Experimental evaluation of the efficiency of lubricating process media during the running-in period of a metal-cutting tool

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Abstract. The possibility of increasing the durability of a cutting insert made of high-speed steel with a wear-resistant TiN coating due to the use of lubricating process media during the running-in period of the cutting tool is considered. Based on the analysis of the data obtained, an analogy in the mechanisms of the hardening action of the refrigerant and wear-resistant coatings is presented. It is shown that the durability of a metal-cutting tool substantially depends on the initial conditions of its operation.

1. Problem statement
The development of mechanical engineering is inextricably linked with the intensification of the processes of blade machining of materials by cutting. Such processing volume accounts for up to 40% of the total labour intensity manufacturing machine parts, while the volume of dimensional processing is continuously increasing. Therefore, improving the performance of metal-cutting tools is an urgent scientific and practical task, the solution of which is related to the development and implementation in the industry of both traditional and the latest surface hardening technologies.

2. Materials and methods of research
Tools with wear-resistant coatings are increasingly used in the modern metalworking industry. The main role of the coating applied to the working surfaces of the tool is to increase the hardness, heat resistance, wear resistance, and physical and chemical passivity in relation to the processed material [1, 2]. At the same time, one of the generally accepted ways to increase the durability of a metal-cutting tool is still supplying lubricant cooling process media to the cutting zone, but due to the increase in auxiliary costs associated with transportation, storage, and subsequent disposal, the profitability of their use is significantly reduced. In addition, the widely used mineral-based industrial oils and emulsions are one of the main environmental pollutants and adversely affect the health of production personnel. Thus, in the global practice of metalworking, tendencies for the use of environmentally friendly vegetable oils and oil-based esters as process media have been identified [3–7]. The higher cost of such compounds can be offset by the implementation of an environmentally oriented minimum lubrication strategy (MMS-Minimal mengenschmierung or MQL-Minimum quantity lubrication) [8 - 11]. The essence of the method is that, with the help of modern highly
efficient dosing technology, the minimum amount of lubricant is purposefully fed into the chip formation zone, where it is consumed completely and without residue during processing. The latter means a sharp reduction in the consumption of process media, and as a result, a significant reduction in the technogenic impact on the environment, which is an important step towards harmonizing production processes and nature with a reduction in the cost of manufacturing finished products.

3. Statement of the main material

The supply of a lubricating medium to the cutting zone leads to a decrease in the total contact area on the front surface of the cutting tool, and as a result to an increase in specific normal loads [12, 13]. An analysis of the obtained experimental data showed that under the conditions of using process media based on vegetable oils (with characteristic higher penetrating, lubricating, shielding, and passivating properties), this effect is enhanced. Thus, under certain operating conditions of a high-speed steel cutting tool (pressures of more than 500 MPa and temperatures of 200 ... 350 °C), we can expect hardening of its contact layers [14]. The adaptation of the working surfaces of the tool to external loading conditions is most fully manifested in the initial period of cutting - its running-in period. This process is typical for the conditions defined above and, by analogy with the running-in of rubbing pairs, it shows a significant increase in resistance to further (stationary) operating conditions. The influence of lubricating process media on the change in the contact area along the front surface and the corresponding wear on the rear surface of the cutting tool are shown in the Table 1.

| Dry cutting without the use of cutting fluid | Emulsion 5 % | Cutting fluid | Industrial oil | Rapeseed oil | The method of supply and flow of cutting fluid |
|---------------------------------------------|--------------|---------------|----------------|--------------|---------------------------------------------|
| Watering the cutting fluid – 5 l/min        | MQL-45 ml/h  | MQL-15 ml/h   |                |              |                                            |

**Table 1.** The influence of lubricating process media on the change in the contact area along the front surface and the corresponding wear on the rear surface of the cutting tool.

![Image of chip contact area](image)

**Chip contact area**

![Image of tool flank wear](image)

**Tool flank wear**

The effectiveness of applying wear-resistant coatings, in terms of the impact on the performance of the tool, is well known [15 - 17]. As a rule, after 10 ... 15 minutes of cutting, a partial or complete destruction of the wear-resistant layer occurs. However, it is still not clear why the effect of increase of durability is expressed in a much longer time even after its destruction.
When explaining this fact, the points of view of researchers diverge significantly. In some works [18], the effect of increase in the durability of a cutting tool after coating destruction is preserved due to the positive contribution of a layer of double tungsten and cobalt carbide Co3W3C (η-phase) formed at the interface with the base (substrate). In others, it is mentioned that the η-phase does not significantly affect the maintenance of the effective operation of the cutting tool after erasing of the coating [19] and possibly even worsens the characteristics of the cutting insert. There are also hypotheses explaining this circumstance by the presence in the contact area of undisturbed (stored) foci of coating or runoff of coating sections to the bottom of the crater [20].

If we consider wear-resistant coatings as a kind of intermediate process medium between the tool and the material to be processed, then we can formulate the conditions under which, using the directed supply of an external tribactive medium, it is possible to control effectively the properties of the tool material, the characteristics of contact processes, chip formation, and, as a consequence, the tool wear rate.

In most cases, the base oils in composition of such a process medium are vegetable oils, the mechanism of action of which is aimed at increasing the durability of the cutting tool, but is still not fully disclosed.

Thus, the extension of the service life of the cutting tool after wear of the coating, one way or another, is associated with a change in the properties of the main material of the tool. A detailed determination of the mechanism of this technically important phenomenon today continues to be an urgent scientific problem.

The aim of the article is an experimental evaluation of the possibility of increasing the durability of a metal-cutting tool by using oil-based process media during its running-in period.

From the point of view of the experimental research methodology, the most convenient one is the turning process, on the basis of which models that are also used on other types of machining are built.

Durability studies were carried out on a high-precision screw-cutting lathe, SAMAT 400 M model. To ensure a constant cutting speed, the Altivar 71 frequency inverter was installed on the machine. Steel 45 and chromium-nickel alloy AISI 321 were machined with ISO SPUN120308 tool turning rotary inserts made from HSSE high-speed steel with a TiN wear-resistant coating and without coating.

The technical rapeseed oil and I-20A mineral industrial oil were chosen as process media.

In these studies, a special dosing device Noga Minicool MMS (Ave. Israel) was used. A general view and principle of operation are shown in Figure 1.

![Figure 1. Dosing device Noga Minicool MMS.](image)
The experiments were carried out at a constant cutting depth $t = 0.5 \text{ mm}$ and a supply $S = 0.2 \text{ mm/rev}$. The cutting speed was $v_C = 70 \text{ m/min}$ for steel 45 and $v_C = 30 \text{ m/min}$ for stainless steel AISI 321.

Measurements of the wear amount of wear were made on the rear surface using an instrumental measuring microscope IMCL 150x75(2), B. The criterion was the value $h_r = 0.35 \text{ mm}$ in the normal wear zone along the rear surface of the tool.

It is commonly known that the use of process media from the point of view of wear reduction is associated with a decrease in the work of friction and temperature, trying to maintain the original properties of the tool material. The results of experimental studies presented below reveal a fundamentally new mechanism of action of process media - the possibility of hardening of the contact layers of the tool and access to wear control through this functional property.

Let’s consider to which extent the influence of lubricating process media during the tool running-in period affects the durability of the metal-cutting tool during its further operation in the “dry” turning (without using process media). On the Fig. 2 and 3 summarize the results of durability tests of a cutter with a wear-resistant coating when turning steel 45 and AISI 321 after 7 minute cutting in a medium of mineral and rapeseed oils.

![Figure 2](image)

**Figure 2.** The durability of the cutter made of high-speed steel P6M5K5 with "dry" turning of steel 45 after preliminary running-in in the medium of mineral and rapeseed oils.

As expected, the presence of the coating significantly affects the wear rate of the cutting tool. So, when processing steel 45, the effect of increase in the durability is recorded by a twofold increase in comparison with an uncoated tool and threefold increase when processing stainless steel AISI 321. The greatest effect of wear reduction up to the accepted criterion $h_r = 0.35 \text{ mm}$ was found after preliminary 7 minute cutting in the selected process media: when processing steel 45 in a medium of mineral oil, and when processing stainless steel in a medium of technical rapeseed oil. After preliminary running-in, further operation of the cutting tool was carried out without the use of process media.

The obtained experimental data can be associated with the following circumstances. During turning, the cutting wedge is subjected to deformation loading. In the presence of a wear-resistant coating, as a result of the contact area reduction, the friction and temperature gradient over its thickness, the normal pressure on the substrate material increases, and the intensity of the heat flux...
decreases. This phenomenon can be likened to a decrease in cutting speed, in the limit corresponding to the range of running-in modes, in which contact layers of a hardened wear-resistant structure are formed on the surface of the tool in the presence of process media.

**Figure 3.** The durability of the cutter made of high-speed steel P6M5K5 with "dry" turning of AISI 321 after preliminary running-in in the medium of mineral and rapeseed oils.

Naturally, there should not be a full correspondence of the properties formed on the working surfaces of the tool, secondary structures during cutting in the preliminary running-in mode and substrate after the destruction of the coating. In the first case, the formation of secondary structures proceeds mainly due to deformation hardening (process media do not penetrate into plastic contact zone), in the second case, due to a combination of deformation and diffusion processes. Coating during the development of secondary structures is an active source of alloying elements and a stimulator of internal substructural mass transfer. Indeed, the diffusion activity strongly depends on deformation processes and the diffusion coefficient is directly proportional to the dislocation density. The implementation of the diffusing element from the coating into the instrumental matrix introduces additional distortion into the crystal structure, which, combined with an increasing density of dislocations, changes the parameters of the hardened layer relative to that formed under diffusion-free conditions. The formation of wear-resistant secondary structures in the surface layers of the tool by the method of preliminary running-in in the process media makes it possible to consider a wear-resistant coating as a highly effective (possibly ideal) lubricant.

4. **Conclusion**

Summarizing the aforesaid, it can be noted that the evaluation of the lubricating action of oil process media as a factor determining the hardening of tool contact layers in the running-in mode opens up new ways of their effective application as process media. On the one hand, taking into account a significant reduction in consumption when using dosing devices, the field of introduction of the environmentally friendly vegetable oils into the industry is expanding, on the other hand, a basis is being formed for modifying special running-in compositions, the operation of which will generally increase the durability of a metal-cutting tool.

5. **References**

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