Проведено експериментальні дослідження акустичної емісії при зростанні глибини обробки композиту. Встановлено, що зростання глибини обробки приводить до зростання статистичних амплітудних параметрів акустичної емісії. Визначені закономірності зростання амплітудних параметрів акустичної емісії. Встановлена чутливість амплітудних параметрів сигналів акустичної емісії. Показано, що найбільший приріст має дисперсія середнього рівня амплітуди реєстрованих сигналів

Ключові слова: акустична емісія, композиційний матеріал, амплітуда сигналу, механічна обробка, статистичні характеристики, глибина різання

Проведены экспериментальные исследования акустической эмиссии при возрастании глубины обработки композита. Установлено, что возрастание глубины обработки приводит к увеличению статистических амплитудных параметров акустической эмиссии. Определены закономерности возрастания амплитудных параметров акустической эмиссии. Установлена чувствительность амплитудных параметров сигналов акустической эмиссии. Показано, что наибольший прирост имеет дисперсия среднего уровня амплитуды регистрируемых сигналов

Ключевые слова: акустическая эмиссия, композиционный материал, амплитуда сигнала, механическая обработка, статистические характеристики, глубина резания

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ANALYSIS OF ACOUSTIC EMISSION AMPLITUDE PARAMETERS WHEN INCREASING THE MACHINING DEPTH OF A COMPOSITE

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1. Introduction

In order to control technological processes during machining of composite materials (CM), the research is conducted using the method of acoustic emission (AE). The research is predetermined by low inertia and high sensitivity of AE to the processes of deformation and destruction of the surface layers of the treated material. These advantages of the method are of particular importance to control, monitor and manage technological processes of CM machining using neural networks.

Research results show that using AE makes it possible to receive significant amounts of information about the processes of deformation and destruction of the CM surface layers. In this case, information is not static. A continuous change in the parameters of registered signals is observed. This is due to a change in the conditions of interaction between a pair of materials – treated and the one that treats. In addition, studies show that acoustical radiation is influenced by various factors. Such factors are: parameters of technological process of CM machining, physical-mechanical characteristics of CM, wear of the machining tools. Presence of the impact factors leads to the problem of the interpretation of the registered information.

The solution to the problem of interpretation of the registered information is based on the theoretical studies into AE. Modeling the AE for the dominant destruction mechanism of the surface layer and the prevailing impact factor makes it possible to explore the character and parameters of acoustic radiation. This refers first of all to determining the sensitivity and the expected patterns of change in the AE parameters. At the same time, experimental regularities are not only the confirmation of theoretical results. Such regularities are the basis when solving the problem on the design of criteria and methods of control, monitoring and management of technological process in the CM machining. This problem is of particular importance for the robotized technologies of the CM machining.

2. Literature review and problem statement

Studies of AE during materials treatment, including CM, cover practically all operations of machining – turning, milling, drilling, grinding, and others. Paper [1] demonstrates the use of AE method to examine condition of the machining tools when turning a variety of materials, including CM. In this case, authors consider methods for processing registered AE signals. To reduce uncertainty in the interpretation of AE (evaluation of wear of machining tools), article [2] investigates the principles and algorithm of AE signal processing during a turning operation. The proposed algorithm of data processing ensures the possibility to monitor and automate processes to achieve the specified quality of the products. An analysis of different research methods, including the AE method, when machining different materials (turning, milling, drilling) was performed in [3]. It was noted that the AE method could be used for optimizing machining parameters, as well as to identify condition of the treated surface and cutting tools (wear and destruction). The application of the AE method to control a technological process of machining is considered in article [4]. In this case, it was pointed out that AE could be used in order to monitor damage to the tool and the treated surface. The strategy of applying AE to control a technological process of drilling the composite is examined in [5]. The algorithm for strategy implementation is based on the fact of relationship between the AE energy and the parameters of technological process. The magnitude of AE energy is also linked to the stratification of the treated material. The results received make it possible to optimize parameters of the technological process. The AE application in a polishing operation is shown in [6]. It was noted that the evaluation of surface roughness in the technological process of machining represented significant difficulties. At the same time, processing and analysis of AE parameters make it possible to track and control roughness.

The studies that are being conducted cover a wide range of issues that relate to the analysis of influence of different technological factors, as well as cutting tool wear, on the parameters of acoustic radiation. In order to find the influence of various factors on acoustic radiation, a wide range of AE parameters is under examination. These parameters include: signal spectrum [4, 7], maximal signal amplitude [7], mean or root-mean-square value (RMSV) of signal amplitude [8], signal energy [9], statistical parameters of amplitude distributions of signals [10] and others.

One of the technological parameters is the CM machining depth. Paper [7] showed that increasing the depth of machining leads to a nonlinear growth in the AE signal amplitude. However, the rate of increase in the AE signal amplitude (character of change in the patterns) with increasing cutting depth greatly depends on the speed of material machining. Article [10] explored the effect of technological parameters of machining on AE. It was shown that an increase in the cutting depth at other technological parameters being constant led to a complex character of change in the mean and RMSV of AE signal amplitudes, as well as in their standard deviation. Such character of change is demonstrated by such statistical parameters of the AE signal amplitude distribution as a coefficient of asymmetry and a coefficient of kurtosis. One observes increasing and decreasing values of the analyzed parameters, which does not allow their mathematical notation. Paper [11] noted that an increase in the depth of CM machining for the assigned magnitudes of cutting speed and the speed of longitudinal feed of the cutter generally leads to an increase in the RMSV of AE signal amplitudes. However, the magnitude of such increase in the RMSV of signal amplitudes is negligible. In this case, depending on the speed of machining there is a modification of the obtained relationships. It was established in article [12] that with increasing depth of machining a nonlinear increase occurred in the RMSV of AE signal amplitude. At the same time, a linear increase in the AE signal amplitude RMSV was shown in paper [13]. The complex nature of change in the AE signal amplitude RMSV with increasing depth of CM machining was also demonstrated in article [14]. In this case, it was noted that increasing the cutting depth exerted a weak impact on AE.

In line with model [15], articles [16, 17] report the results of theoretical study into amplitude and energy parameters of AE at a change in the depth of CM machining. The AE model was considered at a dominating mechanical destruction of the surface layer of the treated composite. Simulation results of AE showed that an increase in the CM machining depth led to an increase in the amplitude and energy of AE signals, as well as the magnitudes of their spread. It was determined that an increase in the depth of machining led to the increased statistical amplitude and energy parameters of AE (the mean levels of amplitude and energy, their standard deviations and variances). In this case, the mean levels of amplitude and energy, as well as the standard deviations, increase in a linear manner. At the same time, an increase in the variances of the mean level of amplitude and energy of AE signals is described by nonlinear functions. It was also shown that at an increase in the depth of machining, the increment of variances in the mean level of amplitude and energy outperforms the gain in their mean levels and standard deviations.

Articles [16, 17] derived theoretical patterns that could be used to develop methods for control and diagnosis of technological processes in the CM machining. To ensure reliability of the developed methods, it is required to conduct experimental studies to determine experimentally the regularities of AE signals parameter changes with increasing depth of CM machining. There are no doubts that such studies are not of only scientific, but also of practical interest.

3. Research goal and objectives

The goal of present work is to undertake experimental research into the influence of CM machining depth on parameters of the AE registered signals. This will make it possible to identify the regularities of impact of a composite machining depth on AE, required to monitor, control and manage the depth of machining.

To accomplish the goal, the following tasks have been set:

– to carry out experimental studies of the AE amplitude parameters at increasing depth of CM machining;

– to process statistically parameters of the AE experimental signals to derive data on statistical amplitude characteristics;

– to determine experimental patterns of change in the AE statistical amplitude parameters at increasing the depth of CM machining;

– to determine the sensitivity of AE statistical amplitude parameters to an increase in the depth of CM machining.

4. Methods and procedure for experimental studies of parameters of acoustic emission signals

The study into experimental AE signals and patterns of change in their parameters was conducted during turning an aluminium-based CM. General schematic of the installation for conducting the research is shown in Fig. 1.

A CM workpiece, which was exposed to machining, represented a cylindrical sample. The original workpiece diameter was 72.4 mm, length of the treated surface was 165 mm. CM machining was performed in the screw-cutting lathe. We used as a machining tool the plate CD10 with an inclusion made of PCD (polycrystalline artificial diamond, which has an average grain size). The research was conducted at the following values of machining technological parameters: cutting speed – 200 m/min, longitudinal feed tool speed – 0.1 mm/rev, initial machining depth – 0.1 mm. Machining depth varied from 0.1 mm to 0.3 mm in a 0.05 mm step.

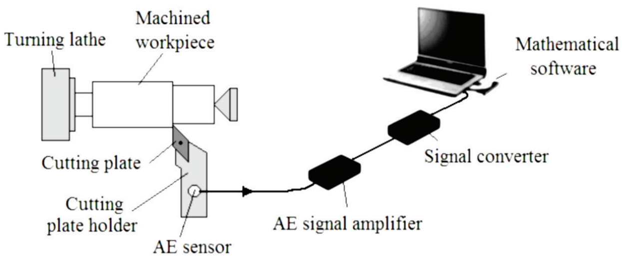


Fig. 1. Schematic of the installation for experimental studies into acoustic emission during machining a composite

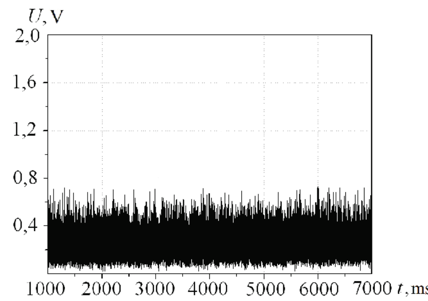
We used a piezoceramic sensor to register the AE signals. The AE sensor was mounted on the machining plate holder (Fig. 1). In order to ensure an acoustic contact, the AE sensor surface was lubricated with an acoustic transparent lubricant of the «Ramsay» type. The AE sensor output signal was amplified and arrived to the input of a signal converter (Fig. 1). The signal converter output was connected to the USB input of the computer (Fig. 1). Conversion frequency amplitude of the AE analog signal into a digital code was 100 kHz. Sensitivity of the signal converter was 2.44 mV per unit of low order. Measurement and processing of parameters of the AE signals was performed under control of the specialized mathematical software.

Research procedure involved the following. A CM workpiece was placed in the screw-cutting lathe. Preliminary machining of the workpiece was carried out in order to eliminate beats and ensure its coaxiality. We assigned the initial depth of CM machining and the turning operation was performed. Simulnaneously with the machining, the AE signals were recorded into computer. Upon completion of the turning operation, the processing of the recorded process was carried out with the formation of data arrays. The CM cutting depth increment was executed and we conducted repeated machining of the workpiece with the recording, processing of the AE signals and the formation of data arrays. The given procedure was performed for all depths of CM machining.

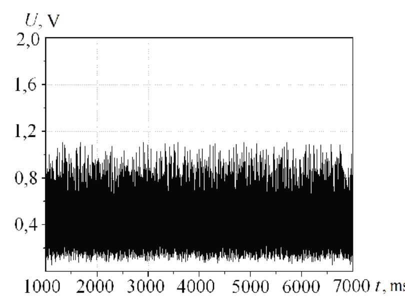
The generated data sets were used for carrying out secondary processing. We built dependences of change in the amplitude of the registered AE signals over time. Data processing was performed with determining statistical amplitude parameters of AE for each cutting depth. We conducted the approximation of change patterns in the statistical amplitude parameters of AE and ran an analysis of their sensitivity to the depth of CM machining.

5. Study of amplitude parameters of acoustic emission signals

Fig. 2 shows the fragments of experimental dependences of change in the amplitude of the AE registered signals over time for different depths of machining the workpiece made of CM. Fig. 2 shows that the registered AE signals are continuous signals. An increasing in the depth of CM machining leads to a higher mean level of amplitude and the magnitude of its variability. Statistical data processing revealed that at the initial depth of CM machining of 0.1 mm, the mean level of the registered AE signal amplitude, its standard deviation and variance are, respectively, $\bar{U}$=0.26753 V; $s_{\bar{U}}$=0.07954 V; $s_{\bar{U}}^2$=0.00633 V^2. With an increase in the depth of machining to 0.15 mm, the mean level of amplitude of the registered AE signal, its standard deviation and variance increase, respectively, by 1.124 times, by 1.159 times, and by 1.315 times. If the depth of machining is 0.2 mm, the statistical amplitude parameters of AE signal $\bar{U}$, $s_{\bar{U}}$ and $s_{\bar{U}}^2$ grow, respectively, by 1.383 times, by 1.395 times, and by 1.946 times. At a CM machining depth of 0.25 mm, the statistical amplitude parameters of AE signal $\bar{U}$, $s_{\bar{U}}$ and $s_{\bar{U}}^2$ increase, respectively, by 1.601 times, by 1.647 times, and by 2.712 times. If the depth of CM machining increases to 0.3 mm, the statistical amplitude parameters of AE signal $\bar{U}$, $s_{\bar{U}}$ and $s_{\bar{U}}^2$ grow, respectively, by 2.066 times, by 2.124 times, and by 4.507 times.



a



b

Fig. 2. Dependences of change in the amplitude of the recorded AE signals over time at CM machining. Machining depth: *a* – 0.15 mm; *b* – 0.25 mm

Values of statistical amplitude parameters of the recorded AE signals at increasing depth of machining are given in Table 1. Fig. 3 shows dependences of change in the statistical amplitude parameters of AE signals with increasing depth of CM machining.

Table 1

Statistical amplitude parameters of AE signals with increasing depth of CM machining

Machining depth, mm	$\bar{U}$, V	$s_{\bar{U}}$, V	$s_{\bar{U}}^2$, V^2
0.1	0.26753	0.07954	0.00633
0.15	0.30068	0.09124	0.00832
0.2	0.37018	0.11098	0.01232
0.25	0.42838	0.13101	0.01716
0.3	0.55276	0.1689	0.02853

The approximation of dependences (Fig. 3) revealed that they were well described by the functions of type

$$A_U = ab^z, \tag{1}$$

where A_U is the statistical amplitude parameter of AE; z is the depth of CM machining; a and b are the coefficients of approximating expression.

The values of coefficients a and b of the approximating expression (1) are equal to: for the mean level of AE signal amplitude – a=0.174, b=43.677; for the standard deviation of the mean level of AE signal amplitude – a=0.05131, b=49.444; for the variance of the mean level of AE signal amplitude – a=0.00238, b=3628.597.

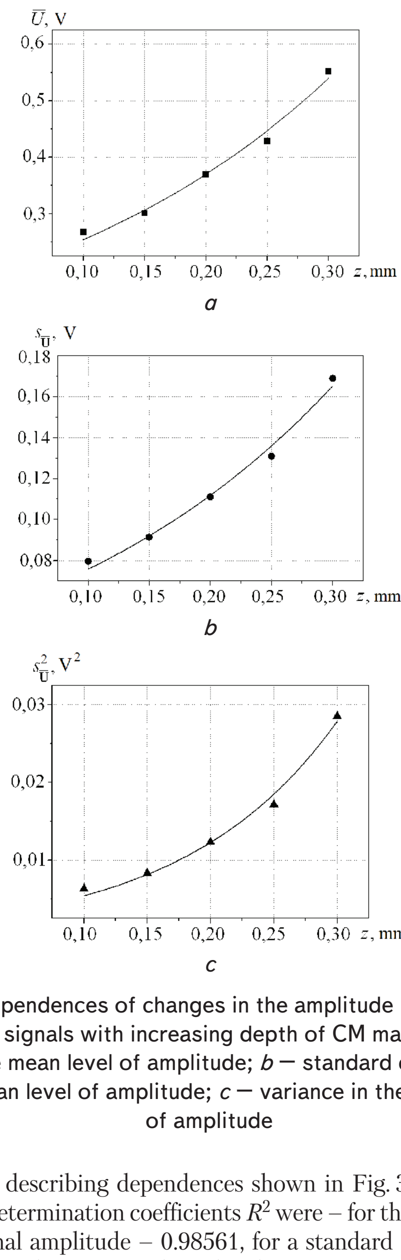


Fig. 3. Dependences of changes in the amplitude parameters of AE signals with increasing depth of CM machining: *a* — the mean level of amplitude; *b* — standard deviation of the mean level of amplitude; *c* — variance in the mean level of amplitude

When describing dependences shown in Fig. 3 by expression (1), determination coefficients R^2 were – for the mean level of AE signal amplitude – 0.98561, for a standard deviation of the mean level of AE signal amplitude – 0.98922, for a variance in the mean level of AE signal amplitude – 0.99015. Selection criteria for the approximating function (1) when describing dependences in Fig. 3 was the minimum of residual variance.

In order to determine the sensitivity and informativeness of amplitude parameters of the signals, we shall calculate their values gain with increasing depth of CM machining. Dependences of per cent growth of statistical amplitude parameters of AE signals relative to the initial machining depth of 0.1 mm are shown in Fig. 4. The following designations are accepted in Fig. 4: ΔA – percentage increase in the mean level of AE signal amplitude, or in the standard deviation of the mean level of AE signal amplitude, or in the variance of the mean level of AE signal amplitude; z – depth of CM machining.

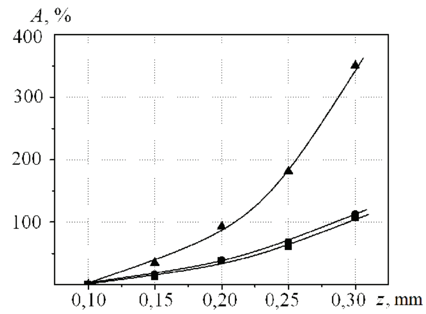


Fig. 4. Charts of percent increase in the mean level of AE signal amplitude $\bar{U}$ (■), its standard deviation $s_{\bar{U}}$ (●) and variance $s^2_{\bar{U}}$ (▲) depending on the depth (z) of CM machining

The results received show (Fig. 4) that at increasing the depth of CM machining an increase in the variance of the mean level of the AE registered signal amplitude outgoes an increase in the mean level of amplitude and its standard deviation.

6. Discussion of results of the study of influence of cutting depth on the amplitude parameters of acoustic emission

Results of the performed experimental studies have shown that during CM machining the registered AE signals are continuous signals. They have a strongly fragmented shape. Increasing the depth of CM machining when other technological parameters remain constant does not affect the character of acoustic radiation. The result obtained is consistent with experimental data [4, 12, 14], as well as with the results of theoretical studies [16, 17].

Studies have shown that increasing the depth of CM machining led to a higher mean level of amplitude and the magnitude of its spread. In a general case, this trend of a change in the amplitude (RMSV) is noted in a number of experimental papers [11, 13] and is in a good agreement with the results of theoretical studies [16, 17]. The obtained experimental regularities of change in the statistical amplitude parameters of AE signals are stable. They are described well by non-linear functions. A nonlinear increase in the statistical amplitude parameters of AE is consistent with some experimental data and theoretical results on a change in the variance of the mean level of AE signals. However, the character of change regularities in the mean level of amplitude and its standard deviation in the experiment and theoretical studies does vary. This is predetermined by the fact that during simulation it was believed that the thickness of the layer to be destroyed was a constant magnitude. In this case, one considered increasing a destruction area, which was considered to be proportional to the cutting depth. Under actual conditions, there is an increase in the deformed and destroyed material whose magnitude is probably non-linear.

The existence of stable patterns of change in the statistical amplitude parameters of the registered AE signals makes it possible to determine their sensitivity to increasing the depth of CM machining. Research results showed that with an increase in the cutting depth the percentage increase in the variance of the mean level of AE signals amplitude outpaces the percentage increase in the mean level ofamplitude and the magnitude of its standard deviation. Indeed, at an increase in the depth of CM machining from 0.1 mm to 0.25 mm, the percentage increase in the mean level of AE signal amplitude $\bar{U}$, its standard deviation $s_{\bar{U}}$ and variance $s_{\bar{U}}^2$ is, respectively, 60.12 %, 64.71 %, and 171.15 %. With increasing depth of CM machining from 0.1 mm to 0.3 mm, the percent increase in the mean level of AE signal amplitude $\bar{U}$, its standard deviation $s_{\bar{U}}$ and variance $s_{\bar{U}}^2$ amounts to, respectively, 106.61 %, 112.35 %, and 350.67 %.

It follows from the results received that the most sensitive and informative amplitude parameter of the registered AE signals to the increase in the depth of CM machining is the variance of the mean level of AE signal amplitude.

The obtained regularities could be used when monitoring, controlling and managing the machining depth of CM of a certain type. However, in order to generalize the results, it is necessary to investigate the sensitivity of energy parameters of AE as well as change patterns in the AE amplitude-energy parameters for composite materials with different structure. As shown by theoretical studies, physical-mechanical characteristics of CM is the factor that affects the parameters of AE. Therefore, when generalizing the results of effect of depth of machining CM with different structure on AE, it should be carried out according to a percentage increase in the parameters of the registered AE signals.

7. Conclusions

1. The dependences are derived of a change in the AE signal amplitude over time when changing the depth of CM machining, which showed that the AE signals were continuous signals with a highly fragmented shape. An increase in the machining depth leads to an increase in the mean level of amplitude and the magnitude of its variability.

2. We performed calculations and obtained values of statistical amplitude parameters of AE signals with increasing machining depth – the mean level of amplitude, its standard deviation and variance.

3. The data approximation was carried out, based on which we derived mathematical notation for the regularities of change in the statistical amplitude parameters of AE with increasing machining depth. It was determined that when machining depth increases, dependences of increase in the mean level of amplitude, its standard deviation and variance are described well by power functions.

4. We establsihed sensitivity and informativeness of statistical amplitude parameters of AE to the CM cutting depth. At an increase in the cutting depth by 3 times, the variance of the mean level of amplitude outgoes by larger than 2 times the increase in the mean level of amplitude and standard deviation.

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STUDY OF THE PROCESS OF SHAPE-FORMATION OF RIBBED DOUBLE-CURVATURE PANELS BY LOCAL DEFORMING

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Розглянуто особливості отримання панелей подвійної кривизни з нерегулярною внутрішньою структурою з використанням перспективного технологічного процесу формоутворення місцевим згинанням з посадкою (розведенням). Наведено опис обладнання і методика розрахунку необхідної кількості місцевих впливів для отримання панелей необхідних форми і розмірів. Проведено експериментальне дослідження точності одержуваних розмірів шляхом порівняння вимірів висот точок формованої панелі з розрахунковими значеннями координат панелі

Ключові слова: подвійна кривизна, нерегулярна внутрішня структура, посадка, пластична деформація, прогин

Рассмотрены особенности получения панелей двойной кривизны с нерегулярной внутренней структурой с использованием перспективного технологического процесса формообразования местной гибкой с посадкой (разводкой). Приведены описание применяемого оборудования и методика расчета необходимого количества местных воздействий для получения панелей требуемых формы и размеров. Проведено экспериментальное исследование точности получаемых размеров путем сравнения замеров высот точек формованной панели с расчетными значениями координат панели

Ключевые слова: двойная кривизна, нерегулярная внутренняя структура, посадка, пластическая деформация, прогиб

1. Introduction

Ribbed panels made in one piece are used in aircraft construction and shipbuilding. They are called monolithic panels. Such panels are obtained most often by rolling or pressing in a flat form. To form panels according to the contour of the product, straightening and refinement of the panel shape, shot peening, free local bending, rolling and other processes