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Influence of Lubricating on the Cutting Process in MQL Turning of Difficult-To-Cut Materials

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Abstract

The influence of lubricating and cooling process media of plant and animal nature on reducing the components of the cutting force and the area of contact of the tool with chips, in the process of turning titanium alloy and stainless steel has been experimentally established. It has been shown that the use of vegetable and animal fats in the initial period of cutting in combination with environmentally oriented minimum lubrication technology (MQL) favorably affect the increase in the contact pressure of the tool with chips, which in turn contributes to an increase in the density of dislocations and therefore hardening the contact layers of the tool.

Keywords: *Turning, Cutting Force, Vegetable Oil, Animal Fat.*

1. Introduction

A wide range of various methods of obtaining the end item can significantly reduce the production cost. Today, the share of use of edge cutting of materials is about 40% of the total labor intensity of manufacturing machine parts and is rarely implemented without the use of various lubricant-coolant process media (LCPM). However, the ecological side of the issue of using process media is attracting more and more attention due to the fact that the compositions traditionally used in production are made mainly from mineral oils, and as additives contain organic compounds of nitrogen, chlorine, phosphorus, and sulfur, decomposition products of which have carcinogenic and mutagenic properties, thereby causing damage to the environment and health of workers [1, 3, 5, 8, 10]. This aspect contributes to the development and implementation of advanced technologies aimed at improving the efficiency of the use of machining of materials and reducing the negative impact on the environment. The use of environmentally friendly LCPM, which include vegetable oils and animal fats, was previously limited due to the high cost of raw materials, as well as the difficulty of supplying animal fats to the cutting zone because of its relatively solid state of aggregation. Today, this task is solved by implementing an environmentally-oriented minimum quantity lubrication (MQL) Figure 1, whose principle of operation is to supply micro-doses of lubricant with a dosing device directly to the chip formation zone. The air-oil mixture (aerosol) is formed by mixing oil and compressed air in the nozzle of the device according to the Venturi principle. The rational area of application of the minimum quantity lubrication technology (MQL) (Table 1) regarding the "dry" cutting process depends on the tool material used and the type of machining [3].

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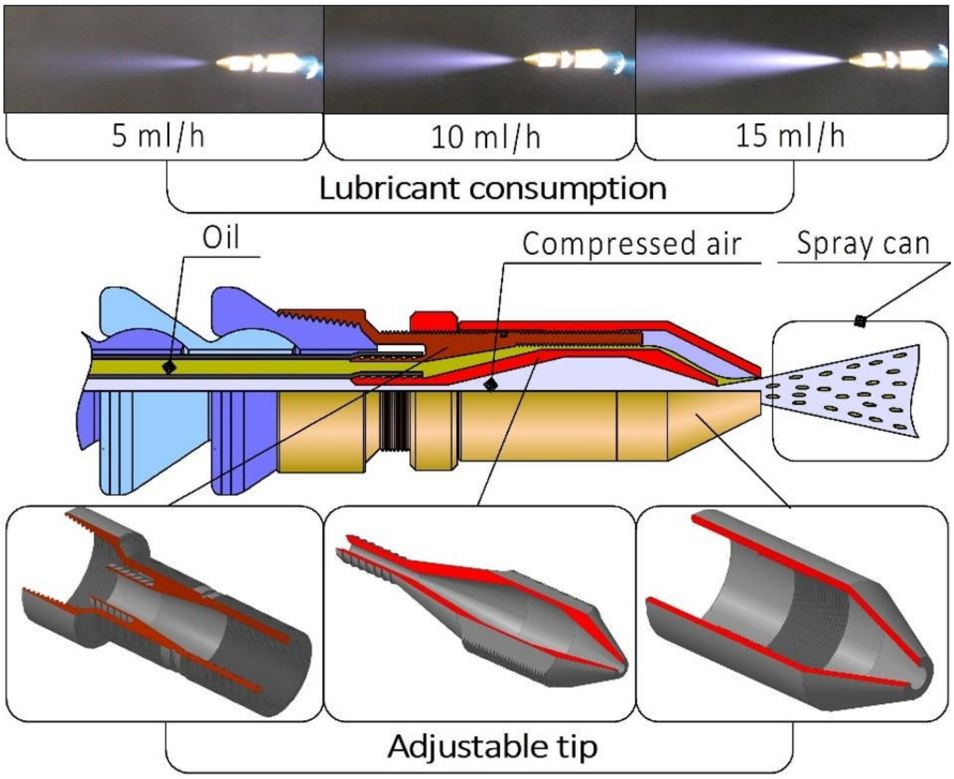


Figure 1. General view of the MQL dosing device

Table 1. MQL application

Type of tool material	MQL	Dry cutting
Tool steel	◨	—
High speed steel	▙	□
Hard alloy	▝	▙
Type of machining		
Turning	▘	▙
Face milling	—	■
Profile milling	▙	□
Drilling	▙	▘
Thread cutting	▙	□
■ - effectively	□ - not effective	

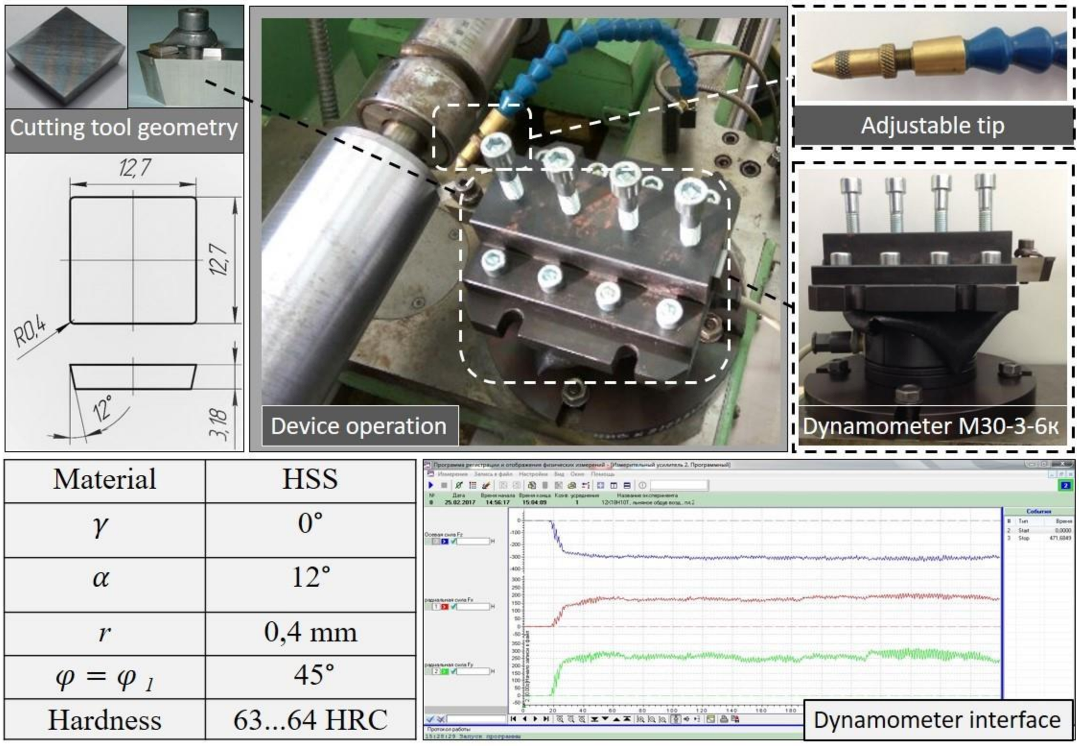
Despite the obvious advantages of using MQL technology in drilling and profile-milling operations regarding the traditional methods of applying LCPM, the study considered the turning process, which is "classical", as well as the most informative and methodically convenient, on the basis of which the main models of contact interaction of the cutting tool and the processed material are built, adapted further on other types of machining.

When using MQL technology, the washing and cooling properties of process liquids fade into the background, the lubricating effect of the LCPM becomes prevailing in this case, and the use of vegetable oils and animal fats is more pronounced in comparison with petroleum oils. Getting into the cutting zone, surface-active substances (SAS) that are part of the LCPM lead to a decrease in the length of contact between the tool and the chips, and as a consequence to an increase in specific normal loads [8]. Based on the analysis of literature data [1, 2, 3, 8, 9, 10], it has been established that under the conditions of using ecologically-friendly LCPM, with their characteristic higher penetrating, lubricating, shielding, and passivating properties, this effect is enhanced.

Based on the above, it can be concluded that under certain operating conditions (temperature in the cutting zone (200 ... 350 °C), specific pressure is more than 500 MPa), it is reasonable to expect hardening of the contact layers of the cutting tool [3, 8, 9]. The process of adaptation of the tool to external loading conditions is most actively manifested in the initial period of cutting (burn-in period), and in combination with the LCPM the burn-in effect increases. Experimental data presented [3, 8, 9] show that after the preliminary burn-in, the tool shows a significant increase in durability in further stationary cutting conditions, however, in the works under consideration, the tool was burned in the vegetable oil medium, and the use of animal fats by means of the MQL implementation was not considered. The purpose of this article is to study the effect of vegetable oils and animal fats on the components of the cutting force and the reduction in the length of the contact between the tool and the chips during the preliminary burn-in process.

2. Theory

Experimental studies were carried out on the turning operation. A straight turning tool with four-sided replaceable throwaway inserts made of HSS was used as a cutting tool. The study of the force parameters of the cutting process was carried out using a three-component dynamometer, model M-30-3-6k (Figure 2).



Material	HSS
γ	0°
α	12°
r	0,4 mm
$\varphi = \varphi_1$	45°
Hardness	63...64 HRC

Figure 1. Geometrical parameters of the cutting tool. Three-component dynamometer (M-30-3-6k)

The choice of materials to be processed consisted in the use of difficult-to-machine alloys, which differ in their physicochemical properties. Thus, in the process of research, a highly deformable, weakly oxidized alloy AISI 304 (analog of ASI 321) and a high-strength chemically active titanium alloy TI 6-4 (5,5Al-5Mo-5V-1Cr-1Fe) were used. The processing of these materials is accompanied by high contact pressures, which in turn will enhance the burn-in effect in combination with LCPM [3.8]. The use HSS tool from stems from the fact that this tool material has enhanced strength characteristics and the ability to withstand high dynamic loads.

The cutting conditions used in the burn-in process are significantly lower than the stationary ones and depend on the temperature state of the cutting edge. To ensure the required temperature in the cutting zone (200...350°C) [3,8,9] (burn-in mode), the dynamic thermocouple method is used, which allows recording the temperature directly on the contact areas [4]. So, for machining stainless steel AISI 304, the cutting speed was 10 m/min, for titanium alloy TI 6-4 - 7.2 m/min. Cutting depth and supply with a preliminary 7.5-minute cutting remained constant (f=0.2 mm/rev.; d=0.5 mm).

In the process of experimental studies, environmentally-friendly materials were used as process media: sunflower, rapeseed, linseed oils, and animal fats as well as industrial oil, which is the basis of many oil compositions and emulsions used in production, was chosen for comparison. The supply of LCPM to the cutting zone was carried out in the form of an air-oil mixture (aerosol) while implementing the MQL minimum quantity lubrication technology as well as by irrigation. The supply of animal fats was carried out using a specially designed installation (Figure 3), which allows supplying a lubricant in the form of an air-oil mixture by means of a rendering, as a result of which the flow rate of the process medium is significantly reduced and the supply of LCPM to the cutting zone is facilitated.

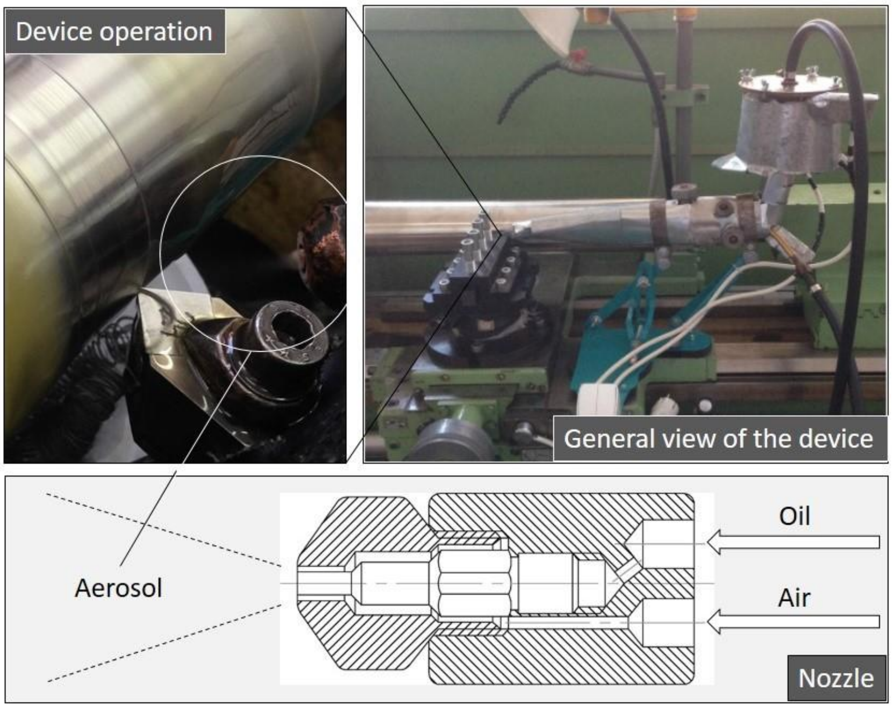


Figure 3. General view of the metering device for spraying animal fats into the cutting zone

Assessment of wear of the cutting tool was carried out according to the method of N.N. Zoreva [11]. The measurement of the length of plastic L_p and elastic L_e contact was made on an instrumentation measuring microscope ИМЦЛ 150 × 75 (2), Б (Figure 4).

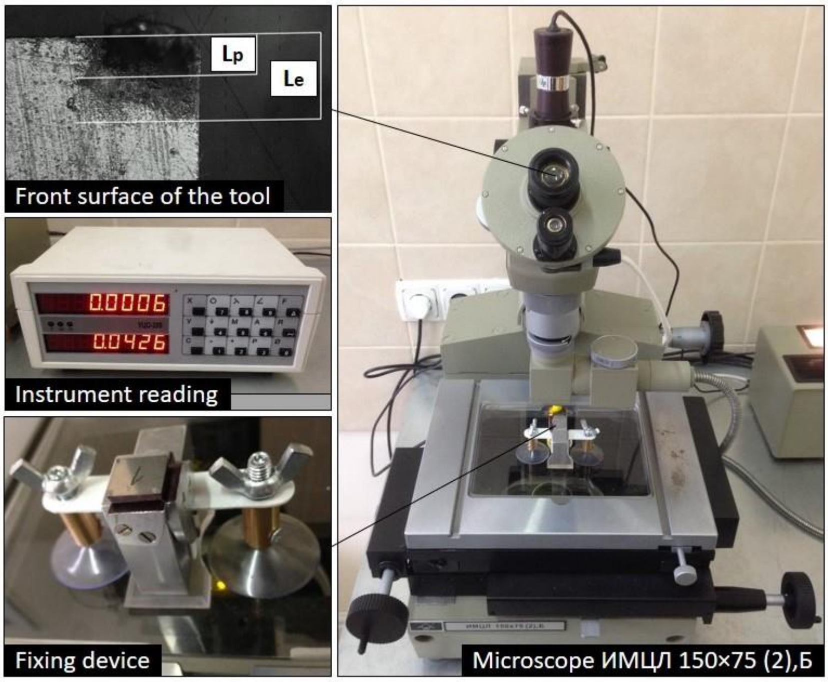
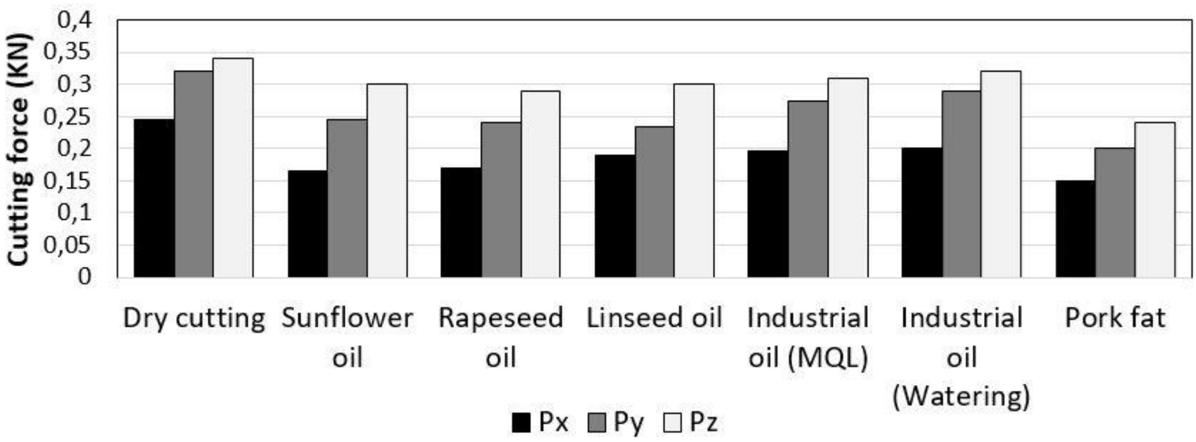


Figure 4. Measurement of zones of plastic and elastic contact (Lp and Le)

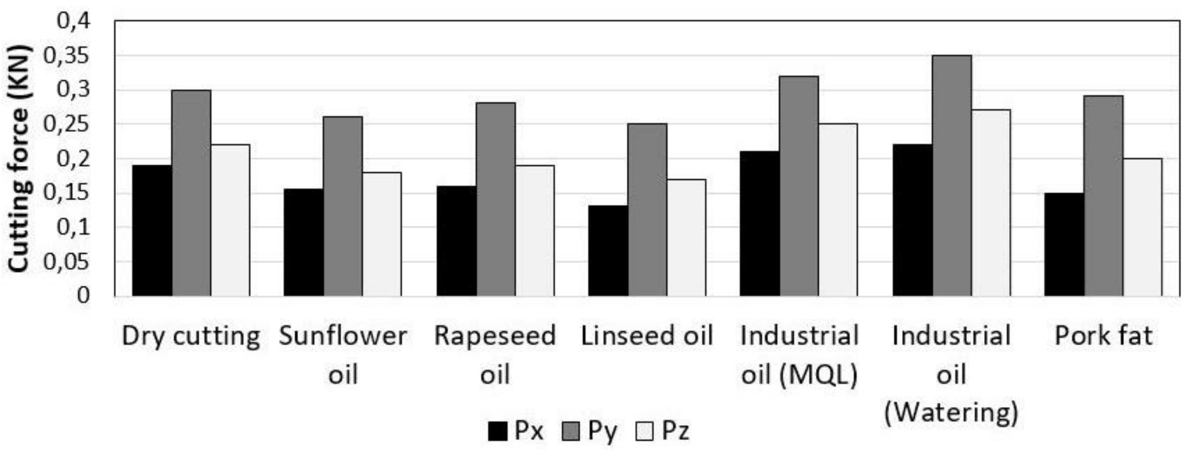
3. Results and Discussions

Experimental data on the effect of environmentally-friendly LCPM and mineral oil on the change in cutting forces and contact area (L_p and L_e) on the rake face of the cutting tool are shown in Figure 5, Figure 6, Figure 7 and Figure 8.



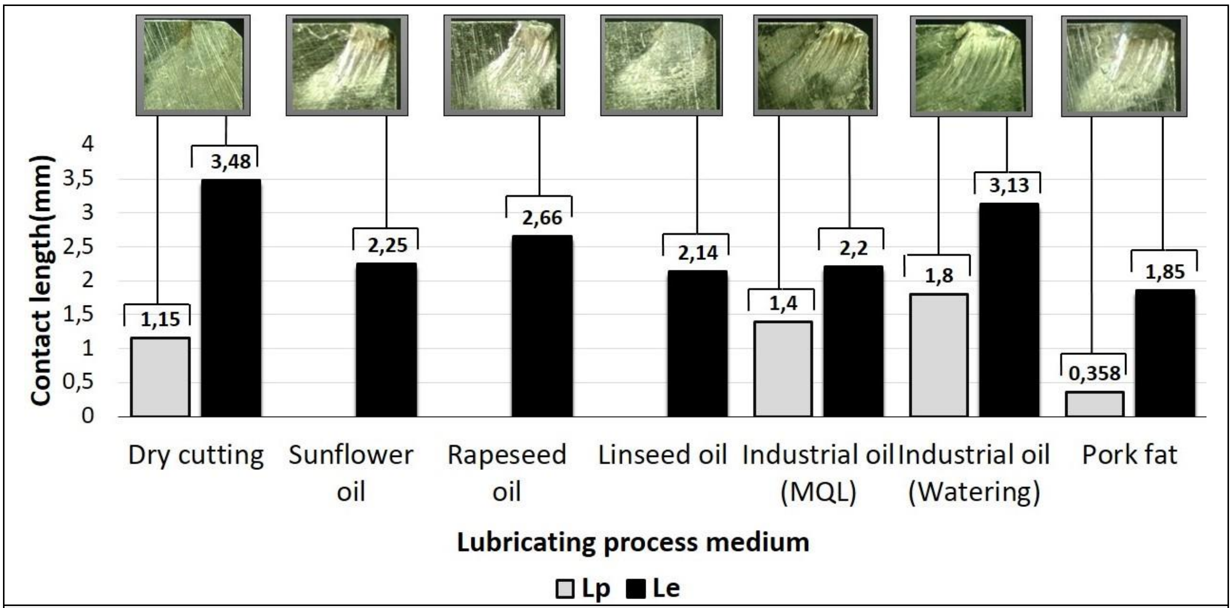
Process – Turning; **Tool type** – P6M5 (HSS); **Treated material** – AISI 304;
Cutting parameters: *Vc*=10 m/min; *f*=0.2 mm/rev.; *d*=0.5 mm; **Cutting time** – 7.5 min;
LCTM consumption – 15 ml/h.

Figure 5. Effect of vegetable and animal oils on the cutting force in the processing of stainless steel AISI 304



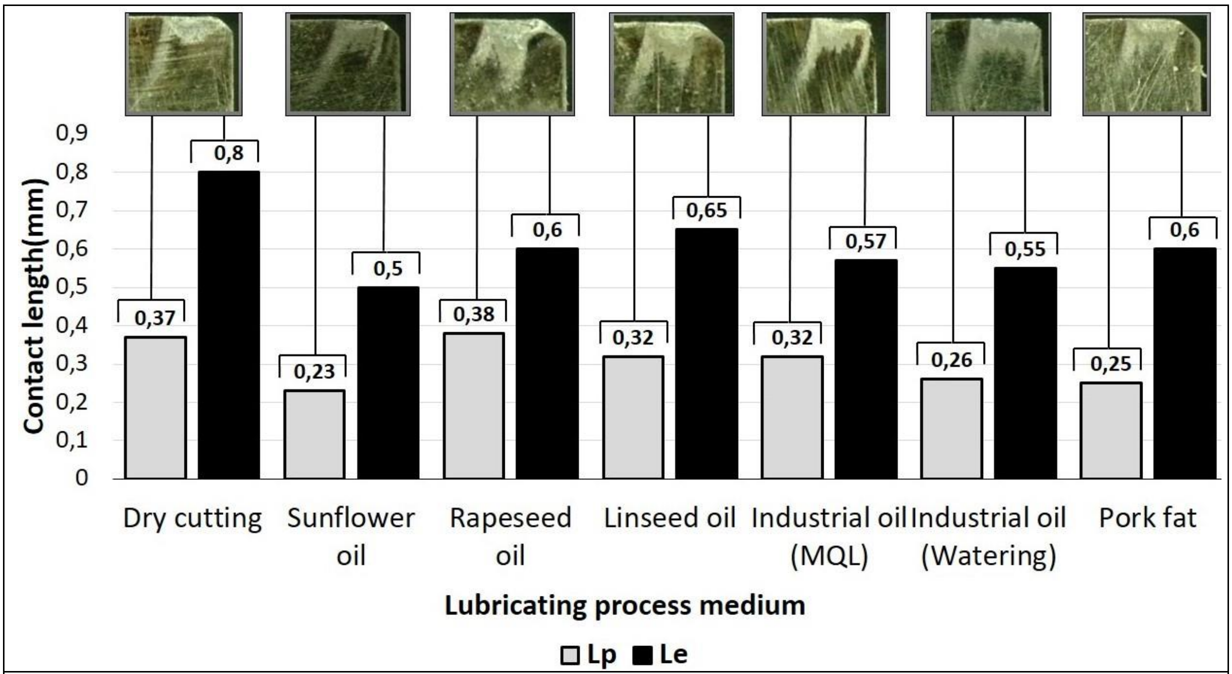
Process – Turning; **Tool type** – P6M5 (HSS); **Treated material** – TI 6-4;
Cutting parameters: *Vc*=7.2 m/min; *f*=0.2 mm/rev.; *d*=0.5 mm; **Cutting time** – 7.5 min;
LCTM consumption – 15 ml/h.

Figure 6. Effect of vegetable and animal oils on the cutting force in the processing of titanium alloy TI 6-4



Process – Turning; **Tool type** – P6M5 (HSS); **Treated material** – AISI 304;
Cutting parameters: *Vc*=10 m/min; *f*=0.2 mm/rev.; *d*=0.5 mm; **Cutting time** – 7.5 min;
LCTM consumption – 15 ml/h.

Figure 7. Effect of oils of plant and animal origin on the length of plastic and elastic contact (Lp and Le) when processing stainless steel AISI 304



Process – Turning; **Tool type** – P6M5 (HSS); **Treated material** – TI 6-4;
Cutting parameters: *Vc*=7.2 m/min; *f*=0.2 mm/rev.; *d*=0.5 mm; **Cutting time** – 7.5 min;
LCTM consumption – 15 ml/h.

Figure 8. Effect of oils of plant and animal origin on the length of plastic and elastic contact (Lp and Le) when processing titanium alloy TI 6-4

Analysis of the experimental data received shows a significant impact on the main indicators of the cutting process of vegetable oils supplied in the form of micro-doses in comparison with mineral oils supplied by the minimum quantity lubrication method and irrigation method.

The main type of wear while working with a high-speed tool is the adhesive and diffusive destruction of working surfaces. One way to combat this phenomenon can be to stimulate the hardening process of the working part of the tool by increasing the density of dislocations or reducing the size of wear particles [3]. The mechanism of action of LCPM during the cutting process is manifested due to the adsorption and chemical interaction of the medium with the material being processed and the cutting tool, while SAS present in the liquid actively interact with juvenile surfaces, saturating free vacancies and reducing growth.

When machining AISI 304 stainless steel, the readings of the cutting forces differed slightly, except for the use of animal oil, which significantly reduced the cutting force in P_x, which is most likely a result of a reduction in the length of plastic contact of the tool with chips compared to cutting without using LCPM.

In the process of cutting titanium alloy TI 6-4, the greatest effect was observed when using linseed oil. This can be explained by the fact that the presence of SAS in the form of fatty acids in the composition of vegetable oils and animal fats is one of the criteria for reducing cutting forces by increasing adsorption and, consequently, facilitating plastic deformations.

4. Conclusion

Lubricating-coolant process media, reducing the area of contact between tool and chips and increasing the level of normal stresses, increase the deformation processes on the working surfaces of the tool, causing in certain conditions the formation of contact layers with a hardened wear-resistant structure.

Vegetable oils and animal fats supplied with the help of MQL minimum quantity lubrication technology qualitatively affect the cutting process and are not inferior, and in some cases exceed, mineral oils supplied by free-falling jet.

Saturated and unsaturated fatty acids present in the composition of vegetable oils and animal fats act as SAS and contribute to more efficient penetration into the contact zone of the instrument at the atomic-dislocation level.

Thus, after the preliminary burn-in process of the cutting tool in the medium of vegetable oils and animal fats, it is legitimate to expect hardening of its contact layers, and therefore an increase in tool durability on further stationary cutting conditions.

The influence of lubricating and coolant process media (LCPM) of vegetable and animal nature on the components of the cutting forces and the area of contact of the tool with chips in the process of processing stainless steel AISI 304 and titanium alloy TI 6-4 was experimentally established.

It is shown that the use of vegetable oils and animal fats in the initial period of cutting in combination with the environmentally oriented minimum quantity lubrication technology (MQL) favorably affect the increase in the level of the contact pressure between tool and chips, which in turn contributes to an increase in the dislocation density and, consequently, to the hardening of the contact layers of the tool.

References

[1] Vereshchaka, A., Kirillov, A., & Vereshchaka, A. (2014). Technological system of environmentally safe cutting for turning. Journal Proceedings of the Kabardino - Balkarian State University, 5, 20-22.

[2] Naumov, A. (1999). Improving the efficiency of cutting with high-speed tools when using environmentally friendly LCTM. PhD thesis. Moscow.

[3] Yakubov, Ch. (2008). The hardening effect of LCTM during metal cutting. Simferopol.

[4] Mazur, N., Vnukov, Yu., & Grabchenko, A. (2013). Fundamentals of the theory of cutting materials. Khar'kov, NTU "KPI".

[5] Berdichevsky, E. (1984). Cooling lubricants for processing materials. Moscow, Mashinostroyeniye.

[6] Chubb, I., & Billenhen, I. (1980). Cooted cutting tools a study of wear mexanisms in high speed mashing, Journal Wear, 2, 283-293.

[7] Vinogradov, D. (2013) The use of lubricating and cooling technological tools for metal cutting. Moscow, Bauman Moscow State Technical University publishing house.

[8] Yakubov, Ch. (2004) Improving the wear resistance of high-speed tools through the directional transformation of their initial properties. PhD thesis. Khar'kov.

[9] Yakubov, F., Yakubov, Ch., & Skakun, V. (2016). Experimental assessment of the effectiveness of lubricating process fluids in the period of in-run of metal-cutting tools, Journal News of Tula State University, Technical science, 8, 246-253.

[10] Aliyev, A. (2011). Improving the performance of complex cutting tools through the use of technological media of plant origin. PhD thesis. Simferopol.

[11] Yakubov, Ch., Dzhemalyadinov, R., & Skakun, V. (2004). Improving material cutting by application of natural origin oil, MATEC Web of Conferences, 224(51):01130, 1-7