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Enhancing the reliability and wear resistance of high-speed cutting tools through the use of ionized air-oil lubrication media in machine part restoration

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Abstract

A comprehensive analysis of the wear processes of high-speed cutting tools and methods of improving their performance during machining has been carried out in this work. An analytical review of scientific sources on modern methods of supplying lubricating and cooling technological means (LCTM) was performed, including the activation of air and air–oil flows and their influence on friction and cutting processes. Special attention is given to the micro-dosed supply of industrial oil Mobil DTE 22 in the form of sprayed air–oil mixtures activated by the electric field of a corona discharge. A nozzle device for the metered supply of viscous fluids with subsequent activation of the air stream has been developed and investigated, ensuring reduced operating pressure and improved operational safety. A tribometric test stand was designed and used to study the lubricating ability of activated LCTM and to determine the friction coefficients of various materials. It was established that ionized air–oil media significantly reduce friction torque, stabilize contact interaction, and decrease surface roughness. Experimental studies of the cutting process demonstrated a substantial increase in the tool life of high-speed steel cutters when using ionized air–oil flow: up to three times compared with dry cutting and up to 2.5 times compared with free oil flooding. The application of the desirability function enabled a comprehensive evaluation of the effectiveness of different LCTM options, showing an increase in machining efficiency of up to 40%.

Keywords: ionized air–oil medium, lubricating and cooling technological means, corona discharge, tribological studies, tool life, micro-dosed oil supply, friction and wear, industrial oil Mobil DTE 22, cutting machining, activated media, surface roughness.

Introduction

Increasing the efficiency of mechanical engineering is inextricably linked to increasing the efficiency of metalworking and reducing the costs associated with the wear of metal-cutting tools. The wear resistance of cutting tools during turning operations largely depends on the used lubricating and cooling technological means (LCTM). In modern mechanical engineering, increased requirements are imposed not only on the functional, but also on the environmental properties of LCTM, since LCTM must not only increase the efficiency of the tool and the quality of the machined surface, but also must not have a technogenic impact on personnel and the environment [1]. In the manufacture of LCTM, they strive to reduce the amount of mineral oil and minimize, and sometimes even eliminate, some effective, but hazardous to health, inorganic and organic components of CTU. Currently, the method of supplying lubricating and cooling fluids (LCF) in the form of sprayed liquids, i.e. in the form of an air-liquid mixture, deserves special attention. However, sometimes the effectiveness of such LCFs is not sufficient. An additional method of increasing the efficiency of processing could be the activation of the environment by electric discharges. Currently, these methods of improving the processes of mechanical processing of materials are actively being developed for metalworking [2]. One of the ways to create environmentally friendly LCFs is to minimize the amount of required LCFs, in particular, this is achieved by introducing microdoses of the LCF air flow with its subsequent activation by electric discharges.

Literature review

Currently, there is no generally accepted theory that explains the numerous aspects of the mechanism of action of the LCF, no scientific principles have been developed for the synthesis and selection of the composition of effective LCFs. The LCF is selected mainly empirically based on the personal experience of specialists or based on the results of machine tests [3 – 5]. This method of selecting the optimal composition requires large time and material costs and guarantees the best results. The results of tests of different LCFs conducted with different tool and machined materials are difficult to compare. If when selecting tool materials it is enough to take into account two or three indicators, for example, such as heat resistance, hardness, then for LCFs these criteria have not been found. The study of complex and diverse processes occurring in the cutting zone is complicated by large temperature and pressure gradients in the surface layers of the tool and workpiece, high deformation rates. Increasing the technological efficiency of LCFs is a complex multi-criteria problem, and the chosen direction of research is relevant [6 – 9].

The choice of coolant for the development of workpiece processing technology is based on the specified technological, economic and operational parameters.

Technological parameters include:

• achieving the required machining accuracy, which is ensured by reducing cutting forces and friction in the contact zones of the workpiece and the tool, better placement of chips in the grooves of multi-toothed tools and better removal of chips and abrasive particles from the cutting zone, which helps reduce deformation of the workpiece and the tool;

• ensuring the specified quality of the machined surface: reducing its roughness, depth and intensity of hardening;

• reducing the intensity of dimensional wear of the tool.

The selection of LCF should be carried out taking into account the material being machined, the operation being performed, the requirements for the quality of the machined surface (roughness, microhardness, etc.), the material and geometry of the cutting tool, machining modes and the associated temperature in the cutting zone.

Research by famous scientists H.H. Zorev, A.I. Isaeva, A.Ya. Malkina, T.J. Burns, M.C. Shaw, K.J. Trigger, B. T. Chao, H. Kopp, Y. Kamata, S. Yamamoto, P. Marty etc. showed that the composition of the LCFs affects the process of surface layer formation and the amount of chip shrinkage [10 – 14]. Currently, a large number of works have been published on the study and implementation of mass-produced LCFs in certain machining operations. It is difficult to determine whether these compositions can be used in other metal cutting operations using other tool or workpiece materials. As a result of the analysis, it is concluded that the development and selection of LCFs for various metal cutting operations should be carried out on the basis of a fundamentally new approach that allows predicting the effectiveness of cutting fluids according to scientifically sound criteria. The use of LCTM in metalworking, as practice shows, has an effective effect on increasing the stability of tools. The physicochemical mechanism of action of LCTM is quite complex and is mainly due to a change in the conditions of interaction of the surfaces of the cutting wedge of the tool with the workpiece, which is expressed, first of all, in a change in the contact conditions. It is generally accepted that when cutting metals, chemically active surfaces of the tool and chips enter into a chemical reaction with the components of the LCTM, as a result of which protective films are formed that shield adhesion between the juvenile surfaces of the tool and the processed materials [15]. At the same time, the constantly increasing requirements for protecting the environment and service personnel from technogenic influences put the safety of LCTM and the ease of its disposal in the first place. Thus, the development of new LCTM compositions and methods of their supply to the cutting zone would improve the ecology of metalworking processes without worsening technological characteristics in comparison with traditionally used compositions of lubricating and cooling compositions [16 – 18]. The study of the mechanisms of influence of such LCTM on chip separation processes and tool stability is an urgent scientific problem. Analysis of the works of scientists M.I. Klushin, V.N. Latyshev, V.V. Podgorkova, R. Beckert, T. Moriwaki and others shows that currently the method of supplying LCF in the form of sprayed liquids, that is, in the form of an air-liquid mixture, deserves special attention [19 – 22].

The effectiveness of LCF is explained by the following features of this method:

- high speed of the jet of the air-liquid mixture provides a significant cooling effect;
- sharp increase in the surface activity of finely dispersed particles of the liquid, the possibility of air penetration into the contact zone of the rubbing surfaces of the tool, chips and the workpiece, some electrical phenomena associated with the electrification of liquid droplets in the jet of the air-liquid mixture, provide an increase in the lubricating effect of LCF;
- blowing the jet of the air-liquid mixture over the cutting zone helps to remove chips and wear products of the cutting tool from the cutting zone, in particular, from the chip grooves of the tool, providing a certain "washing" effect.

Purpose

The purpose of the research is to increase the efficiency of a high-speed cutting tool by using ionization of an air flow containing microdoses of industrial oil Mobil DTE 22, with a corona discharge of different polarity.

Research methodology

The air environment was activated by specially designed units using electrical discharges, with a modified nozzle that allowed for the measured delivery of viscous liquids to the cutting zone.

The unit operates as follows: air from the ionizer chamber enters an air-liquid channel, which passes through a reservoir containing liquid and exits through the diffuser section of the nozzle [23]. The air-liquid channel has an opening inside the reservoir through which the liquid enters, partially mixing with the air. This mixture then enters the diffuser section of the nozzle and is finally broken down by the main air flow, after which it is ionized. The flow rate of the supplied fluid is regulated by needle valves. In our case, this system was calibrated for the flow rate of industrial oil Mobil DTE 22, which ranged from 0.2 to 50 g/hour, in 0.2 g/hour increments [24].

Studies on the particle size of atomized industrial oil Mobil DTE 22 with an oil flow rate of 0.5 g/hour showed that in a non-ionized flow the particle sizes range from 15 to 25 µm, and when using ionization from 5 to 10 µm. To study the lubricating properties of LCTM and determine the friction coefficients of various metals in ionized air-oil environments, a tribometric rig was used [25]. This rig consists of a pendulum tribometer connected to a computer via an ADC. Friction is achieved using a disc-to-disc system. The operating principle of the setup is as follows: the sample is rotated by an electric motor through a gearbox, while the counterweight, attached to a free shaft with a pendulum, remains stationary. The resulting friction rotates the pendulum, and when the torques are equal, slippage begins. The friction torque is determined by the pendulum's angle of rotation. The measurement range is adjusted by varying the pendulum's mass and length. The load is generated by weights on a special platform. The tribometer allows the use of disks of different diameters and variable friction speed. To test the lubricity of ionized LCTM with microdoses of industrial oil Mobil DTE 22, disks with a diameter of 30 mm and a width of 5 mm were made of grade 45, 12Kh18N10T steel, AMg2 alloy, and VT1-0 titanium; the counterweight was made of grade 45 steel with 57 HRC. The contact patch was 2 mm², and the friction speed was 0.5 m/s. The LCTM was supplied through a nozzle at a flow rate of 0.2 – 1 g/h at different corona electrode voltages; comparisons were made with an oil bath. The surfaces were cleaned after each test.

Research results

Comparative studies of the tool life of cutting tools were conducted in positively and negatively ionized air environments with different potential values at the corona electrode, as well as with the introduction of nano- and microdoses of industrial oil Mobil DTE 22 (0.2, 0.5, and 1 g/hour) into the air flow, followed by ionization of the mixture. The effectiveness of various cutting fluid delivery methods and their impact on tool wear were determined by comparing the wear rate and tool life of cutters using pure industrial oil Mobil DTE 22 as the LCTM. During the experiments, wear on the rake and flank surfaces was recorded at regular intervals. The wear criterion was a chamfer width of 0.6 mm on the flank surface. As the results shown in Figures 1 – 2 show, an ionized air flow with microdoses of oil is significantly more effective than either a jet of oil or a non-ionized air-oil mixture at the same oil concentrations. It was also found that the results are significantly affected by the oil concentration, charge sign, and potential at the corona electrode.

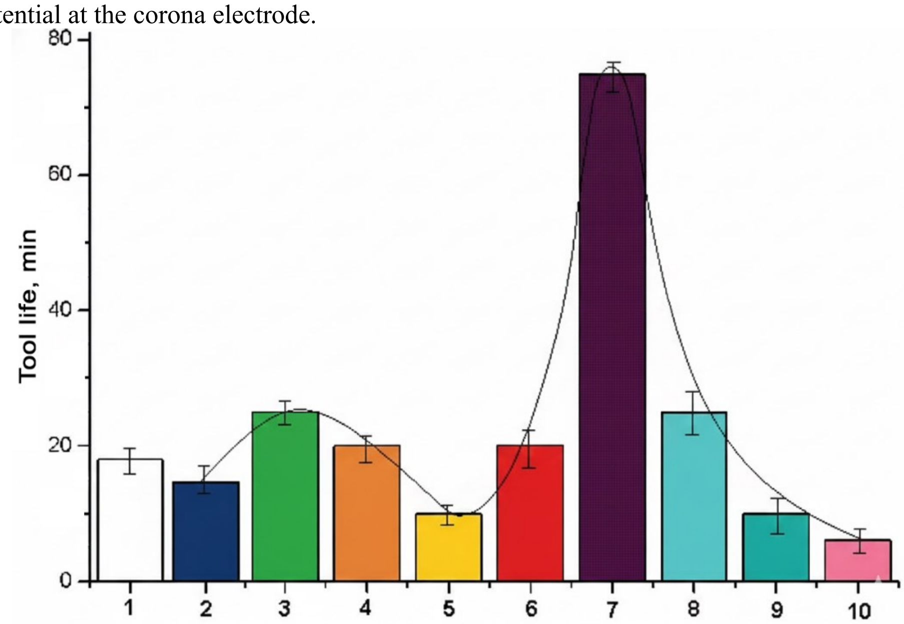

Fig. 1. The tool life of persistent cutters made of high-speed steel R6M5 when turning steel 45 with the introduction of industrial oil Mobil DTE 22 particles into the air flow at a rate of 0.2 g/h: 1 - free irrigation; 2 - blowing with industrial oil Mobil DTE 22 0.2 g/h; 3 - voltage on the electrode 5.5 kV; 4 - voltage 10 kV; 5 - voltage 14 kV; 6 - voltage -1.5 kV; 7 - voltage -3 kV; 8 - voltage -5 kV; 9 - voltage -8 kV; 10 - voltage -10 kV. V = 1.2 m/s, S = 0.1 mm/rev., t = 0.5 mm

For example, at low oil flow rates (approximately 0.2 g/hour), maximum tool wear resistance was observed with negative electrode polarity, while with positive polarity, wear resistance was comparable to that of a non-ionized air flow. Increasing the flow rate to 0.5 g/hour, tool wear resistance with positive and negative ionization became approximately the same, matching that of a non-ionized air-oil mixture [26]. A further increase in flow rate to 1 g/hour resulted in maximum tool performance being achieved with positive corona, while using negative ionization reduced wear resistance to the level of a non-ionized air flow.

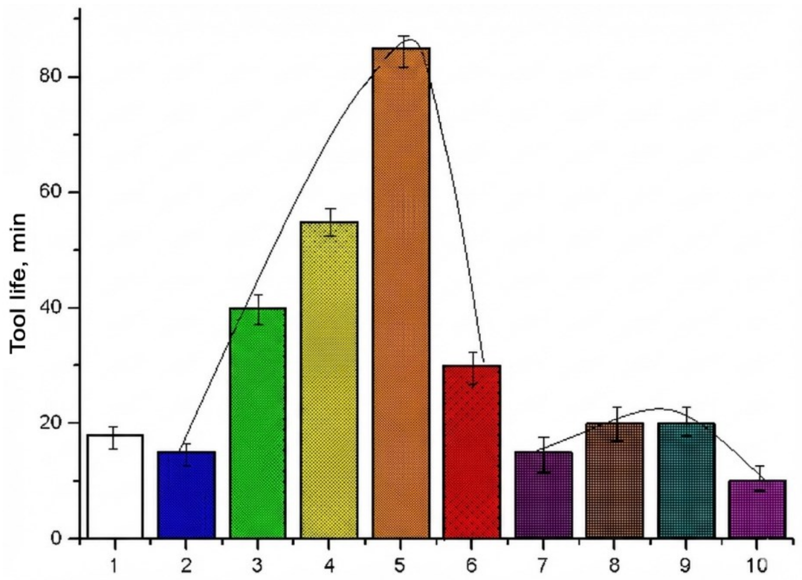

Fig. 2. The tool life of persistent cutters made of high-speed steel R6M5 when turning steel 45 with the introduction of industrial oil Mobil DTE 22 into the air flow at a flow rate of 1 g/h: 1 - free irrigation; 2 - oil blowing 1 g/h; 3 - voltage on the electrode 3 kV; 4 - voltage 5 kV; 5 - voltage 10 kV; 6 - voltage 14 kV; 7 - voltage -3 kV; 8 - voltage -5 kV; 9 - voltage -8 kV; 10 - voltage -10 kV. V = 1.2 m / s, S = 0.1 mm/rev., t = 0.5 mm

Experiments also revealed that, with the same potential sign, increasing the oil content in the air flow shifts the tool's maximum performance to higher potential values.

These data indicate the occurrence of complex, parallel physicochemical processes both in the plasma environment and in the tool-workpiece contact zone. We believe these processes are based on the transition of LCTM particles to an excited state, as well as the partial or complete decomposition of the mixture components in the corona discharge zone. The intensity and sequence of these processes depend significantly on the oil concentration in the air flow. At these potential values, the formation of new compounds is possible, the phase composition of which is determined by the content of the starting materials and the electric field strength around the corona electrode [27].

Studies examining the effect of corona discharge on the physicochemical properties of industrial oil Mobil DTE 22 showed that corona discharge, regardless of its polarity, leads to a decrease in the viscosity, surface tension, and contact angle of the oil. After the corona discharge ceases, the oil's physicomechanical properties are only partially restored [28].

Additionally, the parameters of secondary deformation zones, surface roughness, and chip shrinkage were studied. A summary of the best results is presented in Table 1.

Table 1

Tool life, surface roughness, and chip shrinkage under different treatment conditions

Processing mode	No.	Tool life, min	Surface roughness Ra, μm	Chip shrinkage coefficient, K
Dry machining	1	11	5.684	2.24
Ozone blowing	2	–	3.041	1.72
Air blowing with electrode voltage +10 kV	3	30	3.018	1.89
Air blowing with electrode voltage −9 kV	4	15	4.544	1.60
Oil mist 0.2 g/h, voltage +5.5 kV	5	26	3.770	1.57
Oil mist 0.2 g/h, voltage −3 kV	6	75	3.875	1.45
Oil mist 0.5 g/h, voltage +10 kV	7	30	2.926	1.34
Oil mist 0.5 g/h, voltage −8 kV	8	18	3.302	1.53
Oil mist 1 g/h, voltage +10 kV	9	63	2.821	1.62
Oil mist 1 g/h, voltage −5 kV	10	19	2.246	1.51
Oil flooding	11	18	3.523	1.49

As can be seen from the data in Table 1, the ionized air-oil flow not only positively impacts tool life but also reduces chip shrinkage and improves the roughness of the machined surface.

Conclusions

Using an ionized air stream with microdoses of industrial oil Mobil DTE 22 improves the performance of high-speed cutting tools during turning: up to three times compared to dry machining and up to 2.5 times compared to a free-falling oil jet.

Using an air-oil mixture as a LCTM reduces the average surface roughness Ra by 2.3 times compared to dry machining and by 1.6 times compared to using industrial oil jet.

The effectiveness of an ionized oil LCTM depends on the amount of oil in the stream and the voltage at the discharge electrode. It has been established that at a flow rate of 0.2 g/hour, the best effect is achieved with negative ionization, while at a flow rate of 1 g/hour, optimal results are achieved with positive ionization.

Feeding an ionized air-oil stream to the cutting zone increases the overall efficiency of machining by up to 40%, based on a comprehensive indicator.

The increased efficiency of the ionized air-oil environment is explained by its enhanced lubricating effect. Tribological studies have shown that it reduces the frictional moment of grade 45 steel by 0.75–1.5 times compared to friction in an oil bath and stabilizes contact processes.

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Марченко Д.Д., Матвєєва К.С., Лимар О.О., Курепін В.М. Підвищення надійності і стійкості швидкорізального інструменту шляхом використання іонізованих повітряно-оливних змащувальних середовищ при відновленні деталей машин

У роботі виконано комплексний аналіз процесів зношування швидкорізального інструменту та шляхів підвищення його працездатності під час механічної обробки. Проведено аналітичний огляд наукових джерел щодо сучасних методів подачі змащувально-охолоджувальних технологічних середовищ (ЗОТС), включаючи активацію повітряних та повітряно-оливних потоків і їхній вплив на процеси тертя та різання. Особливу увагу приділено мікродозованій подачі індустріальної оливи Mobil DTE 22 у вигляді розпилених повітряно-оливних сумішей, активованих електричним полем коронного розряду. Розроблено та досліджено сопловий пристрій для дозованої подачі в'язких рідин з подальшою активацією повітряного потоку, що забезпечує зниження робочого тиску та підвищення безпечності експлуатації. Створено та використано трибометричний стенд для вивчення змащувальної здатності активованих ЗОТС і визначення коефіцієнтів тертя різних матеріалів. Встановлено, що іонізоване повітряно-оливне середовище істотно знижує момент тертя, стабілізує контактну взаємодію та зменшує шорсткість поверхні. Експериментальні дослідження процесу різання показали значне підвищення стійкості різців із швидкорізальної сталі при використанні іонізованого повітряно-оливного потоку: до трьох разів порівняно з різанням «насухо» та до 2,5 раза – порівняно з вільним поливом оливи. Застосування функції бажаності дало змогу виконати комплексну оцінку ефективності різних варіантів ЗОТС, що показало підвищення ефективності обробки до 40%.

Ключові слова: іонізоване повітряно-оливне середовище, змащувально-охолоджувальне технологічне середовище, коронний розряд, трибологічні дослідження, стійкість інструменту, мікродозована подача оливи, тертя та зношування, індустріальна олива Mobil DTE 22, обробка різанням, активовані середовища, шорсткість поверхні.