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HIGH-SPEED MACHINING IN DRY CUTTING CONDITIONS – AN OPPORTUNITY FOR CLEAN PRODUCTION – BRIEF REVIEW

BY

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Abstract. This paper presents a brief review on the latest researches in dry high-speed machining consisting in studies regarding the materials of the parts being cut, tools, methods and techniques used in order to investigate all the phenomena occurring during this type of processing. The results have shown that this field of research is continuously developing, emphasizing the possibilities of reaching an environmental-friendly manufacturing.

Keywords: Clean machining; dry cutting; high-speed cutting; cutting forces; tool’s wear.

1. Introduction

Metalworking industry is one of the leading industries in the world as it plays an essential role in the entire economy, which it supports through its products - machinery, industrial and technical equipment, machine tools, cutting tools, part’s material - boosting the development of other industries and economic sectors. It has the highest value in the total of industrial production

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(35-45% in developed countries) and covers worldwide, over 30% of the workforce employed in industry.

Nowadays, the requirement for an environmental-friendly manufacturing is increasing around the world and also the demands for improved metals/materials. This creates new challenges for machining operations and place high demands for high performance cutting tools. Either is called environmental-friendly (Bhokse *et al*., 2015), green (Helu *et al*., 2012) or clean production (Krolczyk *et al*., 2016; Wang *et al*., 2014), it refers to a sustainable production, representing no threat to future generations and not being at the expense of future generations. Clean production does not have to mean increased financial investments. The goal is to reduce the environmental pollution in the process of manufacturing involving reduction of pollution generated by cooling/lubricating with coolants and emulsions (Krolczyk *et al*., 2016).

In his article (Landgraf, 2004), Greg Landgraf is presenting some of the advantages of dry cutting, as follows: the absence of water and atmosphere pollution; the resulted solid waste in form of debris can be recycled easier, without additional costs for cleaning the metalworking fluid, and also it can be sold with higher price; there is no danger for operator's health; dry cutting is economical considering that the costs attributed to the use of coolant are estimated to 16% of machining total cost ((Sharma *et al*., 2016) estimated this cost to 16 - 20%)), which is about 3-4 times the cutting tools cost; for high speed machining the using of dry cutting requires less cutting force; in interrupted cutting, such as milling, dry machining is suitable as it could improve the tool's life.

On the other hand, Neil Canter is presenting in his article (Canter, 2009), some of the advantages of dry cutting, similar to those presented above, but also some limitations of this type of machining, as follows: some companies have shown that the costs of maintaining and disposing the metalworking fluids are a lot less than 16% of company's total manufacturing costs; without using coolant, surface finish and tool life are severely affected as a tremendous amount of heat and friction is generated during the cutting process and this fact could significantly increase manufacturing costs and reduce productivity; not all machining operations are suitable for dry cutting; some alloys of metal being cut are more amenable to dry machining than others.

Other references (Graham *et al*., 2003; www.cnccookbook.com; www.theengineer.co.uk) highlight the advantages of dry cutting in high speed machining conditions and show the overcome of dry cutting limitations as the research in this field is evolving. Thus, in general, the increasing demand for hard machining and high-speed machining especially under dry cutting conditions has made many researchers to work in this field of development of manufacturing processes in order to obtain good surface finish and part accuracy, low energy consumption and maintaining long tool-life while reducing the impact of industrial activity on environment and health. These researches consist of analytical and experimental studies of cutting forces, chips formation, thermo elastic workpiece deformation, tool wear evolution, cutting temperature, cutting parameters optimization, surface roughness, cutting energy etc. when improved or hardened metals/materials are being cut in dry high-speed conditions (Wang *et al*., 2016; Zhang *et al.*, 2016; de Agustina *et al*., 2013; Salguero *et al*., 2013; Liu *et al*., 2009; Wang and Liu, 2015; Fang and Wu, 2009; Ma *et al*., 2015; Soler *et al*., 2015; Singh *et al*., 2015; Xie *et al*., 2013; van Hoof, 2014; Wang *et al*., 2014; Shashidhara and Jayaram, 2010), etc.

2. Workpiece Materials, Cutting Tools, Methods and Technologies for Studying Phenomena in Dry High-Speed Machining

Various studies regarding high-speed machining (HSM) in dry cutting conditions of the improved or hardened metals/materials were developed (Wang *et al*., 2016; Sugihara *et al*., 2015; de Agustina *et al*., 2013; Hanief *et al*., 2016; Salguero *et al*., 2013; Wang and Liu, 2015; Krishnakumar *et al*., 2015; Fang and Wu, 2009; Calatoru *et al*., 2008), etc. Some of these materials are suitable to this type of machining, some of them are submitted to research for optimizing the cutting process. Dry cutting has long been used with materials such as magnesium, which reacts with water, so common coolants are incompatible with it; most alloys of cast iron; carbon and alloyed steel that are relatively easy to machine and conduct heat well, allowing the chips to carry away most of the heat generated; some aluminum alloys.

However, the fast development of automotive, aerospace, shipbuilding, chemical or surgical industries requires improved and hardened metals/materials. Some of the HSM under dry conditions researches refer to these **materials**, as follows: Aluminium alloys (7050-T7451 (Wang *et al*., 2016; Wang *et al*., 2015), UNS A97075 (de Agustina *et al*., 2013), UNS A92024-T3 (Al-Cu) (Salguero *et al*., 2013), Al6061-T6 and Al7075-T6 (Zaghbani and Songmene, 2009), AlMgSi (Al 6061 T6) (Kalyan and Samuel, 2015), Al2016-T6 (Mithilesh Kumar Dikshit *et al*., 2014)), Titanium alloys (Ti–6Al–4V). (Fang and Wu, 2009), TC21 (Wu and To, 2015; Xie *et al*., 2013), Magnesium–calcium (MgCa) alloys (Salahshoor and Guo, 2011), hardened steels (Qing *et al*., 2010; Pawade *et al*., 2007), stainless steel (Krolczyk *et al*., 2016), gray cast iron (Tu *et al*., 2016), superalloys (nickel-based Inconel 718), (Li *et al*., 2006) and Carbon Fiber Reinforced Polymers (Slamani *et al*., 2015; Uhlmann *et al*., 2016).

Also the open literature (Sugihara *et al*., 2015; Fang and Wu, 2009; Ma *et al*., 2015; Xie *et al*., 2013; Kalyan and Samuel, 2015; Martinho *et al*., 2008; Qing *et al*., 2010; Tu *et al*., 2016; Kagnaya *et al*., 2014; Xing *et al*., 2014; Tian *et al*., 2013) covers an entire range of **cutting tools** used in HSM in dry conditions, such as high-performance carbide - multi-layer TiAlN coating, multi-layer hard coating consisting of distinct, alternating ultra-thin layers of

TiN (titanium nitride), TiAlN (titanium aluminum nitride), TiCN (titanium carbonitride) and lubrication coat -, PCBN, ceramics, diamond tools, PVD - applied nanolaminated TiSiN-TiAlN coated carbide tool.

Furthermore, in order to optimize the cutting conditions in dry HSM, the latest literature in this field presents studies conducted in most of the **manufacturing processes**: turning (De Agustina *et al*., 2013; Hanief *et al*., 2016; Bhokse *et al*., 2015; Pawade *et al*., 2007; Xie *et al*., 2013; Krolczyk *et al*., 2016; Kalyan and Samuel, 2015; Tu *et al.*, 2016), milling (Salguero *et al*., 2013; Zaghbani and Songmene, 2009; Mithilesh Kumar Dikshit *et al*., 2014; Singh *et al*., 2015; Kious *et al*., 2010; Li *et al*., 2006; Marinescu and Axinte, 2008; Lu *et al*, 2014; Tian *et al*., 2013; Smith *et al*., 2013), drilling (Harris *et al*., 2003), and gear hobbing (Claudin and Rech, 2009). In this papers, the phenomena occurring during HSM are studied, analyzed and compared using advanced **methods and technologies**, such as the analysis of variance (ANOVA), (Wang *et al*., 2016; De Agustina *et al*., 2013; Slamani *et al*., 2015; Pawade *et al*., 2007), finite element method (FEM) (Zhang *et al*., 2016; Wang and Liu, 2015; Bhokse *et al*., 2015; Ma *et al*., 2015; Puls *et al*., 2016; Wu and To, 2015; Kalyan and Samuel, 2015), finite element analysis (FEA) (Salahshoor and Guo, 2011; Calatoru *et al*., 2008), artificial neural network ANN, (Hanief *et al*., 2016; Krishnakumar *et al*., 2015), Taguchi method (Hanief *et al*., 2016), regression analysis (Hanief *et al*., 2016; Salguero *et al*., 2013; Fang and Wu, 2009), MATLAB (Hanief *et al*., 2016; Fang and Wu, 2009; Mithilesh Kumar Dikshit *et al*., 2014; Pawade *et al*., 2007), SFTC DEFORM software (Puls *et al*., 2016), MountainsMap 7.0 software (Krolczyk *et al*., 2016), Lab-VIEW (Krolczyk *et al*., 2016), field-programmable gate array (FPGA) (Sevilla-Camacho *et al*., 2015), PC208AX Sony data recorder (Li *et al*., 2006), LEICA MZ12 microscopy system (Li *et al*., 2006), optical microscope OLYMPUS SZ61TR (Tu *et al.*, 2016), scanning electron microscope (SEM), (Sugihara *et al*., 2015; Calatoru *et al*., 2008; Singh *et al*., 2015; Xie *et al*., 2013; Krolczyk *et al*., 2016; Kalyan and Samuel, 2015; Martinho *et al*., 2008; Qing *et al*., 2010; Pawade *et al*., 2007; Tu *et al.*, 2016; Uhlmann *et al*., 2016; Uhlmann *et al*., 2016; Kagnaya *et al*., 2014), Infrared radiation (IR) technology (Soler *et al*., 2015), ThermaVision A20V, ThermaCAM Researcher (Qing *et al*., 2010), Infinite Focus Measurement Machine (IFM) (Krolczyk *et al*., 2016), portable surface roughness-measuring instrument Mahr Perthometer Model M2 (Pawade *et al*., 2007), Kistler dynamometers and CNC machinery. Some of the results are presented as follows.

3. Research Background of the Phenomena Occurring in Dry High-Speed Machining

In the latest years, several studies dedicated to dry HSM of improved and hardened materials have been performed as to understand the cutting conditions, such as, cutting forces and temperature, chips formation, tool wear and surface quality, in order to machining process take place within a clean environment, obtaining, at the same time, proper results for productivity, tools and energy consumption and accuracy of the parts.

3.1. Cutting Forces in Dry HSM

Knowing the values of forces as an output data of the cutting process can provide both information about the input variables and parameters of the process, such as, cutting speed, feed, depth of cut, tool material and geometry, and about the machining process evaluation, as force's influence is usually reflected in other output variables, such as, surface quality, temperature, tool life and tool wear. This is the reason why several researches in dry HSM field are related to cutting forces (de Agustina *et al*., 2013; Hanief *et al*., 2016; Salguero *et al*., 2013; Fang and Wu, 2009; Zaghbani and Songmene, 2009; Bhokse *et al*., 2015; Mithilesh Kumar Dikshit *et al*., 2014; Pawade *et al*., 2007; Xie *et al*., 2013; Li *et al*., 2006; Tian X. *et al*., 2013; Thakur *et al*., 2012).

Kalyan C. and Samuel G.L. developed a study (Kalyan and Samuel, 2015) regarding the cutting forces when turning an AlMgSi alloy. To investigate the effect of feed rate and cutting speed on tangential cutting forces, PCD insert without edge preparation was used to turn the work material of 80 mm diameter at three different cutting speeds (400, 500 and 600 m/min), feed rates of 0.007, 0.02, 0.03 and 0.05 mm/rev and a depth of cut of 0.5 mm, without coolant. Also a finite element model to predict the forces during turning was developed. The size effect caused by the combined effect of material strengthening due to increase in strain gradient at low feed rates and the cutting edge geometry was considered in the developed finite element model. Some of the experimental results have shown that the tangential cutting forces reduce with increase in cutting speeds; this could be attributed to the thermal softening of the work material; all the three components of forces increase with the increase in cutting edge chamfer; as the ratio of feed rate and edge chamfer width reduces.

In their paper (Fang and Wu, 2009), N. Fang and Q. Wu made a comparative experimental study of high speed machining of two major aerospace materials – titanium alloy Ti–6Al–4V and Inconel 718. Based on extensive experimental data generated from 40 orthogonal high speed tube-cutting tests that involved five levels of cutting speeds and four levels of feed rates for each work material, the similarities and differences in machining the two materials were summarized as follows: for both materials, as the cutting speed increases, the cutting force, the thrust force, and the result force all decrease; however, the force ratio increases; for both materials, as the feed rate increases, the cutting force, the thrust force, the result force, as well as the force ratio all increase; under the same cutting conditions, the cutting force and the thrust force in machining Inconel 718 are higher than those in machining Ti–6Al–4V; the variation of the thrust force with the feed rate is smaller in machining Ti–6Al–4V than that in machining Inconel 718, especially at the lower cutting speeds. The final analysis revealed that the cutting forces in machining Ti–6Al–4V and Inconel 718 are governed by the interactions among work materials, tool geometry, and the cutting conditions.

3.2. Cutting Temperature in Dry HSM

The open literature in this field relates the cutting temperature to forces, material of the workpiece and tool, geometry of the inserts and cutting parameters, as data input, having an highly impact on tool's life and surface quality, as data output in dry high-speed machining process (Salahshoor and Guo, 2011; Calatoru *et al*., 2008; Soler, *et al*., 2015; Xie *et al*., 2013; Zaghbani and Songmene, 2009; Puls *et al*., 2016; Wu and To, 2015; Qing *et al*., 2010; Kagnaya *et al.*, 2014; Xing *et al*., 2014).

M. Salahshoor and Y.B. Guo developed a study (Salahshoor and Guo, 2011) on cutting mechanics in high speed dry face milling of biomedical magnesium–calcium MgCa0.8 alloy using internal state variable plasticity model. The results have shown the importance of knowing the cutting temperature when magnesium alloys are being cut, as the chip ignition, one of the most hazardous aspects in machining these alloys, does not occur in high-speed dry cutting with sharp PCD tools.

T. Kagnaya *et al*. investigated the damages of WC–6Co uncoated carbide tools during dry turning of AISI 1045 medium carbon steel at high speeds considering more parameters of influence, among which, the temperature played an important role (Kagnaya *et al.*, 2014). In order to take into account the temperature in tool wear analysis, the cutting tool temperature was measured through two isolated K-type thermocouples (ϕ = 0.25 mm). The results have shown that the temperature increases with increasing cutting speed and the reached temperature (about 600°C) is enough high to influence cutting tool wear. The highest temperatures recorded by the thermocouple nearest to the rake face, for the cutting speeds 100 m/min and 400 m/min after about 30 s of machining time, reached respectively of 400°C and 820°C. These temperatures were considered high enough to modify the tool material behavior and the microstructure of WC–6Co.

Zhenhua Qing *et al*. developed a study (Qing *et al*., 2010) on the high-speed and dry cutting chips of hardened alloy-steel with PCBN tool and the results have shown that the infrared image of the trail indicated that the machining generated a lot of cutting heat and most of the heat was carried by chip flow. Along with the cutting speed increasing, the temperature in shear zone increased and then decreased. The cutter were more likely to abrasive at Vc = 500 m/min, Vc = 600 m/min cutting speeds. When cutting speed increased to high as Vc = 800 m/min, a lot of cutting heat was carried out by chip, and the temperature changed little. The cutting temperature was lower than it at Vc = 500 m/min,Vc = 600 m/min cutting speed. The cutting process progressed smoothly. The paper concluded that it is suitable for PCBN cutter machining on 42CrMo hardened steel at high speed without cutting fluid.

3.3. Chip's Morphology in Dry HSM

The cutting principle during machining process refers to chip formation mechanism, in which the workpiece material undergoes large plastic deformation and the removed material is get rid of. Usually, the morphology of chips formed in the cutting speed range of HSM is serrated for ductile materials. The onset of serrated chip relates with cutting force and cutting temperature, tool wear and tool failure, quality of surface finish and accuracy of machined part, etc. (Wang and Liu, 2015; Xie *et al*., 2013; Salahshoor and Guo, 2011; Bhokse *et al*., 2015; Wu and To, 2015; Qing *et al*., 2010).

In their paper, (Wang and Liu, 2015), Bing Wang and Zhanqiang Liu investigated the influence of material constitutive parameters on the serrated chip formation during dry high speed machining (HSM) of Ti6Al4V alloys with finite element simulations and cutting experiments. Both the simulation and experimental results have shown that the serrated degree of chips increases with the cutting speed increasing until the chip becomes fragmented (Fig. 1). The cutting speed break point of chip morphology from serrated to fragmented for Ti6Al4V is about 2,500 m/min. Moreover, the average cutting force decreases with the cutting speed increasing.

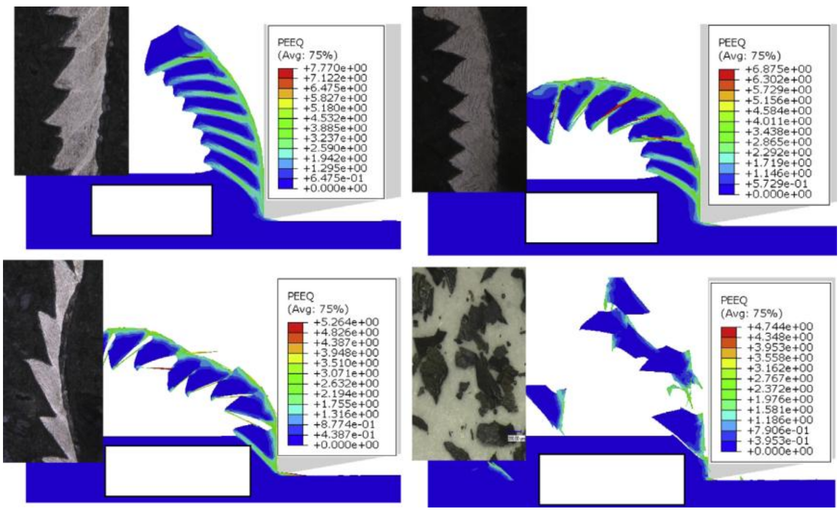

Fig. 1 − Variation of chip morphologies under different cutting speeds (Wang and Liu, 2015).

Hongbing Wu and Sandy To present in their paper, (Wu and To, 2015), an investigation on the cutting mechanism of a new high temperature and high strength titanium alloy named TC21 (Ti–6Al–2Sn–2Zr–3Mo–1Cr–2Nb) using the finite element method (FEM). A modified high temperature split Hopkinson pressure bar (SHPB) test system was employed to obtain the stress– strain curves of TC21 alloy under different temperatures and strain rates.

The study proved that the serrated chip occurred due to the thermal softening by the adiabatic effect. In addition, the results showed that the larger tool rake angle can decrease the extent of the serrated chip, and the cutting forces and the shear band frequency are sensitive to the tool rake angle during the machining process of TC21 alloy.

Zhenhua Qing *et al.* developed a study (Qing *et al*., 2010) on the high-speed hard and dry cutting chips of hardened alloy-steel with PCBN tool, showing that the chips are different from the cutting time. At the cutting beginning the chip is narrow, and saw-teeth-chip was at single side, whit low height and narrow width. The rough side squeezed severely and piles on each other. After a while of cutting, chip flows smoothly, become thinner, and saw-teeth-chip was seen at both sides. The saw tooth chip was different from one side to the other. The saw tooth could also been seen after tool wear down, and looked like band chip-low and small with the rough surface striation.

3.4. Tool’s Life and Tool Wear Monitoring in Dry HSM

Tool wear occurs under conditions of high temperatures (heat is generated and propagated), acting forces generate stresses and there is an internal friction in the deformed layers of material. This makes wear process of machining tools a very complex one, which results from interactions in the cutting zone. Selection of an appropriate cutting tool plays an important role in this perspective, whereas the selection of tool coating shall be adapted to appropriate types of machining. This is a significant factor, as coatings are applied in order to improve thermo physical, mechanical and tribological performance of machining process that depend also on machining process parameters (Krolczyk *et al*., 2016; Li *et al*., 2006; Martinho *et al*., 2008; Tu *et al.*, 2016; Claudin and Rech, 2009; Kagnaya*et al.*, 2014; Xing *et al*., 2014; Tian *et al*., 2013; Liu *et al*., 2013; Harris *et al*., 2003; Thakur *et al*., 2012).

In his paper, (Kious *et al*., 2010), Kious M. investigated the use of cutting force signal measurements to improve the on-line tool wear detection and the monitoring of coated tools in milling process by developing a predictive method of their wear. To achieve this goal, they have used the cutting force analysis to establish a relationship between the wear evolution and the cutting force variations. It was shown that the state of the tool wear observed by the microscope was related to results obtained by cutting force analysis. An automatic monitoring system of tool wear based on neural networks was implemented using the cutting condition, the insert type, the values of the variance, and the first harmonic of the cutting force as input vectors to estimate the tool wear.

Kagnaya T. investigated the damages of WC–6Co uncoated carbide tools during dry turning of AISI 1045 medium carbon steel at mean and high speeds, (Kagnaya *et al.*, 2014). The different wear micromechanisms were explained on the basis of different microstructural observations and analyses made by different techniques. The results have shown that the cutting tool wear depends on cutting speed. At conventional cutting speeds, a normal wear of the flank tool was observed. For high cutting speeds, a faster wear rate on the rake face was predominant. At a macroscopic scale, adhesion, abrasion and chipping wear were observed. The crater wear mode is dominant during machining AISI 1045 at high cutting speeds with WC–6Co cemented carbide cutting tools. The catastrophic wear mechanism of WC–6Co tools during high speed machining of AISI 1045 was activated by the coexistence of two main factors: severe tribological conditions on cutting tool and heat generation.

Krolczyk G.M. performed some researches regarding the tool life in dry turning of a duplex stainless steel using three different carbide tools, (Krolczyk *et al*., 2016). The experiments were carried out in dry and cooling/lubricating conditions, and involved the measurements of surface roughness, cutting force components and tool life (Fig. 2).

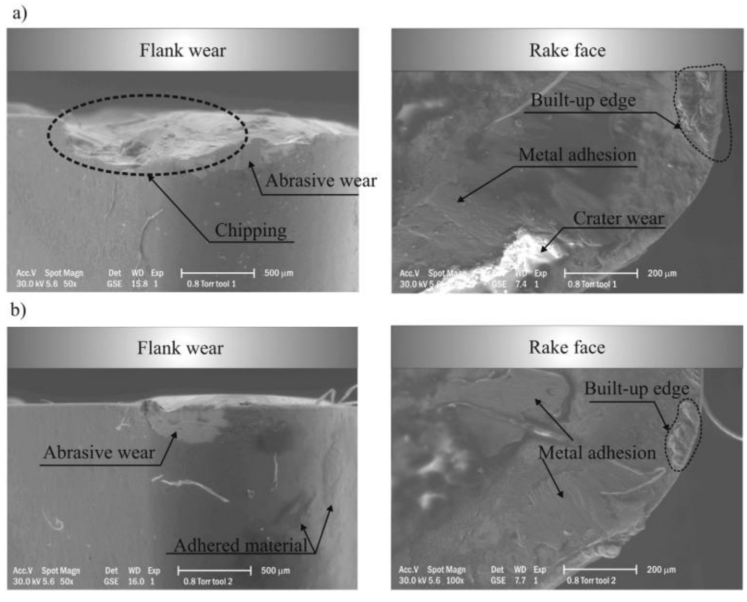

Fig. 2 − Topography of the tool point wear on cutting tools during DSS turning depending on the method of cooling: *a*) dry cutting; *b*) lubricated cutting (Krolczyk *et al*., 2016).

The results presented demonstrate that dry turning with the appropriately selected cutting tool grade and machining conditions induce almost three-fold growth of tool life in comparison to that obtained during cutting with fluids. The results have shown that the cutting tool life of duplex stainless steel depends on the following problems: difficult chip control and excessive thermal and mechanical loads of the cutting tool. It was also concluded that a rational solution in terms of energy consumption is machining without cooling, which involves combination of high cutting speed with low feed rate.

3.5. Surface Quality in Dry HSM

The general manufacturing problem can be described as the achievement of a predefined product quality with given equipment, cost and time constraints. Unfortunately, for some quality characteristics of a product such as surface roughness it is hard to ensure that these requirements will be met. In machining of parts, surface quality is one of the most specified customer requirements, reason why several researches in dry HSM field were dedicated to study this parameter (Kalyan and Samuel, 2015; Singh *et al*., 2015; Krolczyk *et al*., 2016; Uhlmann *et al*., 2016; Marinescu and Axinte, 2008; Pawade *et al*., 2007).

Pawade R.S. *et al*. studied the effect of cutting speed, feed rate, depth of cut and tool cutting edge geometry on cutting forces, surface roughness and surface damage in high-speed turning of Inconel 718 using PCBN tools, (Pawade *et al*., 2007). The experiments have shown that a 30° chamfer angle insert produce lower values of surface roughness at higher cutting speeds; SEM examination indicated that the presence of surface damage in the form of metal debris adhesion, smeared material, side flow and feed marks; the surfaces machined using 20° chamfered tool have fragments of carbide particles adhered on them; the machined surfaces at higher cutting speeds (*i.e*. 475 m/min) shown lesser flaws than those machined at 125 and 300 m/min cutting speeds.

Krolczyk G.M., in his study, (Krolczyk *et al*., 2016), also referred to the surface quality, showing that the roughness profile, after turning with a multi-layer coated tool with cooling led to many more tribological disturbances than in the case of machining without cooling – the surface roughness profile shape can prove a transverse plastic flow of the material in the cutting zone.

Kalyan C. and Samuel G.L. presented in their study (Kalyan and Samuel, 2015), also some results regarding the surface roughness, showing that best surface finish (Ra of 50 nm) was achieved at the lowest feed rate of 0.007 mm/rev at cutting speeds of 300, 400 and 600 m/min; the effect of feed rate is more pronounced on the surface finish than the cutting speed; the minimum feed rate for achieving the best surface finish in high speed turning (cutting speed of 1200 m/min) was found for each insert with different edge chamfer widths; the minimum feed rates obtained are 0.04 mm/rev for 20 μm edge chamfer width, 0.06 mm/rev for 40 μm edge chamfer width, 0.09 mm/rev for 60 μm edge chamfer width and 0.09 mm/rev for 80 μm edge chamfer width; the surface roughness is found to decrease with increase in nose radius when the feed rate is in the region of shearing dominated mode of cutting and the surface roughness is found to increase with increase in nose radius when the feed rate is in the region of ploughing dominated mode of cutting after a particular value of nose radius due to the domination of ploughing action at higher values of nose radius at low feed rate and depth of cut.

4. Conclusions

This paper presents some of the latest researches in the field of dry high-speed manufacturing, aiming to understand the possibilities of a clean production in all machining processes. The following conclusions could be drawn.

1. Researchers agree that HSM in dry conditions is a way to reach clean production, non-polluting and not involving extra costs.

2. Ductile materials (such as, medium and low carbon steels) of the workpiece easily allow this type of processing; however, there are recent studies showing the continuous research of dry HSM of low or medium carbon parts.

3. Problems occur in the case of very hard or improved materials increasingly used in the automotive and aerospace industry, materials that require special working conditions, reason why many studies in dry HSM are related to these materials.

4. High speed dry cutting can be performed in almost all processing methods, fewer studies being developed for drilling and grinding, whereas the removal of coolant from process is almost impossible; in these cases there are analyzed and developed alternative methods of cooling.

5. For certain types of materials it was proven that high-speed cutting is developing better in dry cutting conditions, especially in certain processes, such as milling.

6. Literature study shows the possibility to develop new researches in HSM under dry cutting conditions, both in case of conventional materials (low and medium carbon steels), and especially for hard materials (hardened steels, superalloys), given their continuous improvement.

REFERENCES

Bhokse V., Chinchanikar S., Anerao P., Kulkarni A., *Experimental Investigations on Chip Formation and Plowing Cutting Forces during Hard Turning*, Materials Today: Proceedings 2, online at www.sciencedirect.com, 3268-3276 (2015).

Calatoru V.D., Balazinski M., Mayer J.R.R., Paris H., L'Esperance G., *Diffusion Wear Mechanism during High-Speed Machining of 7475-T7351 Aluminum Alloy* *with Carbide End Mills*, Wear 265, online at www.elsevier.com/locate/wear, 1793-1800 (2008).

Canter N., *The Possibilities and Limitation of Dry Machining*, online at http://www.uscti.com/u_pages/publications/pdfs/ItemGDryMachiningMarch2009CanterSTLEStark.pdf (2009).

Claudin C., Rech J., *Development of a New Rapid Characterization Method of Hob's Wear Resistance in Gear Manufacturing - Application to the Evaluation of Various Cutting Edge Preparations in High Speed Dry Gear Hobbing*, Journal of Materials Processing Technology 209, online at doi:10.1016/j.jmatprotec.2009.02.014, 5152-5160 (2009).

de Agustina B., Bernal C., Camacho A.M., Rubio E.M., *Experimental Analysis of the Cutting Forces Obtained in Dry Turning Processes of UNS A97075 Aluminium Alloys*, Procedia Engineering 63, online at www.sciencedirect.com, 694-699 (2013).

Fang N., Wu Q., *A Comparative Study of the Cutting Forces in High Speed Machining of Ti–6Al–4V and Inconel 718 with a Round Cutting Edge Tool*, Journal of Materials Processing Technology 209, online at www.elsevier.com/locate/jmatprotec, 4385-4389 (2009).

Graham D., Huddle D., McNamara D., *Machining Dry Is Worth A Try*, online at www.mmsonline.com/articles/machining-dry-is-worth-a-try, (2003), accessed on 11th November 2016.

Hanief M., Wani M.F., Charoo M.S., *Modeling and Prediction of Cutting Forces during the Turning of Red Brass* (*C23000*) *Using ANN and Regression Analysis*, Eng. Sci. Tech., Int. J., online at http://dx.doi.org/10.1016/j.jestch.2016.10.019 (2016).

Harris S.G., Doyle E.D., Vlasveld A.C., Audy J., Quick D., *A Study of the Wear Mechanisms of Ti1−XAlXN and Ti1−X−YAlXCrYN Coated High-Speed Steel Twist Drills under Dry Machining Conditions*, Wear, Vol. **254**, *7-8*, online at http://dx.doi.org/10.1016/S0043-1648(03)00258-8, 723-734 (2003).

Helu M., Behmann B., Meier H., Dornfeld D. *et al*., *Impact of Green Machining Strategies on Achieved Surface Quality*, CIRP Annals - Manufacturing Technology 61:1, online at http://dx.doi.org/10.1016/j.cirp.2012.03.092, 55-58 (2012).

Kalyan C., Samuel G.L., *Cutting Mode Analysis in High Speed Finish Turning of AlMgSi Alloy using Edge Chamfered PCD Tools*, Journal of Materials Processing Technology 216, online at http://dx.doi.org/10.1016/j.jmatprotec.2014.09.003, 146-159 (2015).

Kagnaya T., Boher C., Lambert L., Lazard M., Cutard T., *Microstructural Analysis of Wear Micromechanisms of WC–6Co Cutting Tools during High Speed Dry Machining*, Int. Journal of Refractory Metals and Hard Materials 42, online at http://dx.doi.org/10.1016/j.ijrmhm.2013.08.017, 151-162 (2014).

Kious M., Ouahabi A., Boudraa M., Serra R., Cheknane A., *Detection Process Approach of Tool Wear in High Speed Milling*, Measurement 43, online at doi:10.1016/j.measurement.2010.08.014, 1439-1446 (2010).

Krishnakumar P., Rameshkumar K., Ramachandran K.I., *Tool Wear Condition Prediction Using Vibration Signals in High Speed Machining (HSM) of Titanium (Ti-6Al-4V) Alloy*, Procedia Computer Science 50, online at www.sciencedirect.com, 270-275 (2015).

Krolczyk G.M., Nieslony P., Maruda R.W., Wojciechowski S., *Dry Cutting Effect in Turning of a Duplex Stainless Steel as a Key Factor in Clean Production*, Journal of Cleaner Production, online at http://dx.doi.org/10.1016/j.jclepro.2016.10.136, 1-12 (2016).

Landgraf G., *Dry Goods - Factors to Consider when Dry or Near-Dry Machining*, Cutting tool Eng, **56**, *1*, 28-35 (2004).

Li H.Z., Zeng H., Chen X.Q., *An Experimental Study of Tool Wear and Cutting Force Variation in the End Milling of Inconel 718 with Coated Carbide Inserts*, Journal of Materials Processing Technology 180, online at doi:10.1016/j.jmatprotec.2006.07.009, 296-304 (2006).

Li A., Zhao J., Luo H. *et al*., *Progressive Tool Failure in High-Speed Dry Milling of Ti-6Al-4V Alloy with Coated Carbide Tools*, Int. J. Adv. Manuf. 58: 465, online at doi:10.1007/s00170-011-3408-1 (2012).

Liu Y.J., Huang J.B., Qing M.Y., Xia W., Tang Y., *High Speed Machining of AISI 52100 Steel*, Advanced Materials Research Online, ISSN: 1662-8985, Vol. **69-70**, online at doi:10.4028/www.scientific.net/AMR.69-70.466, 466-470 (2009).

Liu Z., An Q., Xu J., Chen M., Han S., *Wear Performance of (nc-AlTiN)/(a-Si3N4) Coating and (nc-AlCrN)/(a-Si3N4) Coating in High-Speed Machining of Titanium Alloys under Dry and Minimum Quantity Lubrication (MQL) Conditions*, Wear Vol. **305**, *1-2*, online at http://dx.doi.org/10.1016/j.wear.2013.02.001, 249-259 (2013).

Lu L. *et al*., *Microstructure and Cutting Performance of CrTiAlN Coating for High-Speed Dry Milling*, Trans. Nonferrous Met. Soc. China 24, online at DOI: 10.1016/S1003-6326(14)63256-8, 1800-1806 (2014).

Ma J., Duong N.H., Lei S., *Numerical Investigation of the Performance of Microbump Textured Cutting Tool in Dry Machining of AISI 1045 Steel*, Journal of Manufacturing Processes 19, online at http://dx.doi.org/10.1016/j.jmapro.2014.10.001, 194-204 (2015).

Martinho R.P., Silva F.J.G., Baptista A.P.M., *Cutting Forces and Wear Analysis of Si3N4 Diamond Coated Tools in High Speed Machining*, Vacuum 82, online at doi:10.1016/j.vacuum.2008.03.065, 1415-1420 (2008).

Marinescu I., Axinte D.A., *A Critical Analysis of Effectiveness of Acoustic Emission Signals to Detect Tool and Workpiece Malfunctions in Milling Operations*, International Journal of Machine Tools & Manufacture 48, online at doi:10.1016/j.ijmachtools.2008.01.011, 1148-1160 (2008).

Mithilesh Kumar Dikshit, Asit Baran Puri, Atanu Maity and Amit Jyoti Banerjee, *Analysis of Cutting Forces and Optimization of Cutting Parameters in High-Speed Ball-End Milling Using Response Surface Methodology and Genetic Algorithm*, Procedia Materials Science 5, online at www.sciencedirect.com, 1623-1632 (2014).

Pawade R.S., Suhas S. Joshi, Brahmankar P.K., Rahman M., *An Investigation of Cutting Forces and Surface Damage in High-Speed Turning of Inconel 718*, Journal of Materials Processing Technology 192–193, online at doi:10.1016/j.jmatprotec.2007.04.049, 139-146 (2007).

Puls H., Klocke F., Döbbeler B., Peng B., *Multiscale Modeling of Thermoelastic Workpiece Deformation in Dry Cutting*, Procedia CIRP 46, online at doi: 10.1016/j.procir.2016.03.195 , 27-30 (2016).

Qing Z., Zuo D., Xie F., Zhang C., *Trail Investigation on Chip of High-speed and Dry Cutting on Hardened Steel with PCBN Tool*, Advanced Materials Research Online: 2010-10-19, ISSN: 1662-8985, Vol. **142**, online at doi:10.4028/www.scientific.net/AMR.142.26, 26-30 (2010).

Salguero J., Batista M., Calamaz M., Girot F., Marcos M., *Cutting Forces Parametric Model for the Dry High Speed Contour Milling of Aerospace Aluminium Alloys*, Procedia Engineering 63, online at www.sciencedirect.com, 735-742 (2013).

Salahshoor M., Guo Y.B., *Cutting Mechanics in High Speed Dry Machining of Biomedical Magnesium–Calcium Alloy Using Internal State Variable Plasticity Model*, Int. J. of Machine Tools & Manuf. 51, online at www.elsevier.com/locate/ijmactool, 579-590 (2011).

Sevilla-Camacho P.Y., Robles-Ocampo J.B., Jauregui-Correa J.C., Jimenez-Villalobos D., *FPGA-Based Reconfigurable System for Tool Condition Monitoring in High-Speed Machining Process*, Measurement 64, online at http://dx.doi.org/10.1016/j.measurement.2014.12.037, 81-88 (2015).

Sharma A.K., Tiwari A.K., Dixit A.R., *Effects of Minimum Quantity Lubrication (MQL) in Machining Processes Using Conventional and Nanofluid Based Cutting Fluids: A Review*, J. Clean. Prod. 127, 1-18 (2016).

Shashidhara Y.M., Jayaram S.R., *Vegetable Oils as a Potential Cutting Fluid an Evolution*, Tribol. Int. 43, 1073-1081 (2010).

Singh K.K., Kartik V., Singh R., *Modeling Dynamic Stability in High-Speed Micro Milling of Ti–6Al–4V Via Velocity and Chip Load Dependent Cutting Coefficients*, International Journal of Machine Tools & Manufacture 96, online at http://dx.doi.org/10.1016/j.ijmachtools.2015.06.002 , 56-66 (2015).

Slamani M., Gauthier S., Chatelain J.-F., *A Study of the Combined Effects of Machining Parameters on Cutting Force Components during High Speed Robotic Trimming of CFRPs*, Measurement 59, online at http://dx.doi.org/10.1016/j.measurement.2014.09.052, 268-283 (2015).

Smith I.J., Münz W.D., Donohue L.A., Petrov I., Greene J.E., *Improved Ti1–xAlxN PVD Coatings for Dry High Speed Cutting Operations*, Surf. Eng. 14, 1998:1, online at http://dx.doi.org/10.1179/sur.1998.14.1.37, 37-42 (2013).

Soler D., Aristimuńo P., Garay A., Arrazola P. J., *Uncertainty of Temperature Measurements in Dry Orthogonal Cutting of Titanium Alloys*, Infrared Physics & Technology 71, online at http://dx.doi.org/10.1016/j.infrared.2015.04.001, 208-216 (2015).

Sugihara T., Nishimoto Y., Enomoto T., *On-Machine Tool Resharpening Process for Dry Machining of Aluminum Alloys Employing LME Phenomenon*, Precision Engineering 40, online at http://dx.doi.org/10.1016/j.precisioneng.2014.12.005, 241-248 (2015).

Tian X., Zhao J., Zhao J. et al., *Effect of Cutting Speed on Cutting Forces and Wear Mechanisms in High-Speed Face Milling of Inconel 718 with Sialon Ceramic Tools*, Int. J. Adv. Manuf. Technol. 69: 2669, online at doi:10.1007/s00170-013-5206-5214 (2013).

Thakur D.G., Ramamoorthy B., Vijayaraghavan L., *Some Investigations on High Speed Dry Machining of Aerospace Material Inconel 718 Using Multicoated Carbide Inserts*, Materials and Manufacturing Processes, Vol. **27**, *10*, online at http://dx.doi.org/10.1080/10426914.2011.654158 (2012).

Tu G., Wu S., Liu J., Long Y., Wang B., *Cutting Performance and Wear Mechanisms of Sialon Ceramic Cutting Tools at High Speed Dry Turning of Gray Cast Iron*, Int. Journal of Refractory Metals and Hard Materials 54, online at http://dx.doi.org/10.1016/j.ijrmhm.2015.08.007, 330-334 (2016).

Uhlmann E., Richarz S., Sammler F., Hufschmied R., *High Speed Cutting of Carbon Fibre Reinforced Plastics*, Procedia Manufacturing 6, online at doi: 10.1016/j.promfg.2016.11.015, 113-123 (2016).

van Hoof B., *Organizational Learning in Cleaner Production among Mexican Supply Networks*, J. Clean. Prod. 64, 115-124 (2014).

Wang B., Liu Z., Song Q., Wan Y., Shi Z., *Proper Selection of Cutting Parameters and Cutting Tool Angle to Lower the Specific Cutting Energy during High Speed Machining of 7050-T7451 Aluminum Alloy*, Journal of Cleaner Production 129, online at http://dx.doi.org/10.1016/j.jclepro.2016.04.071, 292-304 (2016).

Wang B., Liu Z., *Shear Localization Sensitivity Analysis for Johnson–Cook Constitutive Parameters on Serrated Chips in High Speed Machining of Ti6Al4V*, Simulation Modelling Practice and Theory 55, online at http://dx.doi.org/10.1016/j.simpat.2015.03.011, 63-76 (2015).

Wang W.-K., Lu W.-M., Wang S.-W., *The Impact of Environmental Expenditures on Performance in The U.S. Chemical Industry*, J. Clean. Prod. 64, 447-456 (2014).

Wang B., Liu Z., Su G., Song Q., Ai X., *Investigations of Critical Cutting Speed and Ductile-to-Brittle Transition Mechanism for Workpiece Material in Ultra-High Speed Machining*, International Journal of Mechanical Sciences 104, online at http://dx.doi.org/10.1016/j.ijmecsci.2015.10.004, 44-59 (2015).

Wu H., To S., *Serrated Chip Formation and Their Adiabatic Analysis by Using the Constitutive Model of Titanium Alloy in High Speed Cutting*, Journal of Alloys and Compounds 629, online at http://dx.doi.org/10.1016/j.jallcom.2014.12.230, 368-373 (2015).

Xie J., Luo M.J., Wu K.K., Yang L.F., Li D.H., *Experimental Study on Cutting Temperature and Cutting Force in Dry Turning of Titanium Alloy Using a Non-Coated Micro-Grooved Tool*, International Journal of Machine Tools & Manufacture 73, online at http://dx.doi.org/10.1016/j.ijmachtools.2013.05.006 , 25-36 (2013).

Xing Y., Deng J., Zhao J., Zhang G., Zhang K., *Cutting Performance and Wear Mechanism of Nanoscale and Microscale Textured Al2O3/TiC Ceramic Tools in Dry Cutting Of Hardened Steel*, Int. Journal of Refractory Metals and Hard Materials 43, online at http://dx.doi.org/10.1016/j.ijrmhm.2013.10.019, 46-58 (2014).

Yang H., Qing Z., Xie F., Zhang C., *Experiments on High-speed and Dry Cutting with PCBN Tool*, Key Engineering Materials Online: 2010-03-02, ISSN: 1662-9795, Vol. **431-432**, online at doi:10.4028/www.scientific.net/KEM.431-432.114, 114-117 (2010).

Zaghbani I., Songmene V., *A Force-Temperature Model Including a Constitutive Law for Dry High Speed Milling of Aluminium Alloys*, Journal of materials processing technology 209, online at www.elsevier.com/locate/jmatprotec, 2532-2544 (2009).

Zhang K., Liu Z., Wang Y., Liu Y., *Method of Strain-Rate Difference Calculation in High-Speed Metal Cutting*, Measurement 91, online at http://dx.doi.org/10.1016/j.measurement.2016.05.091, 474-478 (2016).

*** *The Fascinating World of Dry and Near-Dry Machining*, online at www.cnccookbook.com/CCDryMachining.html, accessed on 14th November 2016.

*** *The Benefits of Dry Machining*, online at www.theengineer.co.uk/the-benefits-of-dry-machining/, (2016), accessed on 14th November 2016.

PRELUCRAREA CU VITEZE RIDICATE ÎN CONDIȚII DE AȘCHIERE USCATĂ – O OPORTUNITATE A PRODUCȚIEI CURATE – SCURTĂ PREZENTARE

(Rezumat)

Lucrarea prezintă o scurtă descriere a ultimelor cercetări din domeniul prelucrării metalelor în condiții de așchiere uscată cu viteze ridicate, constând în studii cu privire la materialele pieselor prelucrate, scule așchietoare, metode și tehnici utilizate pentru investigarea fenomenelor care apar în timpul acestui tip de prelucrare. Rezultatele au arătat că acest domeniu de cercetare este în continuă dezvoltare, subliniind posibilitățile de a se ajunge la un tip de prelucrare prin așchiere prietenos cu mediul înconjurator.