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MODELING OF QUALITY PARAMETERS OF DRILLING HOLES IN DETAILS MADE FROM POLYMER CARBON PLASTIC

Composite materials are widely used in various fields of instrument and mechanical engineering. Composite materials are characterized by high strength, stiffness, corrosion resistance, low coefficient of thermal expansion, improved fatigue performance during operation, damage and impact, electrical insulation properties and anisotropy, which allows you to control the properties of the final product by changing the number of fibers, their orientation and the type of layer arrangement. Polymer composite materials with carbon fibers and a flexible epoxy resin matrix have become particularly widespread [1].

Despite the fact that most parts made of composite materials are manufactured without machining, but for critical structures, complete exclusion of machining is impossible. To obtain holes for fasteners, drilling is used, which is accompanied by the following defects: delamination, chips, shrinkage of the material and high roughness of the treated surface. This is due to such characteristics of the material as heterogeneity, anisotropy, the presence of highly abrasive and hard-reinforced fibers, the combination of hard abrasive fibers with a soft matrix [2].

The widespread use of composite materials requires increasing the efficiency of the drilling process and ensuring the necessary quality parameters of the machined surfaces, which is possible by determining the optimal cutting modes.

The machinability of composite materials can be analyzed using: axial cutting force, torque, roughness of the machined surface, hole delamination, the degree of uncut fibers and tool wearing out. These parameters are influenced by cutting modes (feed and speed), the properties of the workpiece material and the tool material. Intensification of these modes leads to an increase in cutting force, torque and increased tool wearing out. At the same time, a higher cutting speed allows for better hole quality. Roughness is one of the main characteristics in the drilling process of composite materials, which is used to analyze the quality of the machined surface by studying the micro-roughness of the surface of the detail. The value of this parameter is most often estimated by the parameters Ra and Rz.

The aim of the work is to model the quality parameters of the drilling process in details made from polymer composite materials for its optimization.

To implement the tasks of studying the quality of machined hole surfaces in polymer composite materials, drilling efficiency indicators were considered, since they affect the service life of composite parts. During the drilling of polymer composite materials, various defects can form, such as delamination, damage to the surface layer, high roughness of the machined surface, dimensional error and deviation from roundness.

Delamination is the most common defect in drilling composite materials. This quality parameter is divided into delamination at the entry of the cutting tool into the material and delamination at the exit from it. There are many ways to measure this parameter, but the most common is to use an optical microscope to assess its value.

There are several methods for estimating the delamination value around drilled holes. The most common characteristic of the delamination parameter in drilling composite materials is the delamination coefficient (K_{del}) proposed by Chen [3], which is determined by the formula:

$$K_{del} = \frac{D_{max}}{D}$$

where D_{max} is the maximum diameter of the hole with the damaged area; D is the nominal diameter of the hole.

To analyze delamination in composite materials, Ho-Cheng used a fracture mechanics approach [4]. Here, the critical axial force is presented, exceeding which leads to delamination of the hole surface. This parameter relates delamination to the properties of the composite material according to the following formula: critical

$$P_{crit} = \pi\sqrt{\frac{8G_{Ic}E_1h^3}{3(1-\upsilon_{12}^2)}},$$

where G_{Ic}– interlayer fracture toughness, J/m^2; E_1 – modulus of elasticity, N/m^2; h – thickness of the uncut layer of the workpiece, mm; υ_{12}– Poisson's ratio

To obtain mathematical dependences of the quality parameters of hole processing in composite materials, corresponding experimental studies were conducted.

When conducting experimental studies [5], carbon fiber with a carbon fiber content of 50% with an orientation of 0/90° was used as the processing material. The matrix material was epoxy resin LY564 and hardener HY 564 manufactured by Huntsman Co. The total thickness of the composite material was 8±0.1 mm and contained 32 layers with a thickness of 0.25 mm. The carbon fiber was manufactured using transfer molding technology (RTM - Resin Transfer Molding). The workpiece was a sheet of material 160 mm × 160 mm × 8 mm, which was cut into bars 20 mm wide for further processing.

The total thickness of the composite material was 8±0.1 mm and contained 32 layers with a thickness of 0.25 mm.

The holes were drilled on a vertical milling machine with a CNC SMG-300 with a maximum spindle speed of 5000 rpm. As a cutting tool, carbide drills with a diameter of 5 mm SANDVIK class ISO K20 were used.

The angles at the apex 2φ of the drills were 600, 1000 and 1400, they were formed by the grinding operation.

To measure the axial force signal, the workpiece was mounted on a four-component piezoelectric dynamometer Kistler 9272, which was fixed on the machine table. Experimental data were transmitted via the RS-232C data transfer interface using three Kistler 5070A amplifiers and processed on a PC using the corresponding

DynoWare software from Kistler. The surface roughness of the machined holes, according to the parameter Ra, was measured by the Perthometer M2 device. The value of the base length was 0.8 mm.

The value of the delamination coefficient was determined by photographing the drilled hole using a microscope with a 500-fold magnification, on which a camera was installed.

The maximum diameter of the hole was calculated by processing images using the Lab View v. 6 system.

The study of the hole drilling process with measurement of axial force and determination of its parameters was performed using an experimental plant [6].

The purpose of experimental research on the drilling process of carbon fiber parts is to study the influence of processing conditions and modes (feed, spindle speed and drill tip angle) on the parameters of carbon fiber drilling quality (layering coefficient and roughness of the machined surface) and axial cutting force. The processing modes during the research varied within the following limits: speed n – from 1250 to 4000 rpm and feed S – from 50 to 800 mm/min.

To process the results of experimental researches in order to obtain mathematical dependencies of the quality parameters of the machined hole surfaces, the method of group consideration of arguments (MGCA) was used [7].

Using the GMDH Shell DS software, which implements the advantages of MGCA, mathematical dependencies of the quality parameters on the number of drill rotation n, feed S and sharpening angle φ at the edge of the drill were obtained.

When obtaining the mathematical dependence of the axial force on the number of rotations, feed and angle at the edge of the drill P = f (n, S, φ), 25% of the initial data was used as a test sample to assess its accuracy. As a result, the following dependence was obtained with a coefficient of determination R^2 = 0.994 on the test sample:

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$$
\begin{aligned}
P &= 0{,}37403531 \cdot S + 0{,}80636969 \cdot \varphi - 0{,}042552536 \cdot n + \\
&+ 0{,}0025174804 \cdot S \cdot \varphi - 0{,}00011838289 \cdot S \cdot n - 0{,}00028640392 \cdot \varphi \cdot n - \\
&- 0{,}00000066437653 \cdot S \cdot \varphi^2 + 0{,}000000015512999 \cdot S \cdot n^2 + \\
&+ 0{,}000000037530623 \cdot \varphi \cdot n^2 + 0{,}000000075583524 \cdot \varphi^2 \cdot n - \\
&- 0{,}0001983767 \cdot \varphi^2 + 0{,}0000055761222 \cdot n^2 - 9{,}9045321e - 12 \cdot \varphi^2 \cdot n^2 - \\
&- 2{,}7554812e - 14 \cdot S \cdot \varphi^2 \cdot n^2 - 0{,}00000079678736 \cdot S \cdot \varphi \cdot n + \\
&+ 1{,}0441172e - 10 \cdot S \cdot \varphi \cdot n^2 + 2{,}1027644e - 10 \cdot S \cdot \varphi^2 \cdot n + 99{,}778598
\end{aligned}
$$

Since it is practically impossible to measure the value of the delamination coefficient during the machining process, it is proposed to determine this parameter by an indirect method - by measuring the axial force. For this purpose, the dependence

$K_{del} = f(P)$ was obtained, which allows determining the value of the delamination of the hole in the processed material by the value of the axial cutting force. A similar approach is also proposed to be performed to determine the roughness of the hole surface.

To obtain the analytical dependence $K_{crit} = f(P)$, polynomial regression was used:

$$K_{crit} = 3{,}7813353\text{e-}06P^2 - 0{,}0005009418P + 1{,}0600$$

Using the SPSS Statistics software, an analytical dependence was obtained that best describes the statistical data. It was determined that the power form of the regression equation most accurately approximates the dependence with a coefficient of determination $R^2 = 0.7419$.

$$Ra = 0{,}0898P^{0{,}5064}$$

It is found that the roughness of the machined surface of the holes increases with increasing feed and decreases with increasing drill speed. In addition, by comparing these graphs, it can be concluded that the angle at the edge of the tool does not have a clearly defined effect on the Ra parameter.

The developed mathematical dependencies of the hole surface quality parameters (delamination and roughness) are convenient to use for predicting these parameters when drilling holes in carbon fiber parts and as a constraint in the general mathematical model of the drilling process when solving the optimization issue. At the same time, these mathematical dependencies are adequate for the following machining modes: number of rotations n – from 1250 to 4000 rpm and feed S – from 50 to 800 mm/min.

According to the results of experimental studies, it can be concluded that the values of the axial force and the delamination coefficient can be minimized at high spindle speeds and reduced feed values.

However, modern production is focused not only on the quality of the finished product, but also on its manufacture with the lowest possible costs in the shortest possible time and in accordance with the specified quality indicators.

With adequate mathematical models of the parameters of the drilling holes process in carbon fiber parts, it is possible to determine the influence of cutting modes and conditions on the stability of the cutting process and establish optimal values of modes that provide the necessary dynamic properties.

Optimization of the conditions and modes of machining of composite materials involves solving various technological, structural, economic and organizational tasks. For this purpose, the following optimality criteria are used: the criterion of minimum cost; the criterion of maximum efficiency (productivity), which ensures the minimization of the time spent on machining; the criteria of quality and accuracy of machining, etc.

According to the results of modeling the parameters of the process of drilling holes and carbon fiber parts, the following conclusions can be drawn.

1. As a result of the analysis of the drilling holes process in carbon fiber parts, it was established that the criterion parameters of the quality of the process are the delamination coefficient and the roughness of the machined surfaces, which can be determined by the magnitude of the axial cutting force.

2. A scheme of the installation for conducting experimental research is proposed, which allows obtaining the necessary information for creating mathematical models of quality parameters when drilling holes.

3. As a result of processing the experimental research data, mathematical dependences of the axial force, the delamination coefficient and the roughness of the treated surface on the cutting modes and conditions were obtained, which allow to form a mathematical model of the drilling holes process in carbon fiber.

4. The developed mathematical model of the drilling holes process in carbon fiber details makes it possible to solve the problem of optimizing cutting modes, which ensures obtaining the specified quality parameters of the obtained surfaces with the highest productivity.

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