Studying the function of the lifespan of carbide tools during turning of workpieces made of alloy 12H18N10T from the cooling properties of the cutting fluids

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Abstract. One of the main tasks of industrial production is to increase productivity and to reduce costs. When machining metal blanks, this is associated with an increase in cutting speed and a lifespan of the cutting tool. This work is devoted to the problem of increasing the turning tools lifespan in the stainless steel parts production. Extending the lifespan of the tool is achieved in various ways: the selection of an effective cutting tool with an optimal geometry, the assigning of rational cutting modes, the use of modern machine equipment and the supply of cutting fluids to the cutting zone. The least studied of these ways to increase the tool lifespan, and therefore relevant, is the selection of the optimal coolant. It is known that the lifespan is largely determined by the temperature in the cutting zone. The temperature depends not only on the geometry and material of the cutting blade, on the material being processed and on the cutting modes, but also on the cooling properties of the cutting fluid. The aim of this work is to study the dependency of the cutting tool resistance period while turning stainless steels on the cooling properties of coolant. To achieve this goal it is necessary to solve the following tasks: to conduct experimental studies of the cutting fluid effect on the tool life during stainless steel turning; to evaluate experimentally the cooling effect of the cutting fluids being tested; to establish the dependency of the turning tool lifespan on the parameters of the cutting fluid cooling effect.

Results: There were established the values of periods of carbide tools durability while turning blanks of stainless steel alloy 12X18H10T using various cutting fluids; using the developed unit there was carried out the evaluation of the cooling effects of the tested cutting fluids by the value of the maximum cooling rates of the temperature sensor; by the approximation method there was established the empirical dependency of the carbide cutting tool lifespan on the maximum cooling rate of the temperature sensor in the cutting fluid being tested. The calculation error according to the derived formula does not exceed 10%. The established dependency will make it possible to predict the value of the period of resistance of the cutting tool without carrying out machine tests.

1. Introduction

Processing of stainless steels is accompanied by high forces of friction and cutting, temperatures in the cutting zone, the appearance of a work-hardened layer on the surface of the part. This leads to an increase in the wear rate of the cutting plate and its frequent replacement [1] – [5]. Increasing of the cutting tool lifespan can be achieved through a reasonable selection of tools with cutting plates of wear-resistant alloy and the corresponding geometry of the cutting part. In addition, the tool lifespan increases with the use of appropriate machining modes and strategies [1], [6]. Another way to reduce the wear rate of the tool is to select the optimal cutting fluid (coolant) [7] – [9]. The latter is used quite rarely in production, since enterprises believe that the quality of parts and the durability of the cutting tool practically do not depend on the choice of the cutting fluid [10] – [13]. This opinion is erroneous, which is confirmed by the results of numerous studies of the cutting fluid effect on the cutting process of metals [14] – [16]. Thus, the aim of this work is to study the dependency of the cutting tool resistance period while turning stainless steels on the cooling properties of coolant.
2. Problem formulation
To date, the method of selecting a coolant that ensures the longest possible tool life under specific processing conditions does not exist. The selection of coolant based on wear-resistance tests is a laborious task, since it requires a lot of time and due to the cost of processed blanks and coolant. It is advisable to develop a methodology for the accelerated assessment of coolant that would predict the durability of the cutting tool according to the results of laboratory tests. In laboratory tests, the cutting fluid functional actions are evaluated with the use of specialized stands. One of the main functional actions of coolant that affect the durability of the tool is the cooling effect.

Thus, to achieve this goal it is necessary to solve the following tasks:
1. To conduct experimental studies of the coolant effect on the tool lifespan during stainless steel turning;
2. To evaluate while experimenting the cooling effect of the tested coolants;
3. To establish the dependency of the durability period of the turning tool on the parameters of the cooling effect of the cutting fluid.

3. Theory
The development of methods for the accelerated selection of coolant to increase the turning tools lifespan when machining stainless steel blanks requires the following studies:
1. Carrying out wear-resistance tests with various cutting fluids;
2. Carrying out laboratory tests of cutting fluids to assess their cooling effect.

These tests were carried out and published earlier [1], [17]. Later on, it is necessary to compare the obtained results and to establish the dependency of the durability period of the turning tool on the parameter of the cooling effect of the cutting fluid. Let us briefly review each test separately.

3.1. Methodology of wear-resistance tests
It is a well-known fact that water-based coolant, as compared to oil-based ones, has a high cooling and a sufficient lubricating effect; therefore, this type of coolant is most commonly used by industrial enterprises and has been applied in these studies. For the experimental evaluation there were used water-based cutting fluids of the following brands: Sinertek MX, Addinol WM440, Akvol-6, Sinertek DS.

At industrial enterprises the concentration of a coolant varies from 3% to 10%. For tests a concentration of 10% was taken in order to increase the reliability of the evaluation of the cutting fluid concentrate properties. In addition, the studies were conducted without use of the cutting fluid.

As a cutting tool, a cutter with a CNMG120404-MF1 cutting plate of hard alloy GC1115 from SECO TOOLS was used. Based on the recommendations [1], [18], [19] the following cutting modes were chosen: cutting speed 75 m/min, feed 0.1 mm/rev, cutting depth 0.15 mm.

As the material to be processed there was used one of the most common stainless alloys, 12X18H10T.

The tests were carried out on an IT-42 model lathe with the Маоk-600T CNC-system. The dimensions of the workpieces are the following: diameter 40 mm, length of processing 100 mm.

Experiments with each coolant were carried out until the difference between the measured and programmed diameters reached the specified value \( \Delta d = 0.1 \) mm. Thus, the value of the radial wear limit, which equals to half the difference in diameters \( \Delta d, h_r = 0.05 \) mm.

3.2. Methodology for evaluating the cutting fluid cooling properties
In order to evaluate the cutting fluid cooling properties, a patented stand was used in this work [20], which allows to mix coolant during the measurement process in order to reduce the formation of a steam jacket and to simulate the coolant flow process. The use of this stand allows you to simulate the conditions of metalworking, which reduces measurement errors.

According the data obtained, with the use of this stand graphs of the temperature \( T(°C) \) versus time \( t(s) \) were plotted. Next there were calculated the cooling rate \( V_{cool}, °C/s, \) of the temperature sensor as a derivative of the dependences obtained over time. Then graphs of temperature dependences of the temperature sensor on its cooling rate were plotted.
The cooling rate is a variable value, and therefore, as a parameter for evaluating the cooling effect of the cutting fluid, the maximum cooling rate was applied, $V_{cool,max}$, which makes it possible to evaluate the cutting fluid cooling properties at the initial moment of time.

4. Experimental results
According to the data obtained as a result of wear-resistance testing, graphs of the radial wear value of the cutting plate versus machining time without cutting fluid and using four tested cutting fluids are plotted (figure 1) [1].

![Figure 1. The dependency of the radial wear of the carbide cutting plate on time.](image)

The analysis of the plotted graphs showed that the period of wear-resistance of the cutting plate $T_{wr}$ was:
1. Using coolant Addinol WM440 $T_{wr} = 58$ min;
2. Using Sinertek MX $T_{wr} = 63$ min;
3. Using Akvol-6 $T_{wr} = 68$ min;
4. Using Sinertek DS $T_{wr} = 93$ min;
5. When processing without coolant $T_{wr} = 54$ min.

Thus, the longest period of durability of the cutting plate was achieved when the cutting fluid Sinertek DS was supplied to the cutting zone. The smallest tool lifespan corresponds to machining without the use of coolant. The worst coolant according to the period of wear-resistance of the cutting tool – Addinol WM440.

According to the results of research, it can be concluded that with the use of the most effective cutting fluid the period of tool lifespan increased by 1.72 times compared to the machining without coolant and 1.60 times compared to the least effective of the tested coolants – Addinol WM440.

According to the results of studies of the cutting fluid cooling effect, the following indicators of the maximum cooling rate were established (figure 2) [17]:
1. Addinol WM440 $- V_{cool,max} = 24.67^\circ C/s$;
2. Sinertek MX $- V_{cool,max} = 23.30^\circ C/s$;
3. Akvol-6 $- V_{cool,max} = 24.67^\circ C/s$;
4. Sinertek DS $V_{cool.max} = 24.02^\circ C/s$. 
5. Results discussion
According to the obtained results, it is necessary to establish the dependency according to which it would be possible to predict the cutting tool lifespan without carrying out machine tests. This will significantly reduce the time and all costs of testing, and will not require the use of machine equipment.

Therefore, it is necessary to establish the dependency of the cutting tool wear-resistance period $T_{wr}$ on the maximum cooling rate $V_{cool,max}$.

The definition of the dependence $T_{wr} = f(V_{cool,max})$ was performed in Microsoft Excel. Baseline data for the calculation are presented in Table 1.

**Table 1. Initial data for building graphs of dependency $T_{wr} = f(V_{cool,max})$.**

| Cutting fluid  | $T_{wr, min}$ | $V_{cool,max}$, °C/s |
|---------------|--------------|----------------------|
| Sinertek DS   | 93           | 24.02                |
| Addinol WM440 | 58           | 24.67                |
| Sinertek MX   | 63           | 23.30                |
| Akvol-6       | 68           | 24.67                |

To determine the dependency on the graph $T_{wr} = f(V_{cool,max})$ points were taken from Table 1 for each of the tested cutting fluids. Next, an approximating curve (trend line) was constructed (figure 3). In addition to the curve, the graph shows the formula for the dependency and the reliability value of the approximation $R^2$. From the proposed approximating curves, a polynomial curve of the second degree was chosen, which was distinguished by a high value of approximation reliability $R^2 = 0.92$.

Thus, the empirical dependency of the wear-resistance period of the cutting tool on the temperature sensor cooling rate in the tested cutting fluid was established. The dependency is expressed by the following formula:

$$T_{wr} = -64.134V_{cool,max}^2 + 3076.4V_{cool,max} - 36799. \quad (1)$$

The graph in Figure 3 shows that the dependency $T_{wr} = f(V_{cool,max})$ is nonlinear and has an extreme point. In addition, according to this graph, it is advisable to set the maximum and minimum values of $V_{cool,max}$ between which the wear-resistance period will exceed the resistance obtained without the use
of the cutting fluid. In this way, one can find the interval of the maximum cooling rate $V_{\text{cool,max}}$ within which the coolant will be effective over the tool lifespan period.

For this purpose, in formula (1), as the value of $T_{\text{wr}}$, the tool lifespan obtained without the application of cutting fluid was used: $T_{\text{wr}} = 54$ min.

Further, using the obtained expression, which is a quadratic equation, the values of $V_{\text{cool,max}}$ were calculated when the graph of dependency (1) intersected by $T_{\text{wr}} = 54$ min. As a result, the following limits of the interval were established, within which the application of coolant is effective over the tool wear-resistance period: $V_{\text{cool,max}} \in (23.20; 24.77), \, ^\circ \text{C/s}$. If the value of the maximum temperature sensor cooling rate belongs to this interval, the application of coolant provides increased durability of the cutting plate.

![Graph](image-url)  
**Figure 3.** The dependency of the radial wear of the carbide cutting plate on the maximum thermal sensor cooling rate.

Since the graph $T_{\text{wr}} = f(V_{\text{cool,max}})$ shows that it has an extremum, it is possible to set the optimal value of the maximum cooling rate at which the tool lifespan will be maximum.

In order to determine the inflection point, equation 1 was differentiated by the value of $V_{\text{cool,max}}$. As a result of finding the derivative, the following linear equation was obtained:

$$T_{\text{wr}}' = -128.268 \cdot V_{\text{cool,max}} + 3076.4.$$  \hspace{1cm} (2)

Equating the expression (2) to zero, the value of $V_{\text{cool,max}}$ equals to 23.98° C/s, at which the tool wear-resistance period is maximum and equals to 93.43 minutes.

The closest to maximum resistance period provides the application of the cutting fluid Sinertek DS.

Next, to estimate the relative error of calculations using formula 1, relative errors were determined as compared with experimental data using the following expression:

$$\varepsilon = \frac{|T_{\text{wrE}} - T_{\text{wrC}}|}{T_{\text{wrE}}} \cdot 100 \%,$$ \hspace{1cm} (3)

where $\varepsilon$ is the relative error of calculations, %;  
$T_{\text{wrE}}$ – the wear-resistance period of the cutting tool, obtained experimentally, min;  
$T_{\text{wrC}}$ – the wear-resistance period of the cutting tool, calculated by the formula 1, min.

The calculated relative errors are presented in Table 2.

| Table 2. Relative errors for calculating the tool wear-resistance period $T_{\text{wr}}$. |
Evaluating the Table 2, we can conclude that the calculation of the derived dependency gives an error within 10%, which corresponds to the permissible error for engineering calculations.

It should be noted that in case that the measured value of $V_{\text{cool,max}}$ is outside the established interval (23.20; 24.77)°C/s, the value of the calculated wear-resistance period is likely to have a high error, since these values were not used when receiving the expression (1). However, if at the same time the period of resistance obtained experimentally with a new brand of cutting fluid turns out to be less than the period of resistance obtained without the use of cutting fluid, then we can say that the calculations are correct.

6. Conclusion
Based on the results, the following conclusions were made:

1. It has been established that the use of the most effective cutting fluid will extend the lifespan of the cutting plate to 93 minutes, i.e., 1.72 times compared to the processing without coolant and 1.60 times compared to the worst cutting fluid tested – Addinol WM440.

2. The empirical dependency of the wear-resistance period $T_{\text{wr}}$ of a carbide cutting plate during turning of 12X18H10T stainless steel on the temperature sensor cooling rate $V_{\text{cool,max}}$ with the coolant used in cutting has been established. The dependency $T_{\text{wr}} = f(V_{\text{cool,max}})$ is non-linear and has an extreme point. The calculation error for this relationship does not exceed 10%.

3. According to the dependency graph $T_{\text{wr}} = f(V_{\text{cool,max}})$, the interval $V_{\text{cool,max}}$ (23.20; 24.77)°C/s is set, within which the application of cutting fluid is effective over the tool wear-resistance period compared to processing without the use of cutting fluid.

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