texturing technology, most of the evaluations are, as shown by Grützmacher et al. (2019), focused on contact pressures much lower than those found in machining. Thus, models for design and optimization, such as those presented by Gropper et al. (2018), could not be promptly used to model the cutting interface tribosystems.

The abovementioned facts provide solid grounds for the present paper to review all the related latest publications (2016 to date). This timespan is further supported by the fact that some of the major reviews in the field focused on papers from before 2016. To exemplify, Sharma and Pandey (2016b) review about surface texturing focused on the turning process, which will be evidenced in this paper's conclusion, indicating that the study of the effects of textures in other machining processes is neglected. Arslan et al. (2016) focused on texture manufacturing technologies and the resulting tribological interactions, not providing enough information about the effects of textures on machinability. Gajrani and Ravi Sankar (2016) also focused on texturing manufacturing methods. The discussion in this paper is focused on the effect of the cutting tool surface texturing on the machinability response parameters. Besides, the influence of various texturing techniques, geometries, and texture positions for different cutting processes and parameters and machined materials, has been included as part of the present review.

The cutting processes, as usual, have been addressed in terms of the influence on chip formation, cutting forces and power, cutting temperatures, lubrication, surface integrity, and tool life. Further, to summarize the state of the art, this manuscript presents a graphical review related to the investigation of the performance of cutting tools surface texturing with respect to the main output parameters of the machining processes. Therefore, the present review intends to provide research and knowledge gaps to the budding researchers for executing more advanced research in surface texturing of cutting tools involved in various machining processes.

2. Chip formation

According to Shaw and Cookson (2005), the mechanism involved in the chip formation process may cause harm to the machine operator and damage the equipment or product. In addition, machinability variables such as cutting forces, temperature, lubrication, and tool life, including material handling and disposal, may also be adversely affected. All the aforementioned reasons corroborate the importance of chip formation understanding to achieve a successful cutting operation. Even though the chip movement is restricted to a great extent by its interaction with the rake surface, all other machining parameters have some degree of effect on its formation. Based on these arguments, the implementation of surface texturing mainly on the tool rake surface holds a promising dominance for controlling the chip formation process. Moreover, surface texturing on the tool rake surface directly affects the tribological behavior in the secondary shear zone because of modification of the contact area in the seizure and slipping zones.

In general, the literature indicates that textures perpendicular to the chip flow result in a decrease in the chip curling radius, favoring its breakage (Kang et al., 2018b). Su et al. (2018) reported that texture patterns perpendicular to the chip flow are more efficient to trap debris generated during the chip formation. According to Sivaiah and Bodicherla (2020), the debris trapping is even more efficient with the perpendicular groove pattern, resulting in lower friction at the chip flow interface. The better performance of the perpendicular textures in relation to the chip flow was further assessed from a tribological point of view by Dhage et al. (2019) using a lathe as an open tribometer and evaluating the correlation between the tool-chip contact area and the cutting force with the roughness parameters of the textured rake surface of the tool. Despite that, the texture parallel to the chip flow led to a lower derivative cutting at the texture borders, as reported by Liu et al. (2017).

As described by Duan et al. (2019), one of the biggest challenges regarding chip formation in textured cutting tools is to reduce the formation of derivative cutting zones at the edges of the textures. This phenomenon increases the shear stresses by generating additional shear zones resulting in increased machining forces and wear, especially at the textured region.

Mishra et al. (2018a) developed a model for the chip serration and contact length for plain and textured tools based on a linear regression model, which can be used for 2D machining simulations. The simulation results are shown in Fig. 1 and the chips are seen embedded in the textures at greater feed rates. In the case of $v_c = 200$ m / min and $v_c = 250$ m / min, the chips completely incorporate the textures in the contact zone. Besides this, broken textures are visible in the simulation results. Therefore, it can be proposed that textured tools lose their effectiveness with increased feed and speed due to high embedding and texture reduction. The higher von Mises stresses on the flank and on the rake faces are visible from the simulation results. The contact stresses where the chips are embedded in the textures are comparatively higher than the unfilled textures, suggesting dullness or wear of the textures due to higher stresses. The hot chips embedded in the textures will act as a heat source and cause thermal damage to the tools and, ultimately, break patterns due to high stresses.

Patel et al. (2019) studied the dry turning process of AISI 4340 steel using uncoated micro-textured cemented carbide tools. The textures used were microgrooves perpendicular to the cutting edge, produced by micro-electrical discharge machining (μ-EDM) along the tool's rake face. The textures varied with respect to the width (50 and 100 μm), depth (10, 20 and 30 μm), and spacing (50, 75, 100, 150 and 200 μm). The

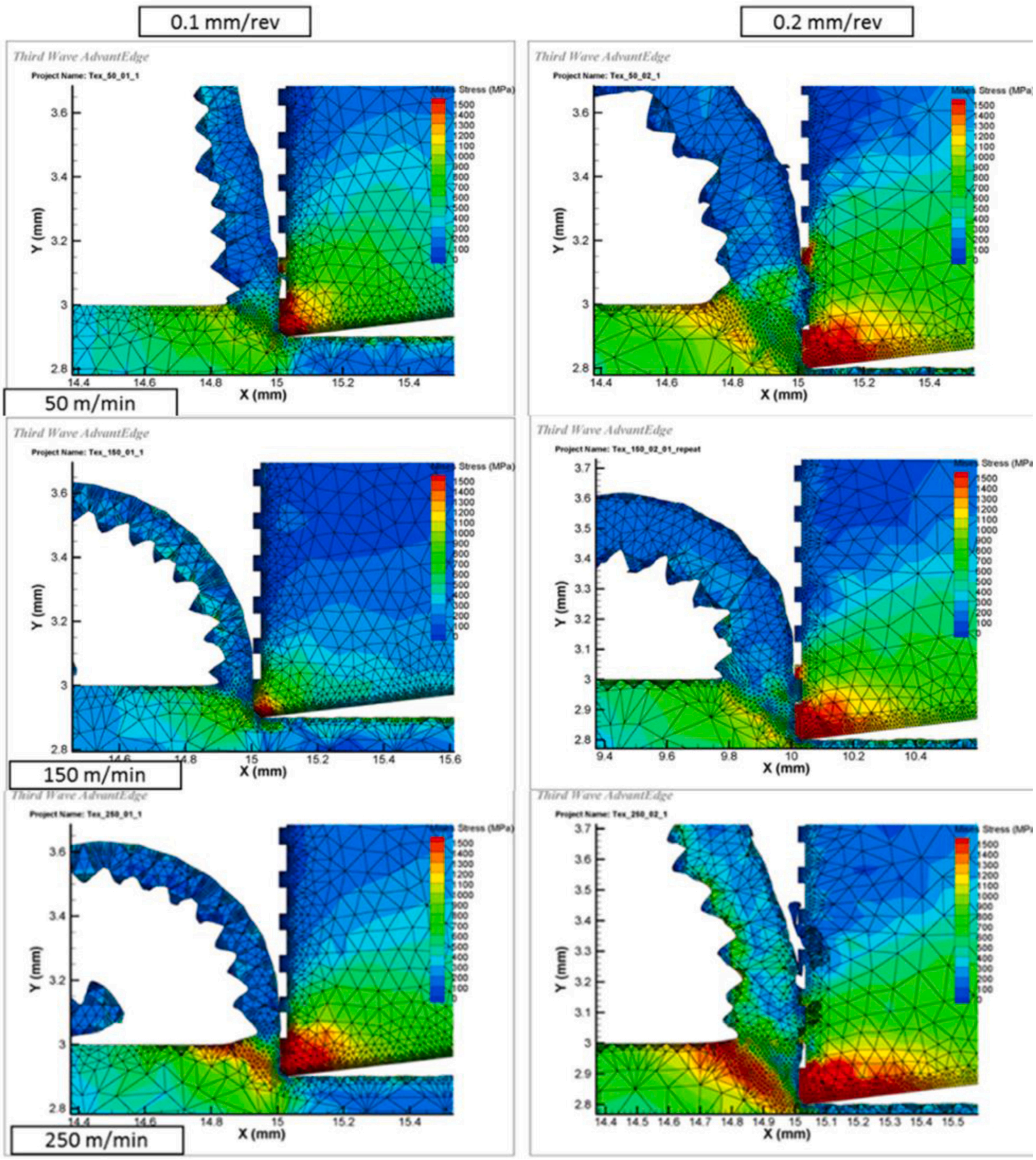

Fig. 1. Simulation results for contact length for textured cutting tools for several cutting conditions. Adapted from Mishra et al. (2018a).

authors found that increased groove width and spacing reduced the chip-tool contact and decreased the chip flow and adherence of the work material into the microgrooves. Changes in the micro-groove depth proved to be less effective in the chip control.

In the dry turning of the AISI 52100 steel, Kumar and Patel (2018) studied the effect of groove textures on the rake surface of Al_2O_3/TiCN composite ceramic cutting tools with EDMed textured tools. The width of the textures varied between 150 µm and 200 µm, with a distance between the patterns ranging from 300 µm to 400 µm. The authors found that textures perpendicular and parallel to the chip flow direction resulted in a reduction and increase of friction, respectively, when compared to non-textured cutting tools. Despite the sliding condition being the significant curling effect for the chips in all situations, the textures perpendicular to the chip flow resulted in greater chip-curling. The authors also found that textures that obstructed the chip flow reduced the material adhesion on the tool face compared to non-textured tools, and the texture direction inclined or normal to the chip flow reduced the stresses in the cutting tool. Similar conclusions regarding the groove direction influence in the chip formation were found by Arulkirubakaran et al. (2019). Durairaj et al. (2018) also concluded that surface texturing in the cutting tools resulted in around 15 % less adhesion than un-textured tools.

Su et al. (2017) investigated the performance of textures on polycrystalline diamond (PCD) tools in dry turning of Ti6Al4V titanium alloy. Regular microgrooves (parallel to the main cutting edge) were fabricated on the rake face of tools by a fiber laser with groove depths ranging from 51.5 µm to 54.4 µm, groove width from 56.5 µm to 60.4 µm, spacing from 83.9 µm to 86.4 µm, and groove distance (from the main cutting edge) from 249.8 µm to 330.9 µm. The authors found that the tool-chip interface's frictional behavior was significantly improved by the micro-grooved tools compared to that of the non-textured tools, even without the use of lubricants. Other authors also found improvements in the tool-chip interface's frictional behavior, such as Feng et al. (2017) who reported reductions of up to 30 % in relation to non-textured tools.

Chen et al. (2017) made numerical investigations of the effects of microgroove laser textured uncoated cemented carbide tools. The microgrooves were designed on the tool's rake face, perpendicular to the chip flow, with the edge distance ranging from 20 to 200 μm, groove width ranging from 30 to 200 μm, and width-to-depth ratio from 1 to 16. The authors found that the microgrooves could be effective in reducing the cutting and thrust forces in general. The authors also found an optimal width to depth ratio between 3 to 7 to minimize the cutting forces and facilitate the chip formation process. Fig. 2 shows the chip formation zone and the stress distributions for two width-to-depth ratios after the cutting force has reached a steady state. Fig. 2(a) shows that the first microgroove at the chip-tool interface serves as a micro cutter as the chip flows over the rake face, resulting in highly localized pressure and microchips curling into the microgroove. As the width-to-depth ratio increases from 1 to 16 (Fig. 2(b)), the microgrooves turn to be shallower and the highly localized stress concentration (at groove walls) gradually disappears. Although the microgrooves may form some local obstacles for chip flow during cutting, they also play an important role in breaking the intimate contact between the chip and tool, thus facilitating chip flow during cutting.

Sivaiah et al. (2020) evaluated the effect of texture patterns in the rake face of a PVD coated cemented carbide tools in the form of dimples and dimples + grooves, in the turning of Inconel 718 under minimum quantity lubrication (1:20 soluble oil at 80 ml/h). The authors found that the tool texturized with dimples + grooves outperformed the tool with dimple textures as well as the non-textured tools in relation to the chip morphology, tool life, and surface roughness. Fang et al. (2016) evaluated the tribological performance of laser patterned grooves and dimples in cemented carbide tools using friction tests similar to the honing process. The authors found that dimples outperformed grooves regarding the hydrodynamic effects and friction coefficient. Similar results were found by Fang et al. (2017b) when evaluating the frictional performance of laser textured cemented carbide surfaces, using a ball-on-flat nanotribometer under linear reciprocal movement. The authors found that laser patterned presented a more stable and without running-in period coefficient of friction compared to polished cemented carbide.

Pratap and Patra (2020) studied the effect of surface textures at the rake face of PCD micro-tools in the micro-slot grinding process of BK7 under dry, low, and high-pressure MQL (minimum quantity lubrication).

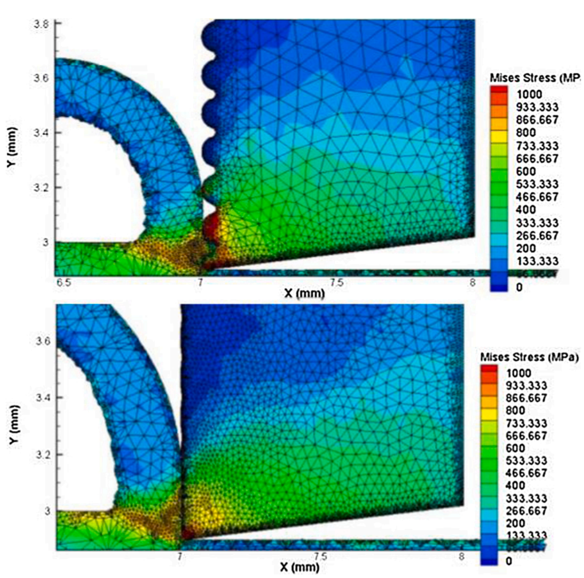

Fig. 2. Chip formation zone and stress distributions (groove width = 70 μm and edge distance = 50 μm). (a) width-to-depth ratio of the groove = 1, and (b) width-to-depth ratio of the groove = 16. Adapted from Chen et al. (2017).

The textures were manufactured using a wire-EDM (wire electrical discharge machining) process with microgrooves perpendicular to the chip-flow direction at two levels of spacing (72 ± 10 and 110 ± 10 μm). The fluid flow rate was kept constant at 7.5 ml/h with application at two pressure levels (2 and 4 bar). For a better comparison, the machining conditions were also evaluated under the dry condition using non-textured tools. The authors found that the surface texturing resulted in provisional chip collection in the rake face's passive areas, indicating lesser chip crushing and material adhesion on the tool active interface. According to the authors, this behavior leads to lower cutting forces, surface roughness, and tool edge chipping.

3. Cutting forces

Cutting forces are the important indicators of the machining process that are practically related to all the process variables and the machine tool existing state and tool design. According to Trent and Wright (2000), the machining process forces are relatively low compared to other manufacturing processes such as forging and rolling. It is due to the small contact areas characteristic involved in the machining operations. However, the stresses associated may be higher than other manufacturing processes. By modifying the contact areas engaged in the process and, consequently, the material flow, surface texturing of cutting tools becomes an effective alternative in reducing cutting forces without altering the tool geometry.

Zhu et al. (2016) evaluated the application of surface textures in the form of microgrooves at the rake face of PCD coated cemented carbide tools by using ultrasonic elliptical vibration texturing method. The textures had pitches of 200 and 400 μm and depth of 12 μm and were tested in the turning of an aluminum alloy. This innovative texturing process showed high potential to improve production with high efficiency and accuracy of surface textured tools even in ultrahard coatings, such as PCD. The texture pattern with lower pitch (200 μm) showed better performance in terms of chip adhesion. Moreover, the cutting force could be reduced to 17.1 % compared to non-textured tools.

The better performance related to chip adhesion is also extensively found in the literature (Ghosh and Pacella, 2020). Furthermore, better results were observed for nano (Liu et al., 2018a), self-lubricating textures (Zhang et al., 2017), and dimple texture pattern (Ahmed et al., 2020). According to most of the authors, the main reason is linked to the reduction in chip-tool contact area. The same was observed and explained by Su et al. (2018). An increase in chip adhesion was reported only when using relatively bigger texture patterns (Singh et al., 2020).

Lian et al. (2018) examined the use of nanotextures in self-lubricating cutting tools during the dry turning of AISI 1045 hardened steel. Four different types of cutting tools were evaluated, a conventional commercial tool (CT), a tool soft-coated with WS_2 (WCT), a textured tool (TT), and a soft-coated textured tool (WTT). The main results are illustrated in Fig. 3. In relation to the non-textured and uncoated tools, considerable reductions in cutting forces (Fig. 3a) were noticed, ranging from 9 to 31% for the soft-coated tool, 8–18 % for the textured tool, and 10–44 % for the tool with both texture and soft-coating. In relation to the friction coefficient (Fig. 3b) at the chip-tool interface, WCT, TT, and WTT tools outperformed the conventional tool (CT) by 2∼13 %, 2∼7%, and 10–25 %, respectively. In relation to the average flank wear (Fig. 3c), WTT outperformed the other tools followed by WCT and TT tools, which indicated that the soft coating decreased the tool wear significantly, when coupled with surface texturing. A similar trend is also observed for the surface roughness (Fig. 3d), with reductions in Ra for WCT, TT, and WTT as 20∼30 %, 15∼34 %, and 32∼37 %, respectively, in relation to the conventional tool (CT). The authors further stated that both coating and texturing benefits were even more pronounced for the higher cutting speeds.

Arulkirubakaran et al. (2019) investigated the use of textured tools in the turning of Al-5Cu-TiB_2 composite, fabricated by in-situ casting. The textures were fabricated in two patterns, areal and linear, on the rake

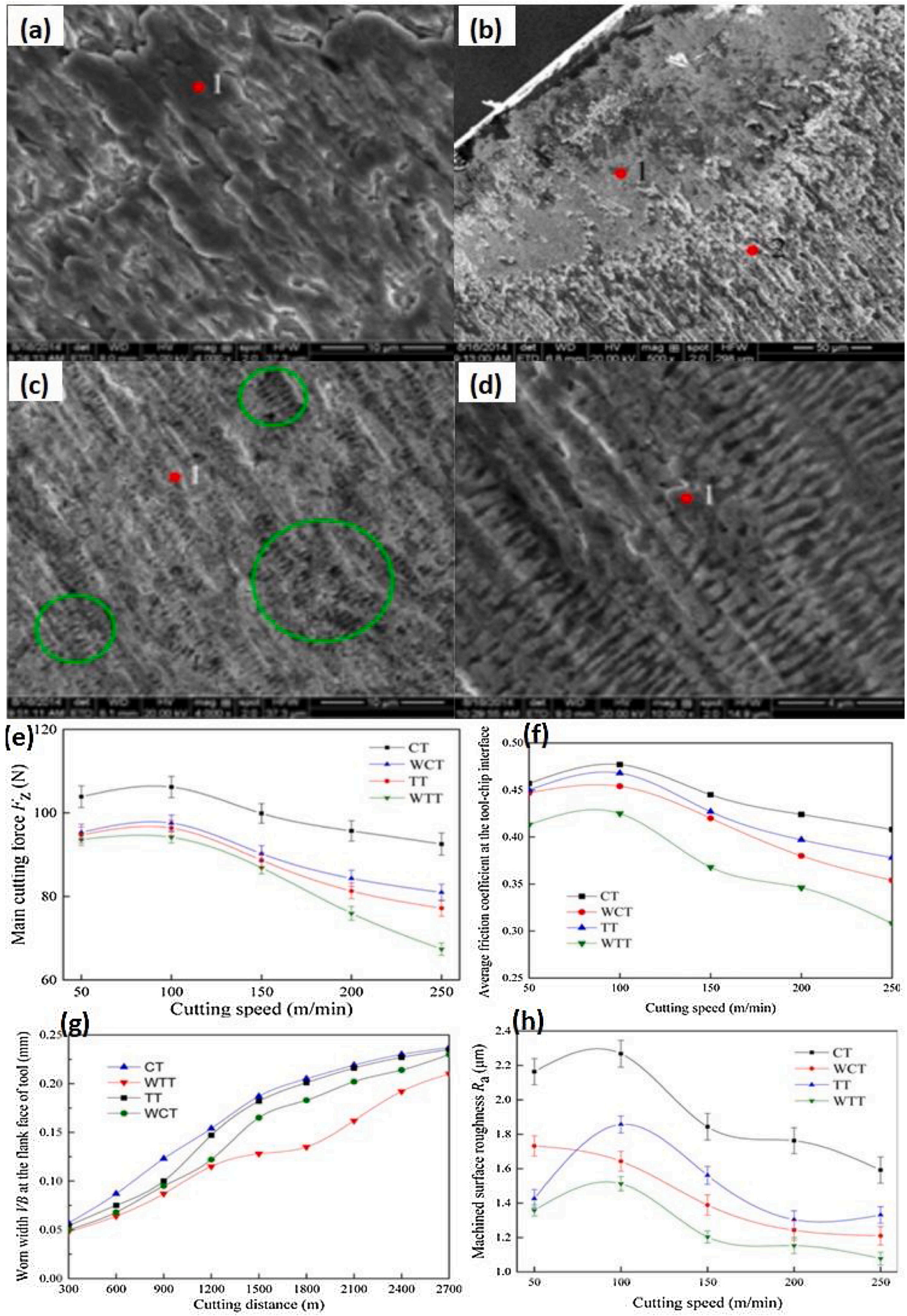

Fig. 3. Machinability of the tools with different textures and SEM photos of the tools after tested. (a) CT; (b) WCT; (c) TT; (d) WTT; (e) cutting force; (f) coefficient of friction; (g) average flank wear; (h) surface roughness. Adapted from Lian et al. (2018).

face of ISO K20 cemented carbide insets using electrical discharge machining (EDM) process. The areal texture was composed of dimples with a size of 200 μm, and the linear textures were evaluated both parallelly and perpendicularly to the chip flow with 250 μm width and 100 μm depth. The authors found a reduction in the cutting force and the specific cutting energy of up to 30 % for the linear texture perpendicular to the chip flow, as shown in Fig. 4. This reduction was explained by lower adhesion of the workpiece material on the tool, absence of built-up edge formation, and overall better lubrication in the chip-tool interface. The tool wear got drastically reduced at perpendicular textured tools, especially under the lubricated condition.

Duan et al. (2017a) studied the use of micro-textures with a single groove (parallel to cutting edge and fabricated by Nd:YAG laser) on the rake face of the WC/Co cemented carbide tools during dry turning of medium carbon AISI 1045 steel. The manufactured grooves had a width of 50 μm, a depth of 13 μm, and a distance of cutting edge of 150 μm. The authors found that the derivative cutting causes filling of the surface textures, increasing the friction at the tool-chip interface, leading to higher cutting forces and chip deformation. Vasumathy and Meena (2017) also evaluated grooves parallel to the main cutting edge and found a reduction of 7.7 % in the cutting force. Gajrani et al. (2018b) studied similar textures perpendicular to the cutting edge and found reductions in the cutting force ranging from 4.23 % to 10.82 % for uncoated tools and 7.31%–17.41% for coated tools. On the other hand, according to Kang et al. (2018b), although the textures have reduced the cutting forces by 15 %, the grooves' orientation did not substantially influence this reduction.

Pratap et al. (2019) used micro-EDM to texture the end face of polycrystalline diamond (PCD) micro-grinding tools. In addition to the non-textured tools, tools with 50 μm deep and 200 μm wide micro-dimple texture in the center of the end face and with one, two and four microgrooves along the diameter of the end face, respectively, were also examined. The dry grinding was performed in BK7 soda-lime silicon glass with a cutting speed of 2000 rpm and feed rate in the range of 25−200 μm/min. The authors found that the tool with four micro-grooves had the lowest cutting force values with a reduction of about 35–40 % compared to the non-textured tool. The tool with a micro-dimple presented a substantial reduction in the passive cutting force with no significant reduction when using the other ones.

Arulkirubakaran et al. (2018) studied the effect of surface textures on the rake face of an uncoated cemented carbide insert in the machinability of Ti-6Al-4 V alloy during turning under semi-solid lubrication (20 % MoS_2 + 80 % SAE 40 oil). The EDMed surface textures consisted of grooves parallel, perpendicular, and oblique to the chip flow direction with 250 μm width and 100 μm depth. The authors found that surface textures on the tool significantly reduced the machining forces under lubricated conditions. The main cutting force was reduced up to 30 % for the grooves perpendicular to the main cutting edge because it reduced the tool-chip contact area and enhanced the lubrication in the cutting zone. The authors also found that power consumption was reduced up to 20 % when the perpendicular groove was used. Similar results of reduction in the cutting forces (of up to 38.4 %) were found with similar texture pattern by Zhou et al. (2019) during wet milling of the same Ti-6Al-4 V alloy.

Xing et al. (2016) evaluated three types of textures (linear grooves, circular dimples, and rectangular dimples) fabricated by a Nd: YVO4 laser, with 10 μm depth and area density of approximately 20 % on the rake face of cemented carbide cutting tools. The authors found that the texture's rectangular dimple configuration presented the smallest cutting forces among all the cutting tools tested. However, as the cutting speed increased, the cutting force reduction's effectiveness decreased, and for the highest cutting speed, it became counteractive. The use of surface textures also reduced the friction coefficient for the lower cutting speeds (55–220 m/min) with the rectangular texture pattern, presenting the smallest friction coefficients for this cutting speed range. According to the authors, at lower cutting speeds, the chip flow is benefited by the smaller contact area, but it became more ductile at higher cutting speeds, flowing over the textures and increasing both the cutting forces and the friction coefficient. Similar results regarding reduction in friction coefficient, when surface textures were used, were found by Aktürk et al. (2015) in flat-on-cylinder tests using a laser textured D2 tool steel cylinder against a 6111-T4 aluminum sample.

Sarma and Rajbongshi (2020) studied the effect of μEDMed groove and dimple surface textures on the rake face of TiN coated cemented

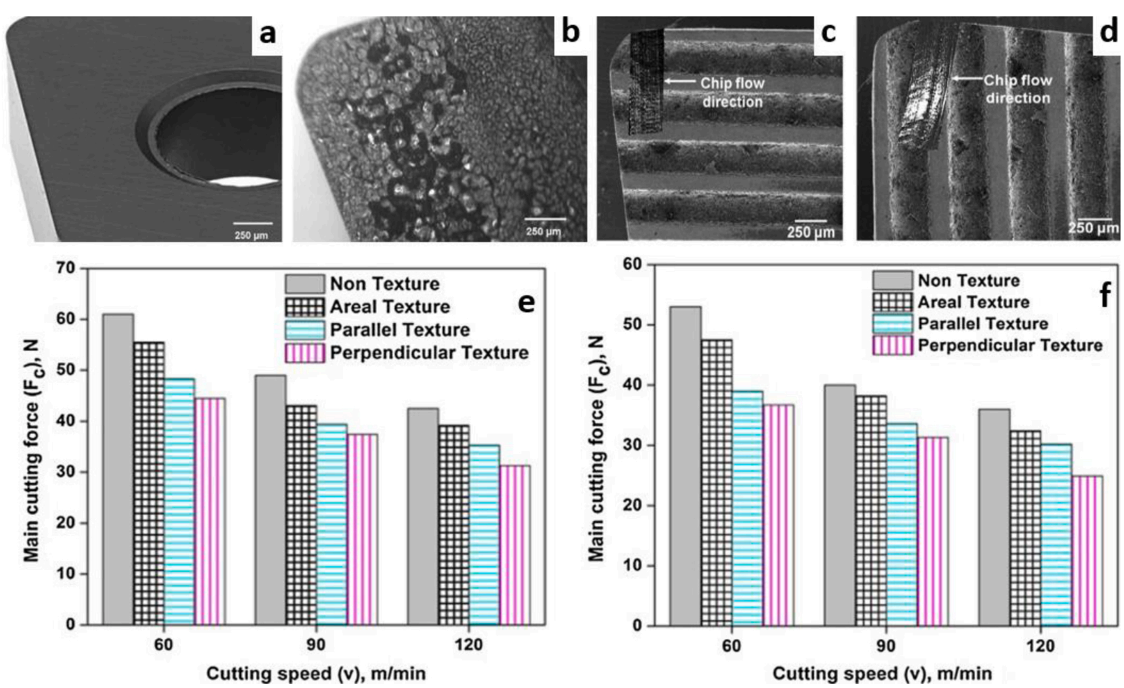

Fig. 4. Comparisons of the machining forces when using the different textured tools and SEM images of textured patterns. (a) Non-textured (b) Areal (c) Linear texture with perpendicular to chip flow direction (d) Linear texture with parallel to chip flow direction. Main cutting forces at different cutting speeds (e) dry condition (f) lubricated condition. Adapted from Arulkirubakaran et al. (2019).

carbide cutting tools. The machining trials were performed amid dry turning of AISI D2 steel (45 HRC) under two cutting speeds (100 and 150 m/min), feed rates (0.05 and 0.15 mm/rev), and depth of cut (0.25 and 0.55). The authors concluded that both textured patterns resulted in lower cutting and feed forces and apparent friction coefficient, compared to non-textured tools with dimple pattern, and thus, present improved results.

4. Cutting temperature

According to Trent and Wright (2000), the machining process costs are generally dependent on the material removal rate. However, the removal rate increase is usually accompanied by an increase in the temperature at the chip-tool-workpiece interfaces. The enormous amount of energy involved in chip formation is converted into heat and acts as a source of many machining challenges related to workpiece quality, tool life, and process productivity. The use of cutting tools with surface textures represents a possibility of reducing the heat generation during the process and helping to dissipate it more efficiently, thus improving the machinability.

Sawant et al. (2018) studied the influence of spot and dimple textures manufactured by micro-plasma transferred arc powder deposition process, on the rake face of grade T-42 HSS cutting tools in the dry turning of Ti-6Al-4 V titanium alloy. The use of dimple-textured HSS tools resulted in better performance regarding cutting and thrust forces, tool temperature, flank wear, and surface roughness for the evaluated cutting conditions. As illustrated in Fig. 5, the cutting temperatures increase for both textured and non-textured tools with the rise in cutting speed. The temperatures for the spot and dimple texturized tools are around 12 % and 4% lower, respectively, when compared to the non-textured tool. Because of their shapes, the spot textures lead to an early separation of the chip from the rake face, enhance the convective heat transfer of the process, and thus, help to improve the tool life during machining.

Song et al. (2017) used micro-EDM to fabricate textured micro-dimples on the rake face of WC/TiC/Co cemented carbide tools, with an average of 150 μm diameter and 200 μm depth. To further improve the tribosystem, graphite was embedded into the micro-dimples to form self-lubricating tools. The textured tools were tested during the dry turning of AISI 1045 hardened steel and were compared with non-textured tools. The textured tool's cutting temperature embedded with graphite was 15–20 % lower than that of the conventional carbide tool. The authors explained that the cutting temperatures were lowered because of the lower contact length and friction between the chip and the tool, caused by the surface textures with embedded graphite.

Sun et al. (2016) fabricated microgrooves, micro-dimples, and hybrid textures via Nd:YAG laser on the rake face of carbide tools with a solid lubricant (MoS_2) applied to fill the micro-textures. They further examined these textures in the dry turning of AISI 1045 steel. The textures had a width and diameter of 40 μm and depth of 50 μm, respectively. Also, they had a distance from the cutting edge of 150 μm and two different spacings of 60 μm and 100 μm. The hybrid texture effect was more evident in the case of high cutting speed (120 m/min), when the cutting temperature was reduced by 6.9–21.7 %. Another work that also studied the effect of solid lubricants of MoS_2 (Gajrani et al. (2018a)), concluded that the workpiece temperature was reduced by 21 % (without MoS2) and 17 % (with MoS2) when compared with those of un-textured cutting tools.

Arulkirubakaran et al. (2016) studied the turning of Ti–6Al–4 V alloy using textured tungsten carbide tools with microgrooves textures on the rake face. The wire EDM textures were in parallel, perpendicular, and cross pattern to that of chip flow orientations, with 250 μm width and 100 μm depth. In a similar way of the previously discussed work of Sun et al. (2016), a mixture of MoS_2 with SAE 40 oil (80:20) was used as a semi-solid lubricant. The authors concluded that, in general, the textures reduced the cutting temperatures of the process as they reduced the contact area. This further reduced friction forces, improved the lubrication in the tool-chip contact interface with the perpendicular pattern, and finally presented the overall best results.

Fang and Obikawa (2017) evaluated microtextures' effect on the flank face of cemented carbide PVD-coated tools with TiAlN. The textures were manufactured using laser irradiation on the tools' flank face, with the parallel, perpendicular, pit, dot, and crosshatch patterns, as shown in Fig. 6. The texture width and interval were 50 μm and a length ranging from 50 μm to 2200 μm, respectively. The machining trials consisted of turning of Inconel 718 alloy using an emulsion with 10 % concentration as coolant, under a constant cutting speed of 120 m/min, feed rate of 0.1 mm/rev, and depth of cut of 0.5 mm. The use of surface textures reduced the cutting temperatures as it increased the shear angles, which improved the process's tribological conditions. The results further indicated that the textures' height or depth strongly influenced its fin behavior, and thus, the thermal conditions of the cutting region.

Rajbongshi and Sarma (2019) compared the performance of dimple, groove, and non-textured coated cemented carbide tools model SNMG 120408-KM3215, in dry turning of AISI D2 steel. The textures with a diameter of 120 μm, depth of 20 μm, and distance from the cutting edge of 50 μm, were fabricated on the flank face of the tools using μ-EDM. The dimple textured tools resulted in lower average cutting temperatures than groove textured and non-textured tools. Similar results were presented by Lian et al. (2018), where the cutting temperatures were lowered by 12–16% with coated and textured tools compared to uncoated tools.

Li and Zhang (2019) studied textured cemented carbide tools in dry turning of northeast China ash wood (Fraxinus spp.). The textures were fabricated on the tools' rake face with dimple shape with diameters ranging from 80 to 200 μm, depth of 10 μm, and texture density ranging from 5 to 30 %. The authors reported that the average cutting temperatures decreased with surface textured tools compared to non-textured ones, although the peak temperatures did not present a significant decrease. According to the authors, the reduction in the average cutting

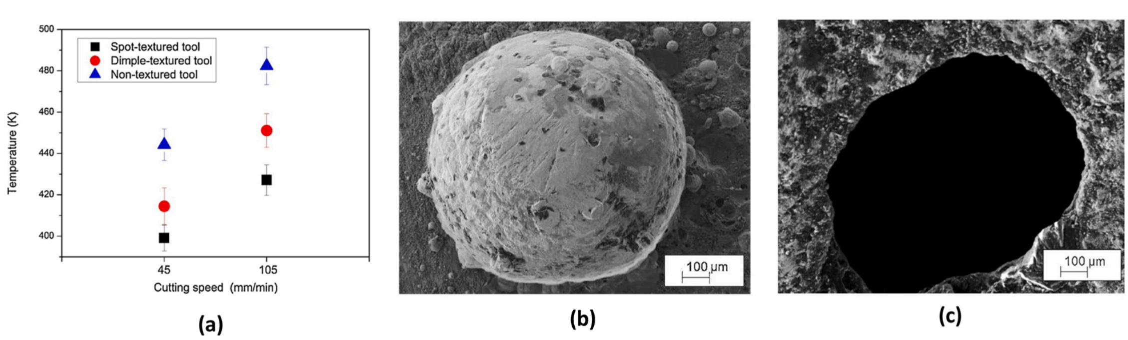

Fig. 5. (a) Temperature of the spot-textured, dimple-textured, and non-textured HSS tools during turning of Ti-6Al-4 V at different cutting speeds; (b) dimple texture; (c) spot Texture (Sawant et al., 2018).

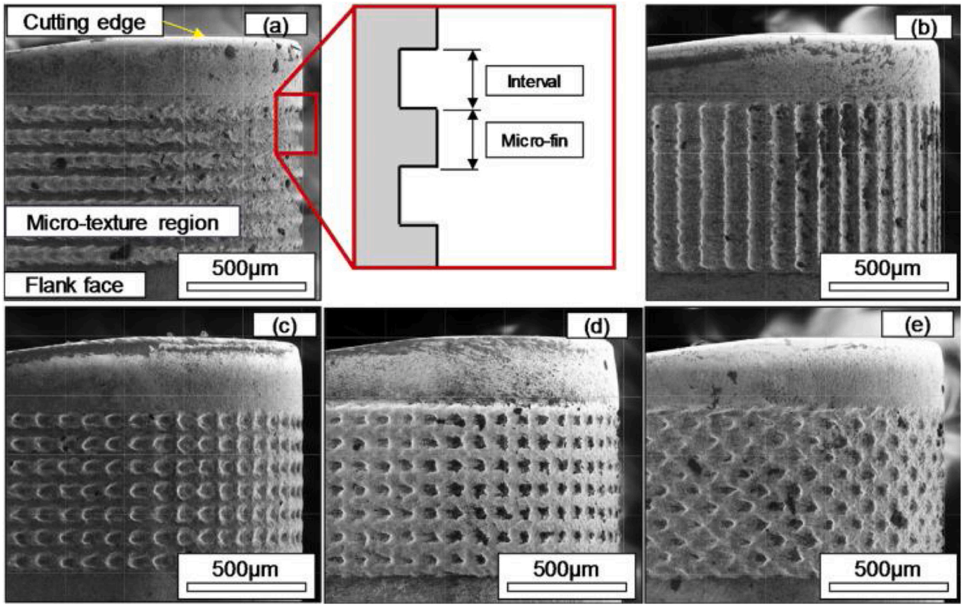

Fig. 6. Laser-irradiated micro-textures (a) parallel (b) perpendicular (c) pit (d) dot (e) crosshatch (Fang and Obikawa, 2017).

temperatures can be attributed to a reduction in the contact area between the chip and the tool's rake face, which reduced the cutting and friction forces. The best results were found for the dimples with 120 μm diameter, 10 μm depth, and texture density of 20 %.

Vignesh et al. (2020) evaluated the effects of surface textured tools in dry turning of AISI 4340 steel. The textures were manufactured using laser marking technique and placed in the rake face of TiN coated cemented carbide tools. The pattern chosen by the authors was the dimple with diameters of 80, 90 and 100 μm, depths of 60 and 70 μm, and density ratios ranging from 0 (non-textured tools) to 45 %. A group of tools had the patterns coated with MoS_2 for enhancing the tribological behavior at the rake face. The authors found that the average heat generation was lower when the tool was textured and coated with MoS_2. It was due to lower friction and wear at the rake face. The authors found that a dimple with diameter of 90 μm, a depth of 60 μm, and a density ratio of 35 % had better morphology related improvements in the machinability.

Patel et al. (2020) evaluated the effects of microtextured tools in dry turning of Ti6Al4V titanium alloy. The patterns were made using micro-EDM at the rake face of an uncoated cemented carbide tool. The pattern designs investigated were microgrooves perpendicular, parallel, diagonal, and cross-patterned to the main cutting edge. The evaluated microtextures had cutting width ranging from 50 to 100 μm, spacing of 15, 50, and 100 μm, and distance from the main cutting edge of 10, 20, and 30 μm. The authors found that the cutting forces significantly increased as the distance of the pattern to the cutting edge and depth increased, thus, resulted in substantial rise in wear rate and cutting temperatures.

5. Lubrication

According to Astakhov (2006), tribology can be understood as the science and technology that studies the interaction of surfaces in relative motion, including friction, wear and lubrication. Many of the phenomena observed in machining can be explained by the tribological interactions of the triad workpiece-tool-chip. The usage of cutting fluids is one of the most common strategies for tribological control systems, including in machining (Da Silva et al., 2019). During the shearing process in metal cutting, a considerable amount of heat is generated due to plastic deformation and friction. In general, the most significant functions of a cutting fluid are lubrication at low cutting speeds and cooling at high cutting speeds (Carvalho et al., 2019). At low cutting speeds the cutting fluid has a greater chance to penetrate into the chip-tool-workpiece interfaces and exerts its lubricant function properly. There are less chances for the lubricant action at high cutting speeds, and the temperatures are usually high and the cutting fluid is called upon to exert its cooling function.

In general, the most significant function of these cutting fluids is found as a lubricant at low cutting speeds and as a cooling medium at high cutting speeds. The study of the effect of cutting fluids with the surface texture of the tools aims to improve the lubricity of the tribosystem in question, thus helping to reduce the severity of interactions at the cutting interface.

Liu et al. (2019b) evaluated the performances of non-textured and micro-textured grooves on uncoated WC-10Ni_3Al and WC-8Co tools in both dry and wet milling (emulsion) of Ti6Al4V alloy. The textures were manufactured using a pulsed fiber laser, perpendicular to the chip flow direction with a distance of 100 μm to the cutting edge and 100 μm of spacing. The authors found that micro-textures reduced the adhesion on the rake face at the lower cutting speed of 50 m/min. At higher cutting speeds, the textured tools outperformed the non-textured ones, especially in the wet condition. The main reason for this lied that these textures acted as a lubricant reservoir to the cutting fluid (Fig. 7), thus reducing the cutting temperature and increased tool life.

Grguraš and Pušavec (2019) evaluated the performance of eight different rake face texturing patterns in cemented carbide inserts. The machining trials were performed in the turning process using a CK45 medium carbon steel as workpiece material. Although the surface texturing did not influence the machining performance compared to non-textured tools, the texturing had a significant influence on the machining forces, with the best results being found for the parallel textured tools. The authors explained the better performance of the textures parallel to the main cutting edge in terms of the better penetration via the cutting fluid and their role as a micro-reservoir for emulsion, which improves the cooling and lubrication of the cutting interface.

Zhou et al. (2019) studied the effectiveness of surface texturing on the rake face, parallel to the main cutting edge of uncoated (K10) cemented carbide tools with 10 mm diameter during down end milling of Ti6Al4V alloy. The textures were fabricated using Nd: YAG laser with 100 μm of width, 100 μm of spacing, and 50 μm of depth. The machining trials were conducted using conventional and nanofluids

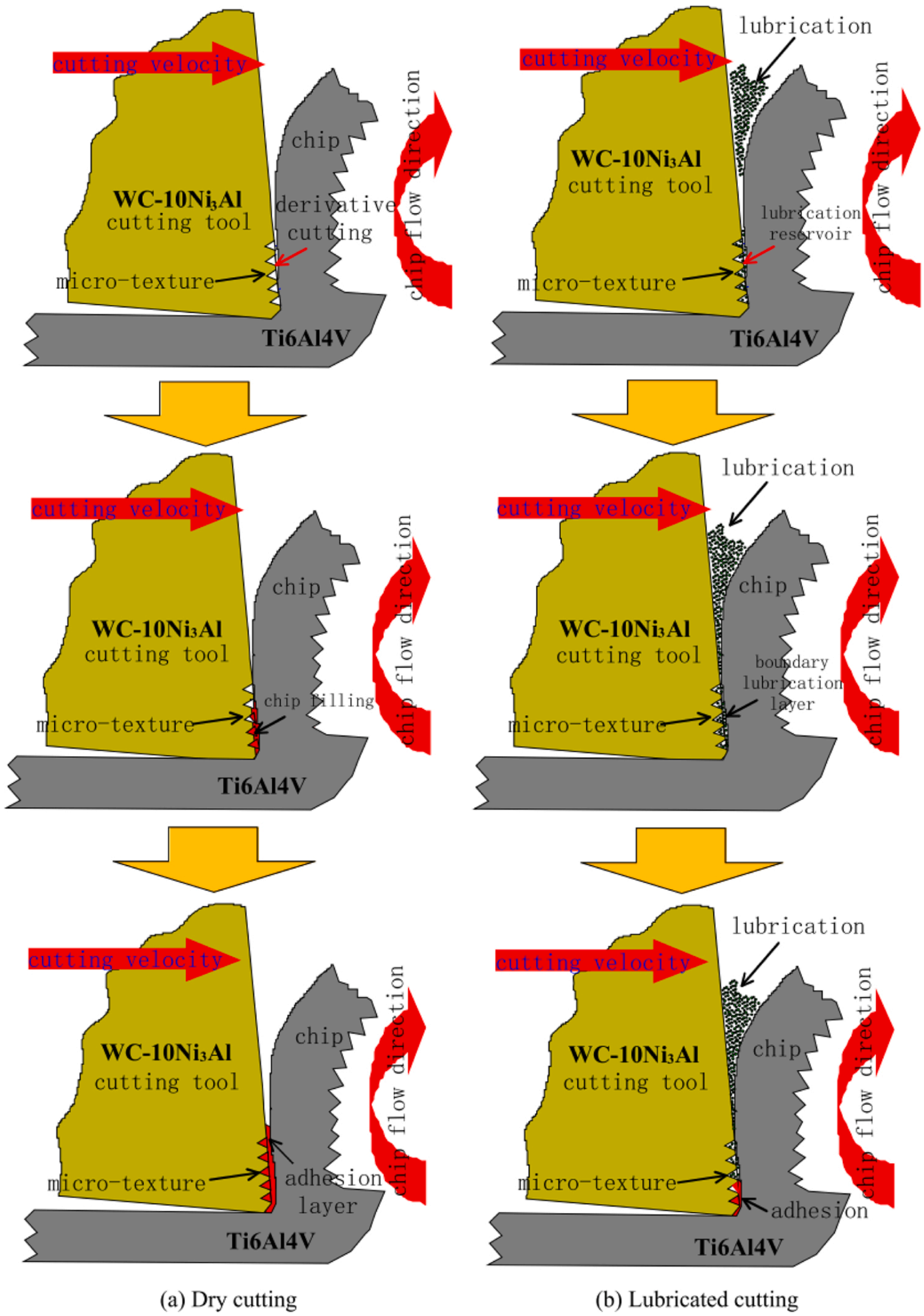

Fig. 7. Functioning mechanisms of the micro-textures proposed by Liu et al. (Liu et al., 2019b).

containing Fe_3O_4 nanoparticles with 80 ηm of diameter, applied under MQL condition. The tool wear and workpiece material adhesion were dramatically reduced under the influence of the combination of texturized tool and MQL nanofluid compared to the other cutting conditions. Compared to the non-textured tool with conventional cutting fluid, the tool wear rate was lowered down to 63.3 %. The authors explained that this reduction is due to the better wettability and spreadability of the nanofluids in the texturized surface, promoting a more stable lubrication film in the tool-chip interface.

Zhang et al. (2017) investigated the effects of a WS_2 solid lubricant film and femtosecond laser texturing on the rake face of PVD TiAlN coated cemented carbide tools. The surface texture was fabricated with a 1.0 mm^2 of area on the tools' rake face, 150 µm away from the cutting edge. The WS_2 lubricant layer was deposited on untextured and textured tools using magnetron sputtering. The authors found that the combination of surface texturing and soft coating resulted in the smallest cutting forces, temperatures, friction coefficient, and material adhesion in the tool-chip interface. The surface textures lead to vacant areas under the counter body's surface (chip undersurface) that are filled with air in dry cutting. This can further result in increased shear deformation and reduction of tool/chip contact length compared to a non-textured tool (as shown in Fig. 8). The reduced tool/chip contact length contributes towards reducing the real contact area of the tool/chip interface, which further causes a decrease in friction. The textures' presence improved the lubrication and made the WS2 deposited layer last for a longer period compared to the untextured tools. The use of surface texturing was also responsible for a stronger adhesion of the WS_2 deposited coating since it forms a barrier preventing the WS_2 slipping, enhances

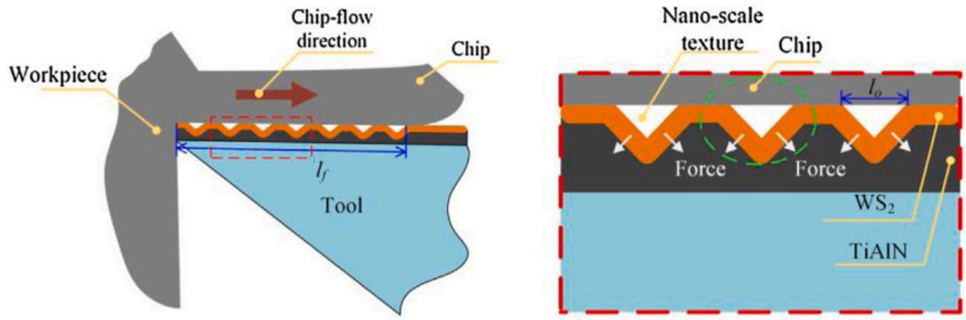

Fig. 8. Schematic mechanism of improved cutting performance due to WS_2 soft-coatings and femtosecond laser-textures on TiAlN coated tool (Zhang et al. (2017).

the TiAlN reactivity, and highlights a good interaction among the techniques.

Orra and Choudhury (2018) investigated the effect of three different geometrically shaped textures impregnated with MoS_2 dry lubricant on the rake surface of Al_2O_3 + TiC ceramic cutting inserts during dry turning of AISI 4340 hardened steel. The authors evaluated textures, fabricated by an epilog laser carrying grooves in an elliptical shape, as well as grooves parallel and perpendicular to the chip flow. The textures' width was between 200 and 215 μm and the gap between the textures was between 150 and 215 μm. Some tool textures were further impregnated with MoS_2 dry lubricant. The microtextures successfully reduced cutting forces, leading to lower flank and nose wear values for all evaluated cutting speeds. The cutting tools impregnated with MoS_2 presented lower effectiveness at higher cutting speeds. This happened due to the higher cutting temperatures generated by the higher cutting speeds, in which the MoS_2 impregnation became unstable and thus, lost effectiveness. According to the authors, the improvement in the machinability was noticed at the application of microtextures (that reduced the tool-chip contact length) and MoS_2 solid lubricant impregnation (that spread on the rake face of the tool) creating a dry lubricant medium, which further improves tool life.

Peña-Parás et al. (2020) studied the effects of interaction between surface textured tools and nanolubricants in the milling of AISI 1018 steel under flood lubrication. The surface patterns were made by laser texturing in the form of micro circles and channels in the rake face of CVD TiAlN coated cemented carbide inserts. The fluid was composed of a dispersion of montmorillonite nanoclay particles in an emulsion (14 % oil and 86 % water) at 0.13 wt% concentration. The authors found that in addition to the role of textures in increasing the machinability with respect to load and surface roughness, the nanoparticles' synergic effect also enhanced the machinability, especially for the microchannel pattern.

Kumar Mishra et al. (2020) evaluated the effect of laser textured tools under MQL and nano-MQL environments during the turning of Ti6Al4V alloy. The textures were manufactured in the rake face of uncoated cemented carbide tools using a nanosecond pulsed laser with dimples of 60 μm diameter. The textures were evaluated under dry, MQL, and nano-MQL environments, using a 1:10 sunflower emulsion as MQL lubricant and 0.5 wt% of Al_2O_3 as nanoparticle additive. The authors found that both MQL and nano-MQL resulted in reduced cutting and thrust forces as well as apparent friction coefficient. The results for the nano-MQL were further enhanced by the formation of a tribofilm of deposited/agglomerated nanoparticles at the texture patterns, especially at the lower cutting speeds.

Dheeraj et al. (2020b) studied the effects of tool surface texturing in aluminum drilling. The textures were manufactured in the drill flute of an uncoated cemented carbide drill using laser micromachining. The machining trials were performed under dry, blasocut, graphite, and MoS_2 atmospheres. The textures were filled with graphite, MoS_2, and MoS_2+graphite. The authors found that textures filled with solid lubricants resulted in better hole accuracy, cylindricity, surface finish, lower burr height, and chip size. The authors further stated that the graphite coated drills had the best results for improved tool life.

Singh et al. (2020) evaluated the effect of graphene-assisted MQL in the turning process of the Ti6Al4V alloy using textured uncoated cemented carbide tools. The textures were manufactured at the rake face of the tools using a femtosecond laser with a dimple pattern of 80 μm diameter, 50 μm depth, and 150 μm of distance to the cutting edge. The machining trials were performed under dry, MQL (using canola oil), and MQL using graphene nanoparticles at 1.0 wt% in concentration. The MQL was supplied at 6 bar of pressure and 120 ml/h of flow rate. The authors found that the use of graphene nanoparticles improved the system's lubricity, outperforming the other cutting conditions in relation to chip curl radius, surface roughness, and tool wear.

6. Surface integrity

According to Shaw and Cookson (2005), surface integrity involves aspects such as surface finish, crack formation, chemical changes, thermal damage, and surface stresses. Meeting the specifications for the parameters described above is a major challenge as they are causally linked to the applicability of the product. Decreasing the volume of material removed is generally associated with improved surface integrity and is often not productively advantageous. By influencing the chip formation process, cutting forces, machining temperature, and lubricity, surface textures' application improves surface integrity.

Rajbongshi et al. (2018) used a micro-EDM to fabricate grooves on the flank face of a CVD TiCN + Al_2O_3+TiN coated carbide tools, which were orthogonal to the main cutting edge. The grooves were distanced in 50 μm from the cutting edge, with 200 μm length and spacing of 50 μm between each other and 20 μm of depth. Machining experiments were conducted in dry turning of AISI D2 steel (45 HRC) using both textured and non-textured tools. The results showed that the surface texturing helped decrease the flank wear, resulting in a substantial improvement of surface finish. The machined surface produced by the textured tool was glossy, when compared to the non-textured tool (Fig. 9). The thickness and hardness of the white layer produced by the textured tools were also lowered. The authors found that due to the high-temperature generation in the case of non-textured tool, the surface topology can be changed. However, it is observed that texturing helps to generate a better surface compared to surface produced by the non-textured tools.

Palanisamy et al. (2019) studied the machinability during dry turning of 17−4 PH hardened stainless steel using cryo-treated cemented carbide textured tools. The tools were textured using wire-EDM with grooves on the rake face, parallel to the chip flow direction. The tool inserts were kept in a cryogenic chamber for 24 h and then tempered at 200 °C for 2 h. The authors found that the cryo-textured tools led to lower cutting forces, vibrations, and surface roughness than the non-textured tools. In the same line of investigation, Rajbongshi and Sarma (2019) used micro-EDM to fabricate textures (dots and grooves) in cemented carbide cutting tools and tested them in the machining of hardened AISI D2 steel. They also found that in terms of surface

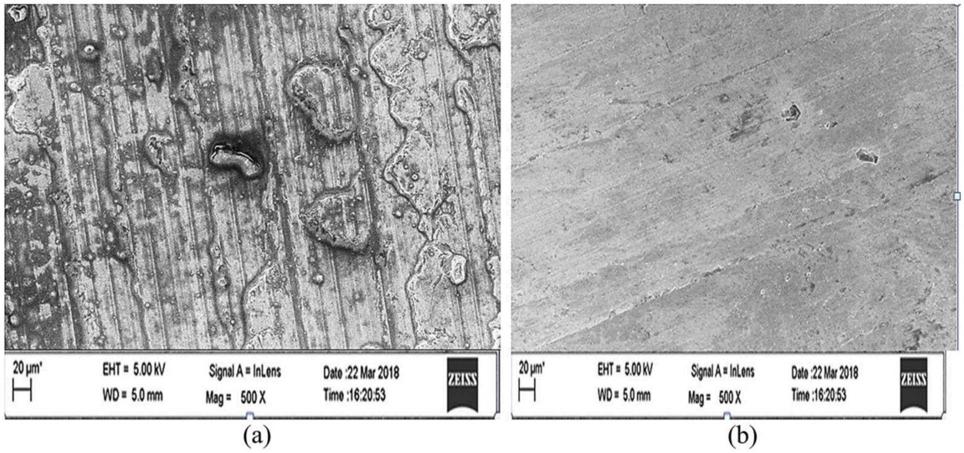

Fig. 9. SEM images of machined surface of AISI D2 steel by (a) non-textured tool (b) textured tool; at v_c =100 m/min, f =0.05 mm/rev, doc =0.25 mm (Rajbongshi et al., 2018).

roughness, the textured tools outperformed the non-textured ones.

Liu et al. (2019a) investigated new designs of curvilinear micro-grooves on the rake face of coated cemented carbide inserts in the machining of 17−4PH stainless steel. Three types of microgrooves were designed on tool rake face: microgrooves with linear surface and bottom cross-sections (LSB), microgrooves with curvilinear surface and linear bottom cross-sections (CSLB), and microgrooves with curvilinear surface and bottom cross-sections (CSB). Wire-EDM manufactured the textures with a groove width of 50 µm, spacing between grooves of 50 µm, and groove depth of 30 µm. The textures' behavior was compared in the dry turning process by 3D FEM. The textured tools showed better cutting performance than the non-textured tools in both FEM simulations and machining trials. The use of curvilinear micro-grooved tools improved the chip formation process and reduced forces, temperature, leading to a better surface integrity. The 3D FEM simulation confirmed that, in comparison to non-textured and linear micro-grooved tools, the curvilinear microgrooves on tool rake face were more effective in promoting chip curling, reducing tool-chip friction, chip thickness ratio, cutting forces, and temperature, and thus, leading to better surface integrity. In addition, curvilinear microgrooves induced tool stress dispersions and weakened the stress concentration on cutting edges (Fig. 10), which is beneficial for suppressing cutting tool wear and fracture/chipping.

Li et al. (2019) used dry turning tests and finite element analysis to compare the textures fabricated on the rake face of PCBN tools, in the machining process of GCr15 hardened steel. The textures were fabricated by laser machining with two sets of dimples, one with 80 µm diameter and 250 µm of spacing, and other with 120 µm diameter and 350 µm of spacing. The authors found that micro-hole textured tools improved the machined surface quality by reducing the surface roughness when compared to non-textured tools, with the smaller textures (80 µm of diameter), presenting the best results. Surface texturing can also achieve surface exhibiting compressive stresses, known for their resistance towards crack propagation. The effect of the micro-hole textures on the workpiece roughness was also explained in terms of residual stress of the machined workpiece surface, as shown in Fig. 11. The micro-holes on the tool surface improve the tools' cutting performance and cause the workpiece to possess and display compressive stresses, which further improves the fatigue performance of the part and reduces the roughness of the part surface, leading to an improved quality of the component.

S, N. and G.L, S. (2018) evaluated the drilling process of Ti6Al4V alloy at different lubrication conditions (dry, wet, and MQL) using uncoated cemented carbide drills with a diameter of 8 mm. The textures were fabricated by Nd-YAG laser micro-machining, in the form of circular micro-dimples with an average diameter of 90 µm, depth of 60 µm, and density coverage area of 35 %. The textures were placed on the drills' flute and margins, with a distance of 30 mm from the tool-tip. The machining revealed a significant reduction in titanium deposited on the

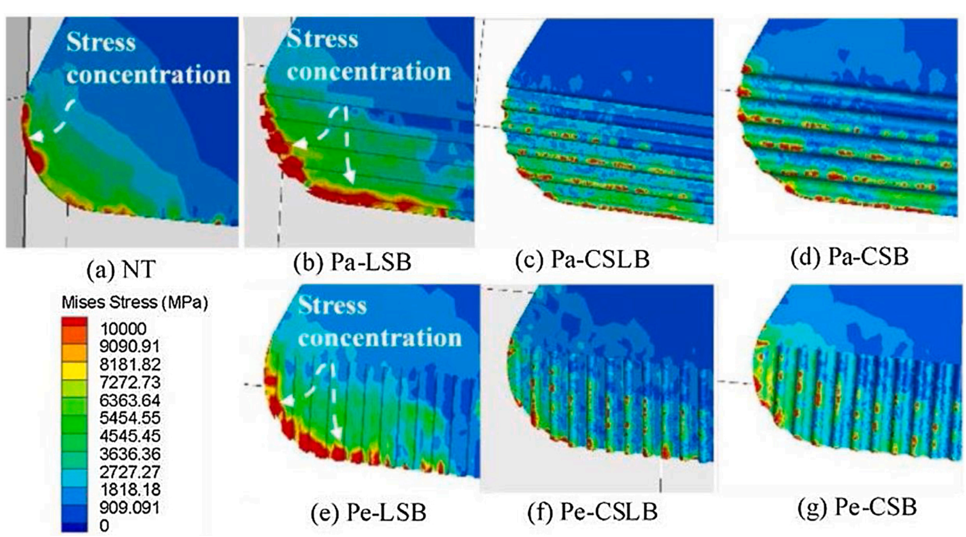

Fig. 10. Effect of micro-grooved tool types on tool stress distributions in rough turning (Liu et al., 2019a).

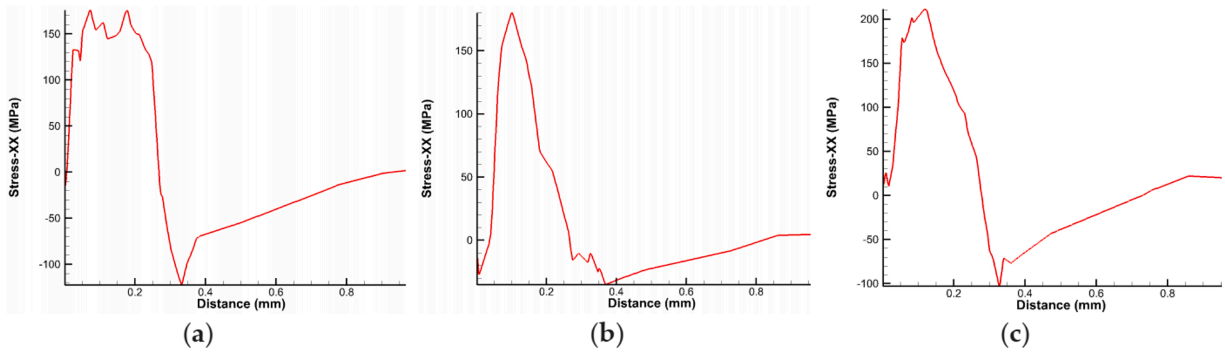

Fig. 11. Residual stress on the workpiece after machining with a) d = 80 μm micro-hole tool, (b) d = 120 μm micro-hole tool, and (c) non-textured tool (Li et al. (2019).

tool by 44 % in the margin textured tool, compared to the non-textured tool. The lower titanium content is a clear indication of the reduction of work material adhesion on the tool surface due to micro-scale textures. The use of surface textured tools leads to lesser surface defects in the drilled holes. In MQL and wet conditions, the surface textured minimized the burr formation in the holes' exit due to enhanced heat dissipation in the cutting interface.

S, N. and G.L, S. (2018) also performed SEM analysis of the rake surface as shown in Fig. 12. Sub-surface defects such as material side flow, chip adhesion, and smearing material were observed under all machining conditions tested. Such defects were found to be more severe under dry condition using the non-textured tool. In the case of textured tools, reduction in sliding friction due to a reduction in contact length and micro-pool lubrication effect favored faster heat dissipation, resulting in better quality surfaces.

Chen et al. (2019a) investigated the dry milling of carbon fiber reinforced plastics laminated at different orientations (0, 45°, 90° and 135°). They evaluated the effect of textures on the rake face parallel and perpendicular to cemented carbide milling cutters' main cutting edge. The authors found that the surface roughness was not significantly affected by the surface texture, with the fiber orientation being the most significant factor regarding this variable. However, the textured tools

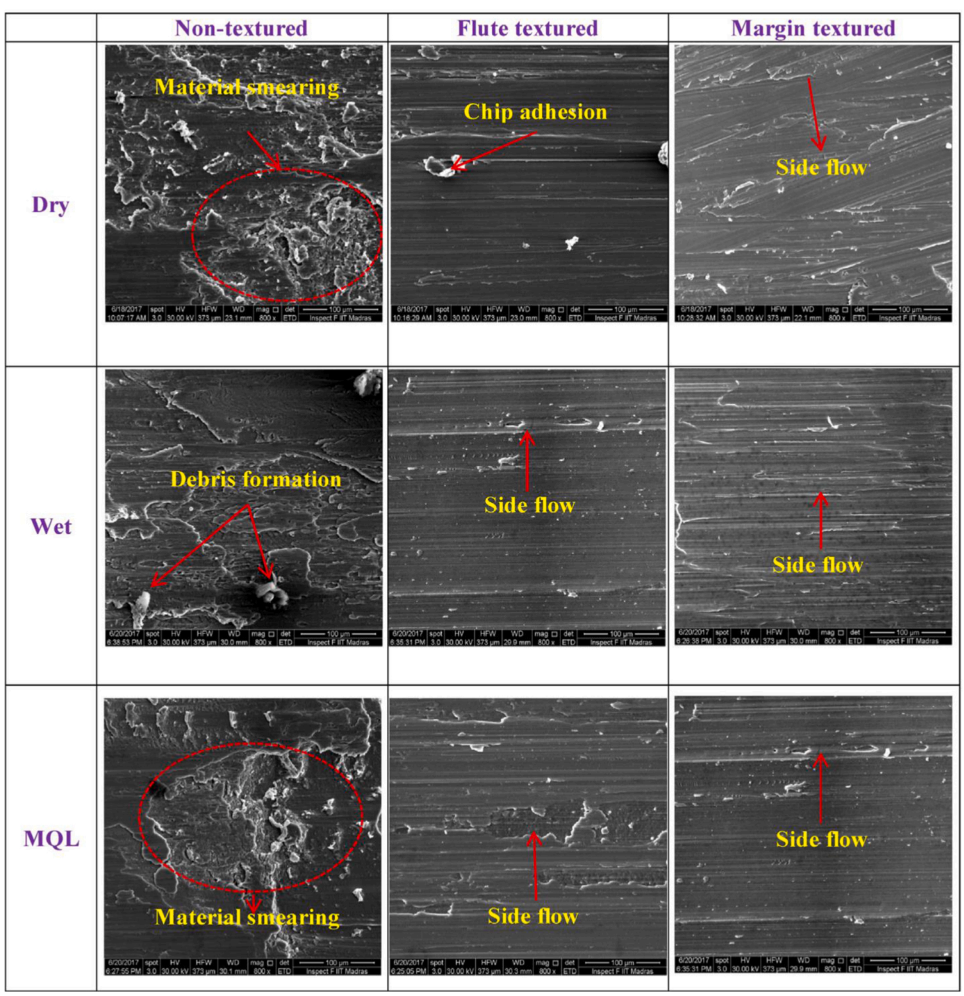

Fig. 12. SEM image of sectioned hole surface at the exit zone under dry, wet and MQL condition (S, N. and G.L, S., 2018).

presented smaller chip segments, as it changed the deformation behavior of the chip fibers and had a pronounced impact on fiber burr formation on the machined surface. The tools with textured grooves parallel to the main cutting edge were more effective in reducing the burr length and tearing phenomenon. The author further stated that the surface texture acted as a storage for the carbon fiber fragments, preventing the fiber chip's slippage on the rake face of the tool. Similar results were found by Ghosh and Pacella (2020) regarding the performance of diamond (PCD) cutting tools in the dry turning of Al-6068 alloy. The authors explained that this texture direction leads to a lower contact area between the chip and the tool, and thus, improves the chip flow and lowering the adhesion.

Sivaiah and Bodicherla (2020) studied the effect of surface texturization on tool wear and surface roughness during the turning of AISI 52100 steel. The tools were textured at the rake face using fiber laser in two patterns: dimples and 45° grooves inclined to the main cutting edge. An emulsion (1:15 ratio), as MQL mist at a flow rate of 100 ml/h, was used in the machining tests. The authors found a direct correlation between the cutting velocity and feed rate with the tool flank wear. The surface roughness had a direct correlation with the feed rate and inverse correlation with the cutting speed. The authors observed that less BUE was formed when using the 45° grooves as surface texture pattern, resulting in a better surface finish than the dimple texture.

7. Tool life and wear

For bringing a significant reduction in the production cost, tool life acts as one of the most important parameters in the machinability assessment. According to Astakhov (2006), the severity of general machining tribosystems causes more frequent tool changes than other manufacturing systems. The same increases the materials cost and unproductive times. This section deals with the understanding and measure of the impact of surface texturing on tool life.

Mishra et al. (2018b) evaluated two different PVD coated (AlTiN and AlCrN) cemented carbide (WIDIA: K-grade CNMA120408) laser textured tools in the dry turning of Ti6Al4V alloy. The novel chevron textures on the tools rake face were fabricated using Nd:YAG nanosecond fiber laser at 100 μm distance from the cutting edge. The authors found that laser textured tools resulted in better coating deposition with reduced microcavities and macroparticles. The better mechanical interlocking provided by the textured surface resulted in further adhesion to the coating. The authors also observed that better coating leads to reduced cutting and thrust forces, and lower flank wear, especially for the AlCrN coated tools. Arulkirubakaran et al. (2016) in their experiments, also found that the use of surface texturing improved the tool wear resistance amid the turning of Ti6Al4V.

Zhang et al. (2019b) evaluated the use of nanotextured tools in dry milling of AISI 316 stainless steel workpiece. The textures were manufactured by selective laser melting (using a femtosecond laser) in the substrate of cemented carbide tools. The tool form placed on the rake face consisted of ripples with 40–160 ηm depth and a period range of 400–600 ηm, and was 150 μm away from the cutting edge. After the substrate's texturing, the tools received a PVD TiAlN coating with 3 ± 0.5 μm of thickness. The authors found that the nanotextures enhanced the coating adhesiveness and increased its critical load from 57 to 73 N when scratched with a diamond Rockwell C stylus. The main wear mechanism observed for both textured and untextured tools was the adhesive wear. The textured tools outperformed the non-textured ones in terms of cutting forces and temperature, surface roughness, and tool wear due to the coating's improved adhesiveness promoted by the texturing of substrate.

According to Liu et al. (2018b), the tool wear could be improved with supplementary abrasive action of hard particles trapped in the texture grooves, which further avoids any additional inclusion between tool and the workpiece, and thus, saves the tool face from further scraping. Additional cutting action on the hard inclusions took place along the textured grooves lower edge (Fig. 13). The phenomenon could remove hard inclusions from the tool-workpiece interface to keep the unworn face safer against the hard inclusions scraping. That was the reason why textures on the flank face could enhance flank-wear resistance.

Liu et al. (2018a) compared cemented carbide tools (WC + 6%Co) with the flank face polished, nano-textured, polished, TiAlN coated and nano-textured, and TiAlN coated tools in the dry turning of green Al_2O_3 ceramic. The textures were manufactured using a titanium sapphire femtosecond laser and were parallel to the main cutting edge. The textures distance was 75 μm from the main cutting edge and possessed a width of 0.6 μm and depth 0.15 μm. The authors concluded that the nano-scale textures significantly affected the adhesion force of TiAlN coating and tool substrate. Both tools with nano texture, with and without coating, were noticed with a greater flank-wear resistance when compared to the non-textured tools. The textured and coated tool demonstrated the best overall results. The authors reported that even after the coating detachment, the surface textures exhibited "derivative cutting", resulting in the protection of the tool surface from further abrasion.

Cui et al. (2018) evaluated the performance of four different patterns of microtexture based on dung beetle and shark skins (Fig. 14), in the intermittent turning of AISI 52100 hardened steel using ceramic (Al_2O_3/(W,Ti)C) tools. The textures were fabricated on the rake face of the tool using nanosecond laser machining. The diameter and depth of the microdimples used were of 50 μm and 20 μm, respectively. The authors found that the increase in cutting length ratio resulted in larger tool performance indicators for each texture pattern. The skin-shark texture TE (Fig. 14) presented the most significant values of this indicator. These higher indicator values mean that the microtexture was the most beneficial parameter for improving the tool life. Similar results were found by Singh et al. (2019) in the turning of AISI 4340 hardened steel under MQL lubrication, when the application of textured tools increased the tool life up to 108 %.

Alagan et al. (2019) studied the effects of three different micro-textured patterns of round and square dimples (Fig. 15) on both rake and flank face of round uncoated cemented carbide inserts during the turning of Inconel 718, under high-pressure coolant lubrication. The textures were fabricated using Nd:YAG laser machining with 250 μm of spacing and pitch, 100 μm of diameter and depth, and 200 μm distance from the main cutting edge. According to the authors, the textured tools did not significantly impact the tool-chip contact area. The tools with square dimples on the flank face and circular dimples on the rake face, presented the higher wear resistance with 30 % higher tool life than the regular insert.

Feng et al. (2019) evaluated different morphologies of micro-texturing on the rake face of ceramic self-lubricating inserts in the dry turning of AISI 40Cr steel. The textures were fabricated with three positional distribution levels, with a width of the groove and space between textures ranging from 0.1 to 0.2 mm. During machining with the groove textured tools, the authors identified a secondary cutting phenomenon provided by the groove patterns' edges. The textured tools presented here reduce the cutting forces and workpiece material adhesion, resulting in reduced tool wear.

Feng et al. (2019) further stated that the groove width significantly influenced the tool wear. It was observed that the degree of damage of MSTW-3 tool was more serious than that of the MSTW-2 tool, as shown in Fig. 16. Additionally, in Fig. 16c and d, a white mark is clearly seen on the microtexture's edge. This white mark is a secondary chip residue which was retained during chip impact. This further indicates that the microtexture cracking damage was due to chip impact. With an increase in the groove width, the secondary cutting phenomenon was aggravated, and the microtexture structure's strength decreased. Concerning the cutting impact, the aforementioned phenomena caused damage to the microtexture and adversely affected (reduced) the tool life.

Pacella et al. (2019) studied the effect of three different texture patterns on PCD tools' wear in dry turning of 6082 aluminum alloy. The

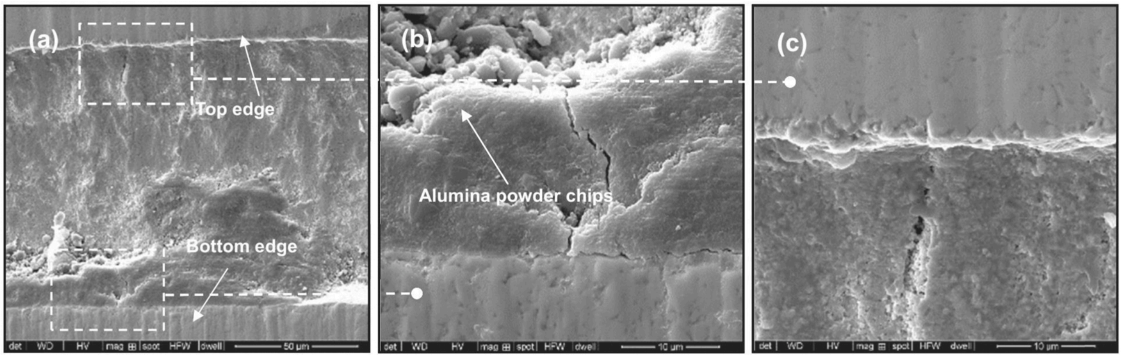

Fig. 13. SEM images of the texture groove on the flank-face of WT-3 tool after cutting a length of 1100 m, (a) texture groove, (b) the lower edge of the groove, (c) the top edge of the groove, (v =120 m/min, ap =0.8 mm, and f =0.051 mm/r) (Liu et al., 2018b).

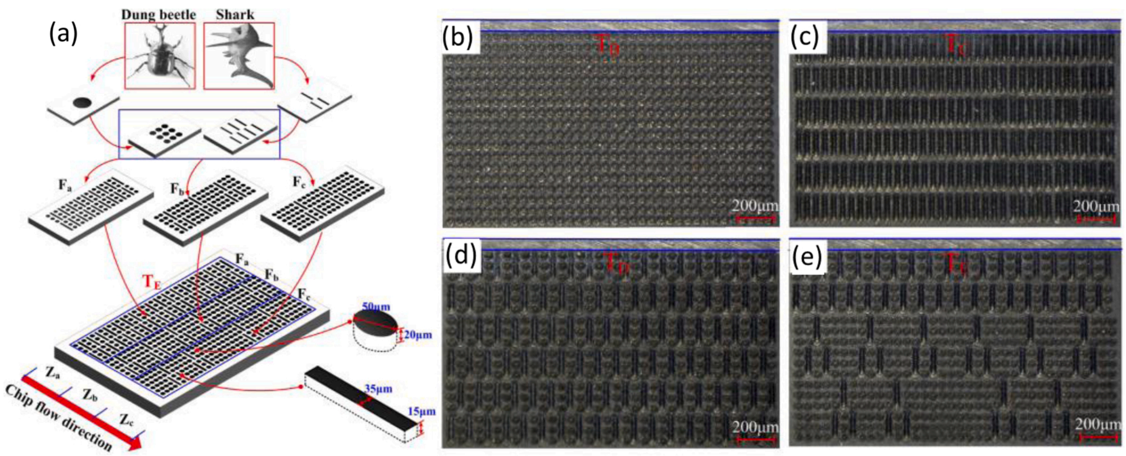

Fig. 14. (a) Design process of microtexture pattern; typical microtexture of different patterns (b) arrays of microdimples - TB; (c) skin-shark patter - TC; (d) hybrid array of microdimples and grooves equally distributed – TD; (e) hybrid array of microdimples and grooves non-equally distributed – TE. Adapted from (Cui et al., 2018).

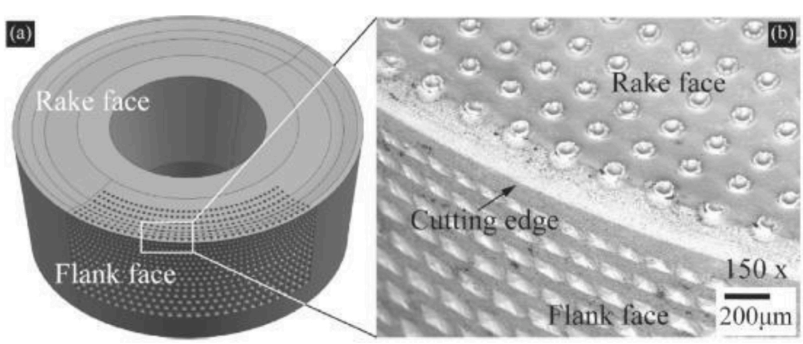

Fig. 15. (a) Illustration of the textured round insert; and (b) SEM micrograph of the insert at the cutting edge (Alagan et al., 2019).

tools evaluated had a 0.5 mm diamond layer over a cemented carbide substrate and were textured using fiber laser. The textures were fabricated on the tool's rake face in the form of parallel and perpendicular grooves. The grooves were maintained at an acute angle in relation to the chip flow direction, with 261 ηm of depth, 7 μm of width, and a pitch of 50 μm. The authors reported that the textured tools presented a reduction in the crater wear and lowered the cutting forces compared to the non-textured. The authors further stated that the tools with grooves parallel to the chip flow, presented a better anti-adhesive effect, reducing the aluminum stiction and the tool-chip contact area, and resulting in reduced cutting temperature and BUE formation.

Ahmed et al. (2020) evaluated the performance of different patterns of surface textures (square, parallel and perpendicular) in turning operation of AISI 304 stainless steel. The textures were manufactured using a femtosecond laser in the rake face of an uncoated cemented carbide tool (WC + 6%Co). The authors found that the squared textured patterns presented significant reduction in relation to the coefficient of friction, cutting, and thrust forces. The textured patterns significantly influenced the chip flow, especially in the square texture, which stabilized the built-up edge formation. The same further results in improved surface finish by 54–68 % and flank wear by 41–78 %.

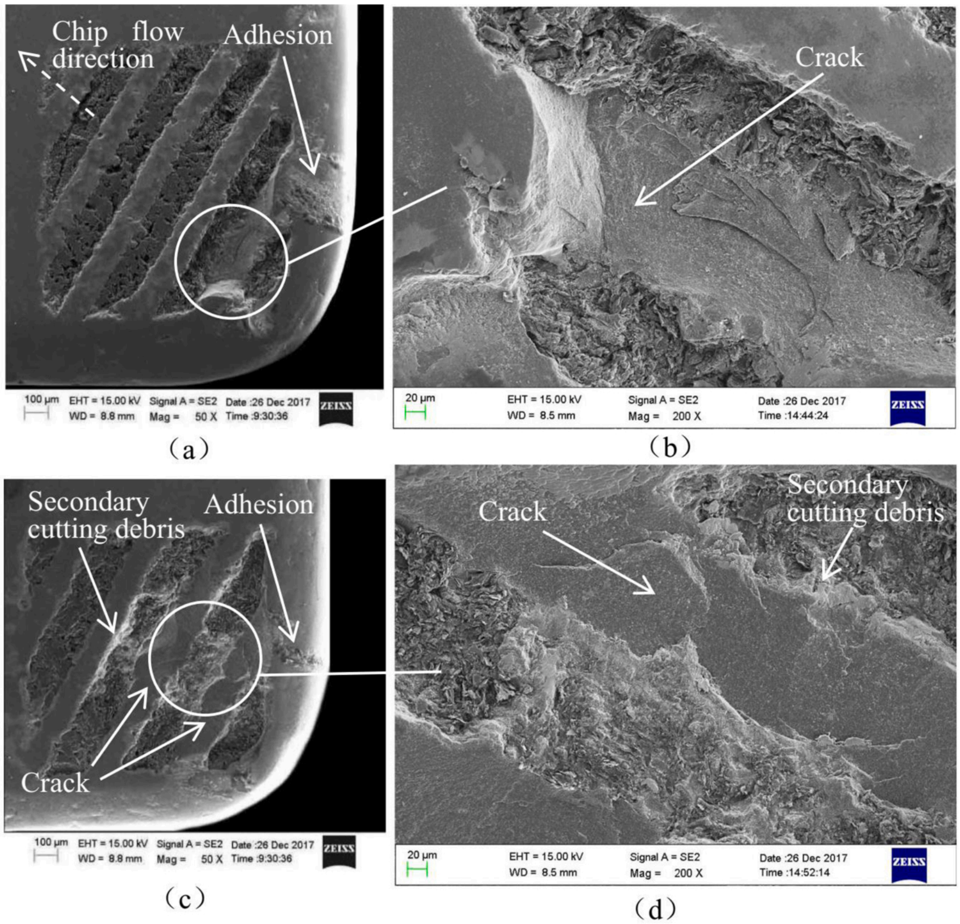

Fig. 16. Wear profiles on the rake faces of microtextured tools with different groove widths (a-b) MSTW-2 and (c-d) MSTW-3 after cutting for 5 min (Feng et al. (2019).

8. Conclusions

During this review, the state of the art of various effects of tool texturization has been considered. The relevant results obtained from the statistics have been highlighted. The reviewed papers under consideration are from 2016 onwards, thus, allow the evaluation of current trends in this field. Moreover, the unidentified areas requiring research have been identified and highlighted.

In general, the parameters with more influence on chip formation, and consequently on the machinability, are the texture width (Feng et al., 2019) and direction (Arulkirubakaran et al., 2019). However, according to Mishra et al. (2018a), the texture density is the parameter with more influence on the cutting forces, since it directly influences the areas of seizure and slipping in the secondary shear zone at the rake surface. The reason lies in the generation of a smaller contact area between the chip and the tool due to higher density. However, an excessive increase in the density can lead to accelerated tool wear since it favors the derivative cutting (Duan et al. (2017b) This further increases the friction between the tool and the surface, since the surface inside the texture is usually rough (Patel et al., 2019). In relation to dimple textures, according to Yang et al. (2020), the diameter is the most influential variable among most of the machinability output parameters.

The effects of surface textures under dry cutting are inferior when compared to any kind of lubricated conditions, such as flood (Pang et al., 2018), MQL (Sivaiah et al., 2020), flood with nanoparticles (Peña-Parás et al., 2020), as well as self-lubricated textures (Xing et al. (2018). The increase in lubrication improves the efficiency and functional performance of the textures. The texture depth is a key point regarding its effects in the lubrication of tribosystem (Fang and Obikawa, 2017), since it can not only change the texture capacity to store and deliver the lubricant but can also act as micro-bearings. As demonstrated by Fang and Obikawa (2017), smaller texture-patterns also tend to increase the system wettability by increasing its lubrication properties.

Fig. 17 summarizes the work materials reported in this paper with the corresponding papers listed in Table 1. Almost 80 % of the papers investigated the texture effects on hardened/high alloy steel, Ti alloys (mostly Ti6Al4V), carbon/low alloy steel, and Al alloys. This was expected as they are the most widely employed materials in engineering. The machining processes of Ni superalloys, stainless steels, and composites remain as some of the gaps of knowledge in this field.

Fig. 18 summarizes the machining processes used in the papers reviewed here to assess the effects of surface texturing in a system's machinability, with the corresponding papers listed in Table 2. The turning process was overwhelmingly the process of choice in the machinability assessment (Fig. 18) of the surface textures. This data is of particular concern because while taking the previous reviews into account, the lack of studies on surface texturing effects on other processes

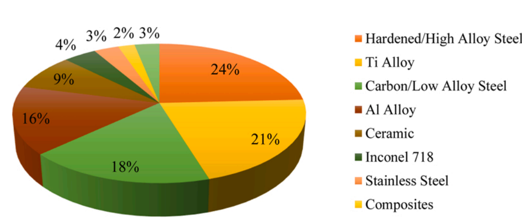

Fig. 17. Workpiece materials reviewed in this paper.

Table 1
Discretization of the machined materials.

Hardened / High Alloy Steel	(Li et al., 2019), (Xing et al., 2018), (Pan et al., 2018), (Gajrani et al., 2018b), (Cui et al., 2018), (Zhang et al., 2017), (Song et al., 2017), (Sharma and Pandey, 2016a), (Sarma and Rajbongshi, 2020), (Singh et al., 2019), (Patel et al., 2019), (Palanisamy et al., 2019), (Ge et al., 2019), (Rajbongshi et al., 2018), (Orra and Choudhury, 2018), (Lian et al., 2018), (Kumar and Patel, 2018), (Kim et al., 2016), (Rajbongshi and Sarma, 2019), (Vignesh et al., 2020), (Sivaiah and Bodicherla, 2020), (Klein et al., 2017), (Zhang et al., 2019a), (Fang et al., 2016), (Fang et al., 2017b)
Ti Alloy	(Zhou et al., 2019), (Mishra et al., 2019), (Yang et al., 2018), (Su et al., 2018), (Sawant et al., 2018), (S, N. and G. L, S., 2018), (Mishra et al., 2018b), (Mishra et al., 2018a), (Li et al., 2018), (Hao et al., 2018), (Arulkirubakaran et al., 2018), (Su et al., 2017), (Niketh and Samuel, 2017), (Li et al., 2017), (Arulkirubakaran et al., 2016), (Liu et al., 2019b), (Mishra et al., 2020), (Patel et al., 2020), (Yang et al., 2020), (Singh et al., 2020), (Zhao et al., 2020)
Carbon / Low Alloy Steel	(Lian et al., 2019), (Gajrani et al., 2019), (Dhage et al., 2019), (Pang et al., 2018), (Gajrani et al., 2018a), (Arumugaprabu et al., 2018), (Sugihara and Enomoto, 2017), (Feng et al., 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Sun et al., 2016), (Duan et al., 2019), (Grguraš and Pušavec, 2019), (Peña-Parás et al., 2020), (Qi et al., 2020), (Feng et al., 2019; Zhao et al., 2020)
Al Alloy	(Kang et al., 2018b), (Kang et al., 2018a), (Durairaj et al., 2018), (Wei et al., 2017), (Sugihara et al., 2017b), (Sasi et al., 2017), (Kawasegi et al., 2017), (Jesudass Thomas and Kalaichelvan, 2017), (Xing et al., 2016), (Stoeterau et al., 2016), (Rathod et al., 2016), (Kawasegi et al., 2019), (Dheeraj et al., 2020a), (Ghosh and Pacella, 2020), (Zhu et al., 2016)
Ceramic	(Liu et al., 2018b), (Liu et al., 2018a), (Liu et al., 2017), (Pratap et al., 2019), (Pratap and Patra, 2020; Wu et al., 2020), (Pratap and Patra, 2020), (Wu et al., 2020)
Inconel 718	(Sugihara et al., 2017a), (Fang and Obikawa, 2017), (Alagan et al., 2019), (Sivaiah et al., 2020)
Stainless Steel	(Ahmed et al., 2020), (Liu et al., 2019a), (Vasumathy and Meena, 2017)
Composites	(Chen et al., 2019a), (Arulkirubakaran et al., 2019)
Others	(Dinesh et al., 2016), (Fang et al., 2017a), (Fang and Klein, 2019)

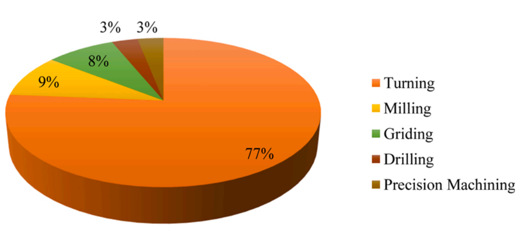

Fig. 18. Machining processes used to test the surface texturing effects.

appears to be perennial.

The noticeable dearth of published articles is even more crucial for studies covering the effect of textured tools on the chip formation and its controlling techniques, which affect all the other output parameters in machining. Despite the existence of recent trend regarding the application of surface textures in grinding and drilling process, less than one tenth of the total research record the same. In this series, milling and precision machining have been recorded by even a lesser number of researchers, consisting of surface textures. Due to this scenario, the authors would like to strongly encourage the researchers to investigate the effects of tool surface texturing in other such machining processes also, where much research is required.

Fig. 19 summarizes the surface texturing methods used to engineer the tools' surface, with the corresponding papers listed in Table 3. Almost two-third of the papers reviewed used laser texturing to fabricate

Table 2
Discretization of the machined process.

Turning	(Singh et al., 2019), (Patel et al., 2019), (Palanisamy et al., 2019), (Mishra et al., 2019), (Liu et al., 2019a), (Lian et al., 2019), (Li et al., 2019), (Ge et al., 2019), (Gajrani et al., 2019), (Feng et al., 2019), (Dhage et al., 2019), (Arulkirubakaran et al., 2019), (Xing et al., 2018), (Su et al., 2018), (Sawant et al., 2018), (Rajbongshi et al., 2018), (Pang et al., 2018), (Pan et al., 2018), (Orra and Choudhury, 2018), (Mishra et al., 2018b), (Mishra et al., 2018a), (Liu et al., 2018b), (Liu et al., 2018a), (Lian et al., 2018), (Kumar and Patel, 2018), (Kang et al., 2018b), (Kang et al., 2018a), (Hao et al., 2018), (Gajrani et al., 2018b), (Gajrani et al., 2018a), (Durairaj et al., 2018), (Cui et al., 2018), (Arulkirubakaran et al., 2018), (Zhang et al., 2017), (Wei et al., 2017), (Vasumathy and Meena, 2017), (Sugihara et al., 2017a), (Su et al., 2017), (Song et al., 2017), (Sasi et al., 2017), (Liu et al., 2017), (Li et al., 2017), (Jesudass Thomas and Kalaichelvan, 2017), (Feng et al., 2017), (Fang and Obikawa, 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Xing et al., 2016), (Sun et al., 2016), (Stoeterau et al., 2016), (Arulkirubakaran et al., 2016), (Sharma and Pandey, 2016a), (Rathod et al., 2016), (Kim et al., 2016), (Dinesh et al., 2016), (Liu et al., 2019b), (Alagan et al., 2019), (Duan et al., 2019), (Rajbongshi and Sarma, 2019), (Grguraš and Pušavec, 2019), (Ahmed et al., 2020), (Mishra et al., 2020), (Sarma and Rajbongshi, 2020), (Vignesh et al., 2020), (Ghosh and Pacella, 2020), (Patel et al., 2020), (Sivaiah and Bodicherla, 2020), (Sivaiah et al., 2020), (Singh et al., 2020), (Qi et al., 2020), (Zhu et al., 2016)
Milling	(Zhou et al., 2019), (Chen et al., 2019a), (Yang et al., 2018), (Li et al., 2018), (Arumugaprabu et al., 2018), (Sugihara et al., 2017b), (Sugihara and Enomoto, 2017), (Peña-Parás et al., 2020), (Yang et al., 2020)
Grinding	(Pratap et al., 2019), (Pratap and Patra, 2020), (Fang et al., 2017a), (Fang and Klein, 2019), (Klein et al., 2017), (Zhao et al., 2020), (Wu et al., 2020), (Pratap and Patra, 2020), (Fang et al., 2016), (Fang et al., 2017b)
Drilling	(S, N. and G.L, S., 2018), (Niketh and Samuel, 2017), (Dheeraj et al., 2020a)
Precision Machining	(Kawasegi et al., 2017), (Kawasegi et al., 2019), (Zhang et al., 2019a)

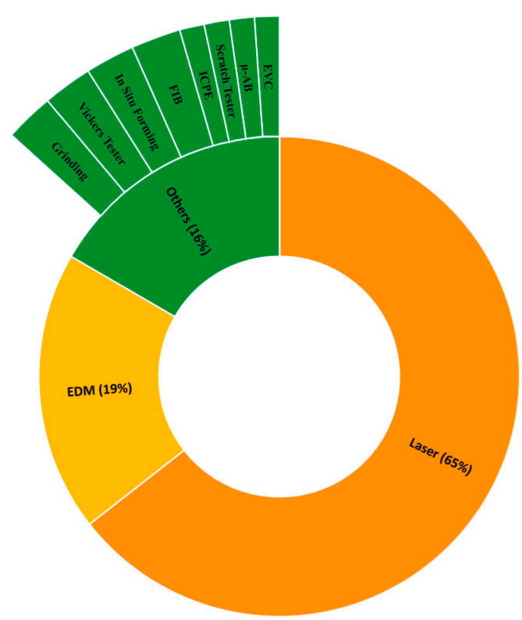

Fig. 19. Texture production process/methods.

the surface patterns. The greater use of laser manufacturing in tool texturing is understandable since the laser ablation process is relatively well established and can easily be applied to the surface of cutting tools, and it provides high accuracy and reproducibility. Electrical discharge

Table 3
Discretization of the texture production methods.

Laser	(Zhou et al., 2019), (Singh et al., 2019), (Mishra et al., 2019), (Li et al., 2019), (Ge et al., 2019), (Chen et al., 2019a), (Yang et al., 2018), (Xing et al., 2018), (Su et al., 2018), (S, N. and G.L, S., 2018), (Pang et al., 2018), (Pan et al., 2018), (Orra and Choudhury, 2018), (Mishra et al., 2018b), (Mishra et al., 2018a), (Liu et al., 2018b), (Liu et al., 2018a), (Lian et al., 2018), (Li et al., 2018), (Kang et al., 2018b), (Kang et al., 2018a), (Hao et al., 2018), (Durairaj et al., 2018), (Cui et al., 2018), (Zhang et al., 2017), (Vasumathy and Meena, 2017), (Sugihara et al., 2017b), (Sugihara et al., 2017a), (Sugihara and Enomoto, 2017), (Su et al., 2017), (Sasi et al., 2017), (Niketh and Samuel, 2017), (Liu et al., 2017), (Li et al., 2017), (Fang and Obikawa, 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Xing et al., 2016), (Sun et al., 2016), (Stoeterau et al., 2016), (Sharma and Pandey, 2016a), (Dinesh et al., 2016), (Liu et al., 2019b), (Alagan et al., 2019), (Duan et al., 2019), (Grguraš and Pušavec, 2019), (Ahmed et al., 2020), (Peña-Parás et al., 2020), (Mishra et al., 2020), (Vignesh et al., 2020), (Dheeraj et al., 2020a), (Ghosh and Pacella, 2020), (Sivaiah and Bodicherla, 2020), (Yang et al., 2020), (Sivaiah et al., 2020), (Singh et al., 2020), (Klein et al., 2017), (Fang and Klein, 2019), (Fang et al., 2017a), (Zhao et al., 2020), (Fang et al., 2016), (Fang et al., 2017b)
EDM	(Patel et al., 2019), (Palanisamy et al., 2019), (Liu et al., 2019a), (Gajrani et al., 2019), (Arulkirubakaran et al., 2019), (Rajbongshi et al., 2018), (Kumar and Patel, 2018), (Arulkirubakaran et al., 2018), (Song et al., 2017), (Arulkirubakaran et al., 2016), (Kim et al., 2016), (Pratap et al., 2019), (Rajbongshi and Sarma, 2019), (Sarma and Rajbongshi, 2020), (Patel et al., 2020), (Qi et al., 2020), (Pratap and Patra, 2020), (Pratap and Patra, 2020), (Wu et al., 2020)
Others	(Lian et al., 2019), (Feng et al., 2019), (Dhage et al., 2019), (Sawant et al., 2018), (Gajrani et al., 2018b), (Gajrani et al., 2018a), (Arumugaprabu et al., 2018), (Wei et al., 2017), (Kawasegi et al., 2017), (Jesudass Thomas and Kalaichelvan, 2017), (Feng et al., 2017), (Rathod et al., 2016), (Kawasegi et al., 2019), (Zhang et al., 2019a), (Zhu et al., 2016)

machining (EDM) is a recent trend, as it is even cheaper than laser texturing. However, this technology allows only those textures that are considerably larger than the ones manufactured by laser texturing. Such a limitation presents an unavoidable drawback of EDM, which goes against manufacturing the smallest possible textures, even at a nano-scale. Although laser texturing fulfills all the current requirements for texture production in terms of precision and accuracy. Hence, the authors would like to recommend the researchers to investigate some potential alternatives for large-scale production.

Fig. 20 summarizes the tool materials used for examining the surface textures, reviewed in the present paper. The corresponding papers are listed in Table 4. Almost 60 % of the textured materials are uncoated cemented carbide. The fact that cemented carbide tools dominate the tooling market (García et al., 2019) combines with the already established knowledge of this material ablation's behavior under laser machining. One of the main gaps of knowledge in this field is investigating the effects of surface texturing on coated tools. The reason is that the process is not expected to weaken the coating adhesion in the substrate or its integrity near the texture edges. The surface texturing of ultra-hard materials is also a challenge since the literature is still scarce regarding the ablation of those materials and the tool's embrittlement near the cutting edges. Research on textured tools of ceraamic, pCBN or PCD is scarce and appears as a future trend.

Fig. 21 summarizes the surfaces chosen to fabricate the surface textures in the reviewed papers. The corresponding papers are listed in Table 5. The rake face corresponds to the overwhelming majority of the

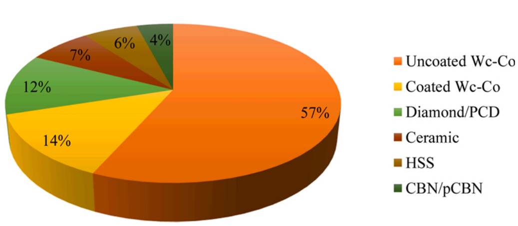

Fig. 20. Tool materials reviewed in the present work.

Table 4
Discretization of the tool materials.

Uncoated Wc-Co	(Zhou et al., 2019), (Singh et al., 2019), (Patel et al., 2019), (Palanisamy et al., 2019), (Lian et al., 2019), (Ge et al., 2019), (Dhage et al., 2019), (Chen et al., 2019a), (Arulkirubakaran et al., 2019), (Yang et al., 2018), (S, N. and G.L, S., 2018), (Pang et al., 2018), (Mishra et al., 2018a), (Liu et al., 2018b), (Liu et al., 2018a), (Lian et al., 2018), (Li et al., 2018), (Kang et al., 2018b), (Gajrani et al., 2018b), (Durairaj et al., 2018), (Arulkirubakaran et al., 2018), (Vasumathy and Meena, 2017), (Sugihara et al., 2017b), (Sugihara and Enomoto, 2017), (Song et al., 2017), (Niketh and Samuel, 2017), (Liu et al., 2017), (Li et al., 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Xing et al., 2016), (Sun et al., 2016), (Stoeterau et al., 2016), (Arulkirubakaran et al., 2016), (Sharma and Pandey, 2016a), (Rathod et al., 2016), (Kim et al., 2016), (Dinesh et al., 2016), (Alagan et al., 2019), (Duan et al., 2019), (Grguraš and Pušavec, 2019), (Ahmed et al., 2020), (Mishra et al., 2020), (Dheeraj et al., 2020a), (Patel et al., 2020), (Sivaiah and Bodicherla, 2020), (Yang et al., 2020), (Singh et al., 2020), (Qi et al., 2020), (Zhu et al., 2016), (Klein et al., 2017), (Fang et al., 2017a), (Fang et al., 2016), (Fang et al., 2017b)
Coated Wc-Co	(Mishra et al., 2019), (Liu et al., 2019a), (Rajbongshi et al., 2018), (Mishra et al., 2018b), (Arumugaprabu et al., 2018), (Zhang et al., 2017), (Fang and Obikawa, 2017), (Liu et al., 2019b), (Rajbongshi and Sarma, 2019), (Peña-Parás et al., 2020), (Sarma and Rajbongshi, 2020), (Vignesh et al., 2020), (Sivaiah et al., 2020)
Diamond / PCD	(Su et al., 2018), (Hao et al., 2018), (Su et al., 2017), (Kawasegi et al., 2017), (Pratap et al., 2019), (Kawasegi et al., 2019), (Ghosh and Pacella, 2020), (Pratap and Patra, 2020), (Fang and Klein, 2019), (Zhang et al., 2019a), (Wu et al., 2020), (Pratap and Patra, 2020)
Ceramic	(Feng et al., 2019), (Xing et al., 2018), (Orra and Choudhury, 2018), (Kumar and Patel, 2018), (Cui et al., 2018), (Wei et al., 2017), (Feng et al., 2017)
HSS	(Gajrani et al., 2019), (Sawant et al., 2018), (Kang et al., 2018a), (Gajrani et al., 2018a), (Sasi et al., 2017), (Jesudass Thomas and Kalaichelvan, 2017)
CBN / pCBN	(Li et al., 2019), (Pan et al., 2018), (Sugihara et al., 2017a), (Zhao et al., 2020)

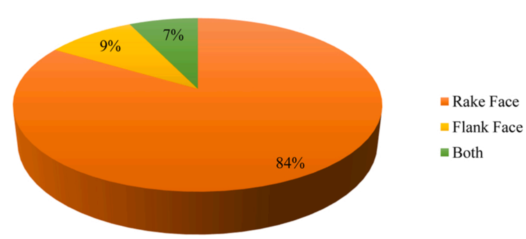

Fig. 21. Location on the tool where the texture was placed in the articles reviewed.

studies. According to most of the authors, the texture choice the rake surface is not only because it is generally easier to fabricate the textures there, but also is the region with more tribological interaction with the chip. As reported by Durairaj et al. (2018), most of the authors found that textures on the rake face decreased the contact area in the chip-tool interface, leading to lower cutting forces, friction coefficient, and machining temperatures. The greatest barrier to the investigation of textures in other regions of the tool is because the laser machining is still the main method of texture manufacturing (as shown in Fig. 19).

Despite the accuracy and reproducibility of this technique, the difficulty in focusing the laser beam on regions with significant changes in the topography such as chip-breakers or curved surfaces (as in integral drills and mills), explains why this process is overwhelmingly more investigated in the rake face of plain cemented carbide inserts. Thus, more flexible technologies of producing the textures are highly desirable, so that this technique can not only be applied for texturing other regions of the tools but can also gain greater industrial competitiveness.

Regarding the textures' location in relation to the cutting edges, their positioning was proven to be the most important geometric parameter.

Table 5
Discretization of the location of the texture.

Rake Face	(Zhou et al., 2019), (Patel et al., 2019), (Palanisamy et al., 2019), (Mishra et al., 2019), (Liu et al., 2019a), (Lian et al., 2019), (Li et al., 2019), (Ge et al., 2019), (Gajrani et al., 2019), (Feng et al., 2019), (Dhage et al., 2019), (Chen et al., 2019a), (Arulkirubakaran et al., 2019), (Yang et al., 2018), (Xing et al., 2018), (Su et al., 2018), (Sawant et al., 2018), (Pang et al., 2018), (Pan et al., 2018), (Orra and Choudhury, 2018), (Mishra et al., 2018b), (Mishra et al., 2018a), (Li et al., 2018), (Kumar and Patel, 2018), (Kang et al., 2018b), (Kang et al., 2018a), (Hao et al., 2018), (Gajrani et al., 2018b), (Gajrani et al., 2018a), (Durairaj et al., 2018), (Cui et al., 2018), (Arulkirubakaran et al., 2018), (Zhang et al., 2017), (Wei et al., 2017), (Vasumathy and Meena, 2017), (Sugihara et al., 2017b), (Sugihara and Enomoto, 2017), (Su et al., 2017), (Song et al., 2017), (Sasi et al., 2017), (Li et al., 2017), (Kawasegi et al., 2017), (Jesudass Thomas and Kalaichelvan, 2017), (Feng et al., 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Xing et al., 2016), (Sun et al., 2016), (Stoeterau et al., 2016), (Arulkirubakaran et al., 2016), (Sharma and Pandey, 2016a), (Rathod et al., 2016), (Kim et al., 2016), (Dinesh et al., 2016), (Liu et al., 2019b), (Pratap et al., 2019), (Kawasegi et al., 2019), (Duan et al., 2019), (Grguraš and Pušavec, 2019), (Ahmed et al., 2020), (Peña-Parás et al., 2020), (Mishra et al., 2020), (Vignesh et al., 2020), (Ghosh and Pacella, 2020), (Patel et al., 2020), (Sivaiah and Bodicherla, 2020), (Yang et al., 2020), (Sivaiah et al., 2020), (Singh et al., 2020), (Qi et al., 2020), (Pratap and Patra, 2020), (Klein et al., 2017), (Fang and Klein, 2019), (Fang et al., 2017a), (Zhang et al., 2019a), (Zhu et al., 2016), (Pratap and Patra, 2020), (Zhao et al., 2020), (Wu et al., 2020)
Flank Face	(Rajbongshi et al., 2018), (Liu et al., 2018b), (Liu et al., 2018a), (Arumugaprabu et al., 2018), (Sugihara et al., 2017a), (Liu et al., 2017), (Fang and Obikawa, 2017), (Rajbongshi and Sarma, 2019), (Sarma and Rajbongshi, 2020)
Both	(Singh et al., 2019), (S, N. and G.L, S., 2018), (Lian et al., 2018), (Niketh and Samuel, 2017), (Alagan et al., 2019), (Dheeraj et al., 2020a)

In general, the related studies showed a direct relationship among the proximity of the textures pertaining to the cutting edge, its efficiency in reducing wear, forces, and cutting temperatures. However, there is still a huge scarcity of the adequate data and publications in alliance to the tangible effects of texture positioning in the machinability of a system. For example, Ling et al. (2013) showed that texturing the margin area of drill bits reduced the wear significantly, showing the potential of texturing other areas rather than the rake face solely, even for the more complex cutting tool geometry of the drill bits.

Regardless the position where the textures were applied, the depth proved to be a parameter of little relevance, as long as the textures are not too shallow to be quickly consumed by wear or too deep to compromise with the tools' surface integrity. The literature in general, recommends a ratio between 3 and 7 for the width / depth, since this range influences the lubrication of the cutting fluids and the chip flow the most.

Fig. 22 summarizes the surface texture geometries evaluated in the papers and reviewed here. The corresponding papers are listed in Table 6. The groove textures are most commonly found in more than half of the studies, followed by dimple ones in almost a quarter of the papers. The last quartile consists of chevron textures, nano-textures, and other geometries or combinations of geometries. Regarding the groove textures, besides geometric parameters, the texture orientation in relation to the chip flow direction is pointed as a crucial variable. As pointed by Arulkirubakaran et al. (2019), most authors concluded that grooves

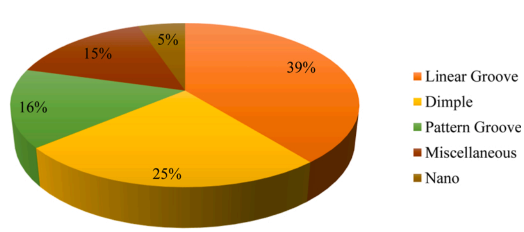

Fig. 22. Texture geometries used in the papers reviewed in the present work.

Table 6
Discretization of the texture geometries.

Linear Groove	(Zhou et al., 2019), (Patel et al., 2019), (Palanisamy et al., 2019), (Liu et al., 2019a), (Lian et al., 2019), (Ge et al., 2019), (Gajrani et al., 2019), (Feng et al., 2019), (Dhage et al., 2019), (Chen et al., 2019a), (Su et al., 2018), (Rajbongshi et al., 2018), (Pang et al., 2018), (Liu et al., 2018b), (Kumar and Patel, 2018), (Gajrani et al., 2018a), (Arumugaprabu et al., 2018), (Vasumathy and Meena, 2017), (Sugihara et al., 2017a), (Su et al., 2017), (Liu et al., 2017), (Kawasegi et al., 2017), (Feng et al., 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Kim et al., 2016), (Dinesh et al., 2016), (Liu et al., 2019b), (Kawasegi et al., 2019), (Duan et al., 2019), (Ghosh and Pacella, 2020), (Patel et al., 2020), (Sivaiah and Bodicherla, 2020), (Pratap and Patra, 2020), (Zhu et al., 2016), (Pratap and Patra, 2020), (Fang et al., 2016), (Fang et al., 2017b)
Dimple	(Singh et al., 2019), (Li et al., 2019), (Yang et al., 2018), (Sawant et al., 2018), (S, N. and G.L, S., 2018), (Mishra et al., 2018a), (Li et al., 2018), (Durairaj et al., 2018), (Sugihara et al., 2017b), (Sugihara and Enomoto, 2017), (Song et al., 2017), (Sasi et al., 2017), (Niketh and Samuel, 2017), (Jesudass Thomas and Kalaichelvan, 2017), (Stoeterau et al., 2016), (Sharma and Pandey, 2016a), (Alagan et al., 2019), (Vignesh et al., 2020), (Dheeraj et al., 2020a), (Yang et al., 2020), (Singh et al., 2020), (Klein et al., 2017), (Fang et al., 2017a), (Zhang et al., 2019a)
Pattern Groove	(Mishra et al., 2019), (Arulkirubakaran et al., 2019), (Orra and Choudhury, 2018), (Mishra et al., 2018b), (Cui et al., 2018), (Arulkirubakaran et al., 2018), (Sun et al., 2016), (Arulkirubakaran et al., 2016), (Rathod et al., 2016), (Pratap et al., 2019), (Grguraš and Pušavec, 2019), (Ahmed et al., 2020), (Sivaiah et al., 2020), (Zhao et al., 2020), (Fang et al., 2016), (Fang et al., 2017b)
Miscellaneous	(Pan et al., 2018), (Kang et al., 2018b), (Kang et al., 2018a), (Gajrani et al., 2018b), (Wei et al., 2017), (Li et al., 2017), (Fang and Obikawa, 2017), (Xing et al., 2016), (Rajbongshi and Sarma, 2019), (Peña-Parás et al., 2020), (Mishra et al., 2020), (Sarma and Rajbongshi, 2020), (Qi et al., 2020), (Fang and Klein, 2019), (Wu et al., 2020)
Nano	(Xing et al., 2018), (Liu et al., 2018a), (Lian et al., 2018), (Hao et al., 2018), (Zhang et al., 2017)

perpendicular to the chip flow are better since they restrain the chip flow and reduce its curling radius. However, as pointed by Su et al. (2018), some authors claim that grooves parallel to the chip flow are better, as this configuration facilitates the chip flow. Some authors even claim that the groove direction is an irrelevant variable (Kang et al., 2018a). For future studies, a deeper evaluation of the groove direction in the tribo-system of chip-tool interface, is highly recommended. It is also suggested to conduct more numbers of studies on the effects of other surface texturing patterns rather than grooves and dimples.

According to most of the studies, generally texturing, even at the nanoscale, leads to a reduction (up to 60 %) in the effects of adhesion. The reduction in material adhesion appears to be inversely proportional to the cutting speed with the positive effects, which is generally negligible at lower cutting speeds. The dimple textures proved to be the most efficient pattern in reducing material adhesion. This effect occurs mainly by reducing the workpiece-tool-chip contact areas, acting in the reduction of the mechanical interlock phenomenon.

Tribologically, the best direction of groove textures is perpendicular to the chip flow (parallel to the main cutting edge), being more effective in roughing type of material removal. However, for finishing material removal, the linear grooves are not relevant, with the probable explanation of being the ones which allow a lesser flow of material over the textures. In general, the grooved textures parallel to the main cutting edge, also added an improvement in the access of lubricant at the cutting interface, due to its additional advantages with flood, MQL or cryogenic cooling systems concomitantly.

The frequency and degree of segmentation of the chip can have significant reductions in the presence of textures. The textures in the form of grooves presented the greatest influence in the chip formation (mainly by the groove size), and when the groove is in the direction parallel to the chip flow (perpendicular to the main cutting edge), the formation of the chip occurs more effectively. In general, textured tools cause smoother chip formation when compared to non-textured tools. Dimple textures gave the best results in finishing operations, producing the smoother chips.

The density of the textures is more influential than its geometry with respect to the reduction in cutting forces. This parameter is correlated with the reduction of chip-tool contact area, where the denser (close to each other) the textures, the lesser is the contact. However, if the textures' width is too large, there may be chip stickiness on the textures.

In the case of dimple-type textures, the parameter that most impacts the cutting forces, roughness, and reduction of adhesion effects, is the size of textures. But for tool wear, the most influential parameter is the distance between the textures and the cutting edge. For extremely high cutting speeds, dimple textures only work if the texture density is also high. The textures' size is more influential on dimple textures than grooved textures when it comes to temperature-reduction effects.

The atmospheric condition's influence is a variable of utmost importance since the claim for texturing the tool surfaces is to improve the lubrication of the tribosystem. Fig. 23 summarizes the atmospheric condition used for analyzing the effect of tool surface texturing in the machinability. The corresponding papers are listed in Table 7. Almost three-quarters of the papers investigated the surface texturing effects under dry or flood conditions, which is understandable since those cutting atmospheres are more common in machining.

The increasing pressure to move towards greener manufacturing made the self-lubricating coatings a trend, with more than one-tenth of the papers researching this technique. Although the MQL is also labeled as a greener alternative to flood lubrication, yet the studies involving this technique represent only around one-tenth of the papers. The MQL (or spraying) technique generally presented superior results in relation to the flood lubrication. According to the authors, the same reason lies in the higher delivery pressure combined with the textures generating a thicker lubricating layer in the vicinity of the cutting interface. Because of MQL technique's potential, further research with varying the parameters of the spray system using different types of textured tools is highly encouraged. Investigations regarding the combination of cryogenic and high-pressure lubrication were almost absent. The probable explanation of the same lies in the higher difficulties and costs of implementing those techniques.

The textures can trap particles/debris originated in the cutting process. For groove textures, the direction perpendicular to the chip flow is the one with the most retention capacity. For dimples, this effect is directly proportional to the size of the texture since they have smaller dimensions than most debris. However, the nano textures did not show this effect on a significant scale.

Textures have been increasingly used as reservoirs of solid lubricants, particularly with molybdenum disulfide (MoS2). The lubricant mechanism action occurs because tool worn particles, which are denser and harder than the work material, penetrate the textures through high cutting pressures, causing solid lubricant to overflow towards the cutting interface. In nano-scale textures, solid lubricants' action is different as there is no significant entrapment of particles. The textures filled with solid lubricants act as sliding bearings. Due to the chaotic movement of material at the cutting interface, mixed textures (involving dimples, grooves or other more complex patterns) showed better results regarding this effect.

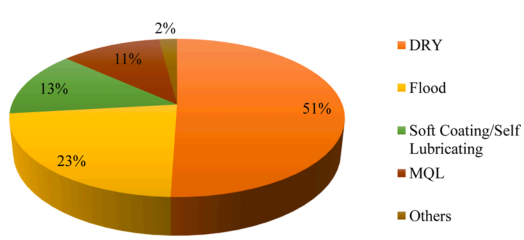

Fig. 23. Atmospheric conditions of the machining tests covered in the present paper.

Table 7
Discretization of the atmospheric conditions in the revised papers.

Dry	(Patel et al., 2019), (Palanisamy et al., 2019), (Mishra et al., 2019), (Liu et al., 2019a), (Lian et al., 2019), (Li et al., 2019), (Feng et al., 2019), (Dhage et al., 2019), (Chen et al., 2019a), (Yang et al., 2018), (Xing et al., 2018), (Sawant et al., 2018), (Rajbongshi et al., 2018), (Pan et al., 2018), (Mishra et al., 2018b), (Mishra et al., 2018a), (Liu et al., 2018b), (Liu et al., 2018a), (Li et al., 2018), (Kumar and Patel, 2018), (Kang et al., 2018a), (Gajrani et al., 2018b), (Gajrani et al., 2018a), (Cui et al., 2018), (Vasumathy and Meena, 2017), (Sugihara et al., 2017b), (Su et al., 2017), (Sasi et al., 2017), (Niketh and Samuel, 2017), (Liu et al., 2017), (Li et al., 2017), (Jesudass Thomas and Kalaichelvan, 2017), (Duan et al., 2017b), (Duan et al., 2017a), (Chen et al., 2017), (Xing et al., 2016), (Kim et al., 2016), (Dinesh et al., 2016), (Pratap et al., 2019), (Duan et al., 2019), (Rajbongshi and Sarma, 2019), (Sarma and Rajbongshi, 2020), (Ghosh and Pacella, 2020), (Patel et al., 2020), (Yang et al., 2020), (Zhao et al., 2020), (Wu et al., 2020)
Flood	(Ge et al., 2019), (Pang et al., 2018), (Kang et al., 2018b), (Durairaj et al., 2018), (Arumugaprabu et al., 2018), (Wei et al., 2017), (Sugihara et al., 2017a), (Sugihara and Enomoto, 2017), (Fang and Obikawa, 2017), (Stoeterau et al., 2016), (Liu et al., 2019b), (Kawasegi et al., 2019), (Alagan et al., 2019), (Grguraš and Pušavec, 2019), (Ahmed et al., 2020), (Peña-Parás et al., 2020), (Qi et al., 2020), (Zhu et al., 2016), (Zhang et al., 2019a), (Fang et al., 2017a), (Fang and Klein, 2019), (Klein et al., 2017), (Fang et al., 2016), (Fang et al., 2017b)
Soft Coating / Self Lubricating	(Gajrani et al., 2019), (Arulkirubakaran et al., 2019), (Orra and Choudhury, 2018), (Lian et al., 2018), (Zhang et al., 2017), (Song et al., 2017), (Kawasegi et al., 2017), (Feng et al., 2017), (Sun et al., 2016), (Sharma and Pandey, 2016a), (Rathod et al., 2016), (Vignesh et al., 2020), (Dheeraj et al., 2020a)
MQL	(Zhou et al., 2019), (Singh et al., 2019), (Su et al., 2018), (S, N. and G.L, S., 2018), (Hao et al., 2018), (Kumar Mishra et al., 2020), (Sivaiah and Bodicherla, 2020), (Sivaiah et al., 2020), (Singh et al., 2020), (Pratap and Patra, 2020), (Pratap and Patra, 2020)
Others	(Arulkirubakaran et al., 2018), (Arulkirubakaran et al., 2016)

9. Future trends

Due to the development of materials that are increasingly difficult to machine, there is a constant need to develop increasingly cost-effective tools, leading to changes in the material and geometry of the cutting tools and their surface. The superficial texturing of the tools is presented as one of the most promising development fronts for improving the cutting tools' tribological performance.

The understanding of how textures affect variables such as machining forces and temperature, tool life, and surface finish, is paramount, however, the understanding of the actual mechanism is still a knowledge gap. This is in part due to the complexity of the cutting interface, caused independently by the wide range of tribological pairs of tools, workpieces, and varieties of the lubricating and coolant media, as well as their combined effect along with high pressure characteristics during the shearing of the materials. According to the literature survey conducted in this review, some of the key-points pertaining to the application of textured tools in machining, are still dubious and therefore, need to be raised and addressed. Hence, the following research topics are recommended:

- Mostly articles only indicate an increase in tool life on the basis of reductions in cutting forces and temperatures. Probably the major reasons for the lack of deep studies on the tool life are some of the challenging analyses which include monitoring of classic parameters such as flank, crater, or notch wear, wear mechanism analysis involving the textures themselves, and evaluation of critical analyses associated with derivative cut in the edges of textures.

- Mostly studies in the literature have reported the influence of textures on cutting tools when machining carbon steels, titanium, and aluminum alloys. Therefore, this work encourages further research on the effects of surface texturing of tools applied to machining Ni-based superalloys, stainless steels, ceramic, and composite materials. These materials have high aggregated value and if the improvements from texturing are confirmed, then the application of textures can be boosted for large-scale industrial applications.
- The turning process corresponds to almost all the research associated with textured cutting tools. The possible cause is the availability of facilities for texturing turning tools as well as assessing forces and cutting temperatures in this process. However, texture presents much broader potentials, making it necessary to focus on research on other machining processes.
- The advantages of using lasers to texturize cutting tools include the versatility, precision reproducibility, and range of materials which can be textured. However, laser machines are expensive and have relatively low productivity for a large-scale production of textured tools. Therefore, it is recommended to investigate faster and more cost-effective methods for mass production of textured tools.
- Carbide tools dominate the cutting tool market, and therefore, there is a greater opportunity of texturing this material, especially using laser ablation. The surface texturing of ultra-hard materials such as ceramic, PCBN, and PCD remains as a challenge, as evidenced by the still scarce literature covering the surface texturing methods for these materials. The primary reason of the same is the possibility of embrittlement of the tool close to the cutting edges resulting from the texturing process. The need of exploring the production of textures in these materials is largely important because the high hardness of such cutting tools can enhance the duration of texturing process and, consequently, their benefitting effects.
- Another chief knowledge gap in the tool texturing field is the investigation of producing textures on the coated cutting tools. The main disadvantage lies in the fact that it is necessary to have a very precise control on the texturing method so that it does not reach the substrate, otherwise stress concentration points may arise, which can initiate and propagate cracks followed by reduction in tool life.
- Additionally, there is a huge scope of studying the influence of textures of more complex patterns. These textures can be more effective in retaining cutting fluids and reducing the workpiece-tool-chip contact areas. This can further lead to lower cutting forces and machining temperatures, and consequently, increasing tool life. Even the most researched patterns (groove and dimple) have not been investigated enough for clearly defining the most effective increase in the tool life.
- Understanding the effect of textures on other tool regions (apart from the rake surface) is another area requiring further exploration. The difficulties in texturing the regions such as the flank surface, the corner, or the chamfer, can better explain this knowledge gap. However, the application of non-traditional techniques such as ion beam machining - IBM or micro-EDM, can be some of the possible solutions to this problem.
- It is also important to consider economic, social, and environmental factors, arising from the tools' texturing processes and their interaction with cutting fluids. Therefore, it is highly encouraged to conduct investigations on the effects of textured tools amid cryogenic, MQL, and self-lubricated conditions. The use of these techniques can reduce cutting forces due to the possibility of increased wettability and fluidity of the cutting fluid in the textured surface (textures can work as micro reservoirs for cutting fluids).
- For studying the performance of textured tools, mostly authors used flat tool geometries without chip-breakers (CB) because of the difficulties in producing the textures on tools with CB, moreover, in the orthogonal cutting process due to the ease of monitoring. Thus, the studies on the effect of textures on tools of more complex geometries including their interaction with chip-breakers, are also essential. It is also suggested to use techniques which can allow a better assessment of the effects of textures on the thermal behavior of cutting interface, such as the use of tool-workpiece thermocouple measuring system. The understanding of material flow in textured tools should also be looked over using special methods, such as quick-stop device and high-speed cameras. Pieces of information derived from such experiments will lead to a better modeling of the textures' effect. This will further allow a greater accuracy in simulations, especially those implemented using the finite element method.
- With respect to the practical aspects, in all the research works, the texturing parameters were chosen on a random basis. For example, the parameters such as: width, depth, and orientation are defined more on the grounds of production capabilities of the texturing equipment rather than focusing on its effects. It would be essential to define a method of modeling the effects of the dimension, orientation, and shape of the texture more precisely for a certain machining condition. This way it can be made possible to optimize these patterns without any random investigation.

10. Dedication

This paper is dedicated to the memories of two of the authors, Prof. Wisley Falco Sales and Prof. Emmanuel Okechukwu Ezugwu. Prof. Sales was sadly defeated by the COVID19 virus, dying on 15th of June 2020, one week after the first submission of this paper. Prof. Sales was a talented researcher with many contributions in the field of machining and tribology and has idealized the publication of this article. Prof. Ezugwu died on 17th of September 2020. He was the Provost of the Air Force Institute of Technology of Nigeria (AFIT), in the city of Kaduna, Nigeria and his uncountable contributions in the field of metal cutting, principally in the machining of superalloys, have guaranteed a step ahead in the knowledge of this fantastic research area. With no doubt the whole machining community will miss both the researchers. Before departing from this world, Prof. Ezugwu have put his fingers in this paper without knowing that it would be the last. God bless the souls of these two fantastic colleagues.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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