Optimization of cutting tool design by power and thermal parameters of machining process

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Abstract. The article presents the results of experimental studies to determine degree of influence angles of cutting wedge of end mill on force and thermal processes occurring in cutting zone. On the basis of the obtained data, the ways of reducing level of deformations thin-walled body parts made of aluminum alloys are considered. A comprehensive analysis of designation front angle of cutting tool was carried out in design at preproduction stage.

Products of many engineering and aircraft manufacturing enterprises include parts the quality and manufacturing precision of which directly affect the product’s performance. Some of them are thin-walled basic parts made of aluminum alloys, which are subject to high demands on dimensional accuracy, shape tolerances, and roughness [1, 2, 3]. These parts are characterized by low stiffness, which, together with vibrations and oscillations of the tool, leads to surface deformations and excess in their location tolerances.

Deformations of such parts are a consequence of the influence of technological internal stresses caused by power and thermal loads in the chip formation zone [4, 5]. Structural features of the cutting tool wedge are one of the factors determining the value of the arising loads.

The degree of influence of a cutter’s cutting angle on the force and temperature in the cutting zone is different. The front angle has a significant impact on the cutting process, and when it becomes bigger, the formation and shrinkage factor of facing, as well as friction force on the front surface of the tool increase, leading to an increase in the components of cutting forces [6]. In addition, the front angle of the tool affects the ability to remove heat from the cutting area. The main approach angle ϕ and the gradient of the main cutting edge λ have a smaller impact on power and thermal processes [7].

Selection of optimal values of the cutter’s front angle at the pre-production stage allows for given boundary conditions to establish its value, ensuring implementation of design requirements for thin-walled basic parts after their machining [8].

Thus, one of the urgent tasks to improve the manufacturing quality of thin-walled basic parts is to study the control action of the front angle size on the force and thermal parameters of the cutting process and to optimize the geometry of the cutter’s working surfaces according to the results.

The purpose of the study is to experimentally determine the degree of influence of the cutter’s front angle on the force and temperature in the cutting zone when machining thin-walled basic parts.
In the course of experimental studies, work was performed to measure the force and temperature in the cutting zone. Measurement of cutting forces was carried out using a specially developed software and hardware. The temperature measurement in the cutting zone was made using Raynger MX4 pyrometer. With the help of SDSHotFind 8 thermal imager, the picture of thermal processes arising during cutting was controlled [9]. The temperature measurement diagram is shown in Figure 1.

![Figure 1. Diagram of temperature measurement during cutting](image)

1 - workpiece; 2 - cutter; 3 - pyrometer; 4 - thermal imager

To determine the degree of influence of the front angle on the force and temperature in the cutting zone, experimental studies were performed using carbide end cutters Ø16 with the front angle of $\gamma = 3^\circ$, $\gamma = 10^\circ$, $\gamma = 20^\circ$, $\gamma = 30^\circ$.

Adjustment of the cutters used in the thermal cartridge is shown in Figure 2.

![Figure 2. End milling cutter in a thermal cartridge](image)
The results of experimental studies on the effect of the rake angle on the force in the cutting zone are shown in Figure 3.

Experimental data were processed using the least squares method. The processing results are shown in Figure 3 with a thin line.

![Figure 3. Dependence of the cutting force on the tool rake angle](image)

Analysis of the results shows that with an increase in the rake angle, the cutting force decreases. Thus, with an increase in the angle (from 10° to 20°, the cutting force decreased by 9%).

Influence of the rake angle on the tangential component of the cutting force is determined by the empirical dependence:

\[
P_z = 840 \cdot \gamma^{-0.08}
\]  

(1)

The results of experimental studies on the effect of the rake angle on the temperature in the cutting zone after mathematical processing in the form of a graphical dependence are shown in Figure 4.

![Figure 4. Dependence of cutting temperature on the rake angle of the tool](image)

The graphs clearly demonstrate that when machining with a tool with a larger rake angle, a lower cutting temperature occurs. The greatest reduction in the cutting force is observed in the area from
\( \gamma_1 = 10^\circ \) to \( \gamma_2 = 20^\circ \): with an increase in the rake angle by 1\(^{\circ}\), the cutting temperature decreases evenly.

Dependences of the cutting temperature on the rake angle are determined by the following expression:

\[
T = 246 \cdot \gamma^{-0.22}
\]  

Correction factors in expressions 1 and 2 are not given, since they were obtained in the conditions of a particular enterprise for internal use.

At the same time, an increase in the rake angle leads to a reduction in the cutting angle and worsens the heat sink conditions, which can adversely affect the cutter’s durability. In this regard, experimental studies of the effect of the rake angle value (on the cutting tool’s durability) were carried out. The results of experimental studies are shown in Figure 5.

Analysis of the results showed that in terms of achieving maximum durability, the most rational is the rake angle value in the range of about 18-22\(^{\circ}\).

According to the research results, empirical dependences of the rake angle effect on the force and temperature in the cutting zone are obtained, which clearly demonstrate that an increase in the rake angle of the end milling cutter leads to a decrease in the force and temperature in the cutting zone. The information obtained does not exhaust all work requirements on the optimization of geometry of end milling cutters, since it does not deal with issues of roughness of the machined surface and other equally important conditions necessary to ensure the process operation requirements [10]. Subject to the fulfillment of above-mentioned requirements, it is necessary to strive for the maximum value of the rake angle, limiting its value to the optimum tool durability.

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