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THE CONNECTION OF ACOUSTIC EMISSION WITH A PROPERTIES DISPERSION OF COMPOSITE MATERIAL MACHINING

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Abstract. *The results of acoustic emission signals modeling during the composite materials machining for the mechanical model of material's surface layer destruction in dependence of its properties dispersion is considered. It is shown that variation of composite materials disperse properties does not effect on the nature of acoustic emission. The influence of composite materials disperse properties on acoustic emission amplitude parameters is determined. It is show that with global increase of acoustic emission amplitude parameters the variance of the average level of the resultant acoustic emission signal amplitude has the highest sensitivity.*

Keywords: acoustic emission; composite material; resultant signal; amplitude; machining; surface layer destruction

1. Introduction

The quality of parts that are produce with the machining of composite materials (CM) is affect by many factors, namely parameters of technological processes and CM characteristics. The presence of influencing factors stipulates a wide range of researches of CM machining using different methods. Research focuses on optimization of CM machining parameters and elaboration the methods of their control, diagnostics and monitoring.

In the study of CM machining a method of acoustic emission (AE) is widely used. It has a high sensitivity and low inertia to the inside processes, that occurring in the material during its deformation and destruction at the micro and macro levels. This allows carrying out the control of changes in the conditions of CM surface layer destruction. At this time, the results of studies show that the registered AE signals are affect by many factors. They are technological factors (parameters of CM machining) and properties of treated and treating materials. Given the dynamics of the processes of deformation and fracture of CM surface layer, research of influence of various factors and their contribution to AE introduces considerable difficulties. These problems make it harder to generalize the research results and restrict the application of the AE method in control, diagnostics and monitoring of CM machining.

Theoretical studies with the modeling of AE are very important in order to solve the mentioned problems. These researches will allow analyzing influence of separate parts of technological process on the AE and regularity of its changes, to determine the sensitivity of AE parameters to the changes in conditions of CM machining. In addition, it will allow to select and to interpret the predominant factors that lead to change in these terms and conditions. The results of researches are the main thing in the development of methods the control, diagnostics and monitoring of CM machining technological processes. One of the influencing factors is the disperse properties of CM machining. Of course, the determination of its impact on the parameters of AE signals is of great scientific and practical interest.

2. Analysis of the latest research and publications

The research of AE during CM machining is a subject of numerous papers. Those papers different types of CM treated and various kinds of machining (cutting, drilling, milling) [1 - 3] are observe. Analysis of the obtained data spend with the search of patterns of AE parameters change at operating the influential factors. Those factors are the parameters of technological process of machining (cutting speed and longitudinal feed, depth of cut) and the parameters of cutting tool (wear, destruction, etc.).

Results of published researches show that the registered AE signals are continuous signals [2, 4, 5]. They have a complicated character of changes in time. Such kind of signals practically observed at all kinds of CM machining. In the analysis of acoustical radiation, the processing of various parameters of registered AE signals carried out. However, the main processed parameters are mean or mean square value of the registered AE signals amplitude, their amplitude spectra and the statistical characteristics (the standard deviation, the coefficient of asymmetry and others) [2, 4, 6, 7].

Studies show, that dependence of AE amplitude parameters change during an increase of values of CM machining technological parameters (cutting speed and longitudinal feed, depth of cut), as well as the wear of the cutting tool have a complicated character. Weak stability of the gained regularity thus observed and some results contradict each other. Interpretation of the obtained regularities is quite difficult from the positions of the existing ideas about the processes of deformation and fracture of surface layers of materials during their machining.

From this point of view, theoretical studies of AE during the machining different materials are very important. However, the major part of papers relies to the machining of materials with the crystalline structure [8 - 10]. In papers [8, 9] analytical description of AE signal amplitude RMS value based on the assumption, which lies in the fact that work that is spent on plastic deformation during cutting, is proportional to the volume of material, which comes into plastic deformation, to the acting stress and to the strain rate. In addition, between work on the plastic deformation and energy of AE there is a directly proportional relation. However, as the many researches show, these models are poorly align with the regularities of change of AE signal amplitude RMS value during the machining of materials. In the paper [10] analytical description of resultant AE signal (amplitude) during the machining are based on the physical ideas of forming of acoustic emission during the flow of sequential processes of plastic deformation and fracture of the material. These processes lead to the formation of pulse AE signals. The approaches discussed in [10], used in model of acoustical radiation for a case of CM machining at prevailing thermoactivative destruction of the surface layer [11]. The resultant AE signal presented in the next form

$$U_p(t) = \sum_j U_R(t - t_j)\,, \qquad (1)$$

where t – the moments of time when AE pulse signals appear, arising at the prevailing thermoactivative destruction of certain areas of CM. The expression for the pulse AE signal U_R in the destruction of a given area of CM, consisting of basic elements considered in [11].

Analysis of the modeling results, according to [1], showed that formed AE resultant signal is a continuous signal with a very jagged shape. When the process of CM surface layer destruction is stable, observed the stable values of statistical amplitude characteristics of the AE resultant signal at various moments of analysis. Thus, the parameters in the expression of AE pulse signal (U_R), allow carrying out study of the influence of various factors (machining speed, depth of cut, etc.) on the AE resultant signal.

The approaches discussed in [11], can be use in the analysis of AE in the case of the prevailing mechanical destruction of CM surface layer. In this case, processes of destruction of surface layer flow with the high speeds, in respect to the thermoactivative processes. On this evidence, it is possible to identify patterns of change of AE parameters during the action of various factors.

3. Research tasks

In the paper, we will investigate the influence of dispersion of CM properties during its machining on the AE amplitude parameters in the case of the prevailing mechanical destruction of surface layer. A modeling of the AE resultant signals during the CM machining at change of dispersion of its properties will be spent. Statistical processing of modeling results will be carry out. We also will obtain the data on acoustic emission amplitude characteristics. The effect of CM properties dispersion on the AE amplitude characteristics will be determined. Sensitivity of AE amplitude characteristics to the change of CM properties dispersion will be determined.

4. Researches results

Conditions of CM machining will be the same as in the paper [11]. CM machining is carry out with constant depth, cutting speed and the speed of longitudinal feed. On small intervals of a time, there is a consecutive destruction of areas of the CM surface layer. These areas have the same size. We will not take into attention a tool wear. Each area destruction leads to the formation of AE signal. Under such conditions, the resultant AE signal, as in [11], it is possible to present as the sum of sequentially generated pulse signals

$$U_p(t) = \sum_j U_j(t - t_j), \quad (2)$$

where $t_j = j\Delta t_j \pm \delta$ – moments of time when the AE pulse signals U_j appear; Δt_j - the time interval between the beginnings of the formation of the subsequent AE pulse signal compared to the previous; j = 0,……, n – the number of consequently destructed areas; δ – random component in a moment of occurrence of each subsequent AE pulse signal.

Random component δ in a moment of time t_j can be cause by instability of CM machining parameters (rotation speed of details, speed of longitudinal feed, size of destructed areas and other factors). The instability of these parameters will affect the duration of the destruction process, and as a result, the duration of generated AE pulse signals. If the destruction of CM areas with the prescribed size occurs at the prevailing mechanism of mechanical destruction, formed AE pulse signal is describe by expression [12]

$$U_j(t) = u_0 t\alpha\upsilon_0 e^{r\alpha t} e^{-\frac{\upsilon_0}{r\alpha}(e^{r\alpha t} - 1)}, \quad (3)$$

where $u_0 = N_0\psi\delta_S$ - the maximum possible elastic displacement, which is distributed in the material at the instantaneous destruction of a given CM area; N_0 – the number of CM single elements in a given area of destruction; ψ – the proportionality factor between the mechanical stress and amplitude of the perturbation of a single pulse which is generated during the destruction of the single element (constant variable); δ_S – the value which is proportional to the pulse duration of disturbance of the CM element fracture unit; α – the loading velocity; υ_0, r – the constant variables determined by CM physical and mechanical characteristics.

Formula (3) includes parameters that influence AE amplitude parameters. These include: technological parameters – velocity α of loading process or cutting velocity; cutting depth which is determine the destruction area or the number of CM destructive element; physical and mechanical CM characteristics determined by υ_0 and r parameters. Parameter r characterizes the dispersion of CM properties. Conduct a study of its impact on the AE amplitude parameters during CM machining.

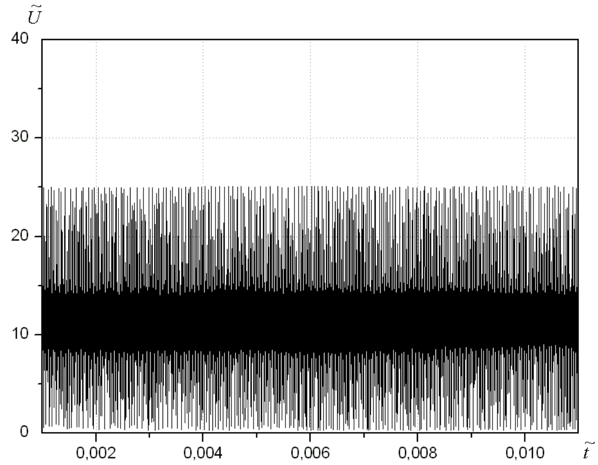
According to (2) and (3), let's simulate resulting AE signal taking into account the time randomness during the destruction of CM elements. Here we determine the dependence of the resultant AE signal amplitude in time in relative terms. At calculations parameters, which enter into expression (3) we will lead to dimensionless sizes, and the time will be present in normalized units. Signal amplitude will be normalized on u_0. To calculate the parameters υ_0 and α will be considered: $\tilde{\upsilon}_0$ = 100000; $\tilde{\alpha}$ =20. Value of parameter $\tilde{r}$ will be changed in the range from $\tilde{r}$ = 10000 to $\tilde{r}$ = 26000 with 4000 increments. Increase value $\tilde{r}$ means reduction of dispersion (disorder) of CM properties. Time interval $\widetilde{\Delta t}_j$ and range of the random component δ on the time will be specified on the basis of the duration of the AE pulse signals generated for the prescribed speed $\tilde{\alpha}$. According to calculations AE pulse signal duration for $\tilde{\alpha}$ = 20 and $\tilde{r}$ = 10000, $\widetilde{\Delta t}_j$ is considered equal $\widetilde{\Delta t}_j$ = 0,000007. The value of $\tilde{\delta}$ is randomly changed in range from 0 to 0, 0000082.

AE pulse signal, calculations according to (3), showed that the increase $\tilde{r}$ leads to decrease duration of AE pulse signals. According to these calculations during the simulation of AE resultant signals for all other $\tilde{r}$ valuations $\widetilde{\Delta t}_j$ and $\tilde{\delta}$ will be decreased proportional to the duration decrease of AE pulse signal.

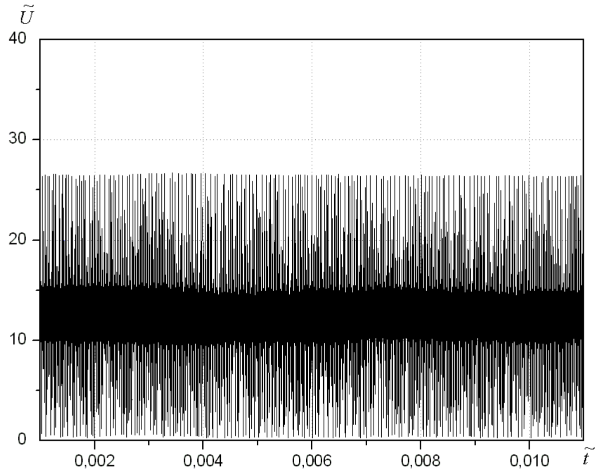
Fig. 1 shows the results of AE resultant signals simulating for prescribed conditions. Results on Fig. 1 are present as plots of the resultant AE signals amplitude changes in time in relative units for accepted values of the parameter $\tilde{r}$. The graphs in Fig. 1 constructed according to the 5000 calculation values of the amplitudes for each AE resultant signals. In constructing the graphs of Fig. 1 the current time is normalized to the time of the destruction process of the CM surface layer during its machining.

The modeling results (Fig. 1) show that the AE resultant signals represent continuous signals with very rugged shape. Increase the value $\tilde{r}$ at a constancy of all other parameters does not change the form and nature of AE. However, increase of the average AE resultant signals amplitude and the magnitude of its spread is observe. Table. 1 show the results of a statistical data processing of with definition the average amplitude of the AE resultant signal ($\tilde{\tilde{U}}$), its standard deviation ($s_{\tilde{\tilde{U}}}$) and dispersion of medium level amplitude ($s^2_{\tilde{\tilde{U}}}$).

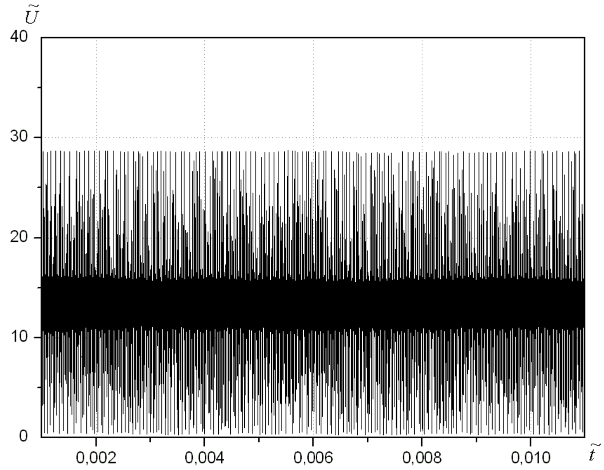
According to received data (table 1), when $\tilde{r}$ increase by 1,4 times (from 10000 to 14000) average level amplitude of AE resultant signal ($\tilde{\tilde{U}}$), its standard deviation ($s_{\tilde{\tilde{U}}}$) and dispersion ($s^2_{\tilde{\tilde{U}}}$) are increase, respectively, by 1,052 times, 1,014 times and by 1,029 times. If the value of $\tilde{r}$ increase by 1.8 times the values of $\tilde{\tilde{U}}$, $s_{\tilde{\tilde{U}}}$ and $s^2_{\tilde{\tilde{U}}}$ are increase, respectively, by 1,124 times, by 1,055 times and by 1,114 times. When $\tilde{r}$ increase by 2,2 times



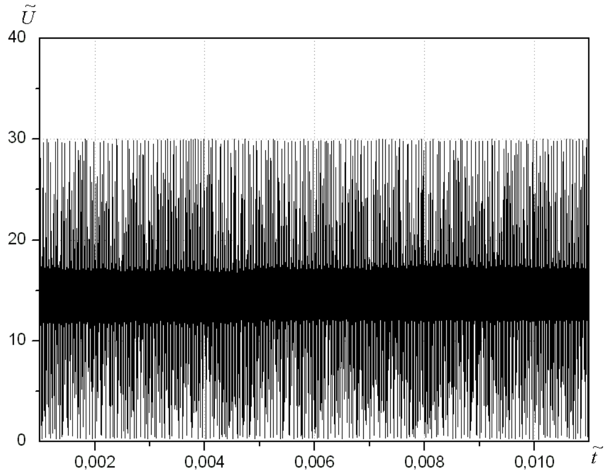
a



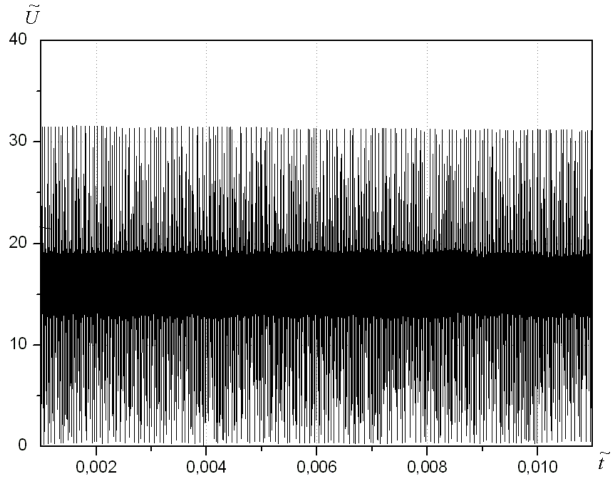
b



c



d



e

Fig. 1 - Graphs of the variation of the resulting AE signals amplitude over time, according to (2), in relative units for mechanical model of CM surface layer destruction during its machining. Modeling parameters: $\tilde{\alpha}$ = 20; $\tilde{r}$ = 10000. The value $\tilde{r}$ in relative units: *a* - $\tilde{r}$ =10000; *b* - $\tilde{r}$ =14000; *c* - $\tilde{r}$ =18000; *d* - $\tilde{r}$ =22000; *e* - $\tilde{r}$ =26000

(up to 22000) values of $\tilde{\tilde{U}}$, $s_{\tilde{\tilde{U}}}$ and $s^2_{\tilde{\tilde{U}}}$ increase by 1,19 times, 1,122 times and 1,259 times. If the value of $\tilde{r}$ increases by 2,6 times the values of $\tilde{\tilde{U}}$, $s_{\tilde{\tilde{U}}}$ and $s^2_{\tilde{\tilde{U}}}$ increase, respectively, by 1,266 times, 1,208 times and 1,458 times.

Research results show that decreasing of CM destructed surface layer dispersion properties (increase the value of the parameter $\tilde{r}$ in expression (3)) leads to increase the all AE resultant signal amplitude parameters. However, the greatest increment is observe in a dispersion of the average level of AE resultant signal amplitude. Truly, from the data in table1 it follows that if the value of parameter $\tilde{r}$ increase up to 26000, gain of the average level of AE resultant signal amplitude, its standard deviation and average level amplitude dispersion, relatively to their values at $\tilde{r}$ =10000, accordingly, makes 26,61%, 20,74% and 45,79%.

Table 1. Amplitude parameters of AE resultant signals when changing the parameter $\tilde{r}$ value for the mechanical model of CM surface layer destruction

Value of $\tilde{r}$	$\tilde{\tilde{U}}$	$s_{\tilde{\tilde{U}}}$	$s^2_{\tilde{\tilde{U}}}$
10000	11,63615	5,66525	32,0951
14000	12,23427	5,7463	33,01996
18000	13,07825	5,9781	35,73768
22000	13,85072	6,35584	40,3967
26000	14,73245	6,84043	46,79143

5. Resume

The simulation of the resultant AE signals during CM machining for the mechanical model of the acoustic emission formation, depending on the parameter $\tilde{r}$, which is determined by dispersion properties of destroyed CM surface layer, had been carried out. It was determined that an increase of the parameter $\tilde{r}$ does not change the nature and shape of generated AE signals. The resultant signals are continuous AE signals with very rugged form. However, decrease of CM properties dispersion (increase the value of parameter $\tilde{r}$ expression (3)) leads to increase the average level of AE resultant signal amplitude, and to increase of its standard deviation and dispersion. Statistical processing of the data showed that in overall increase of AE amplitude parameters, dispersion of the average level of AE resultant signal amplitude has the highest sensitivity. Obtained results showed that it is possible to determine the deviation of the physical and mechanical characteristics of CM workpiece during development the methods of control, diagnosis and monitoring of machining technological processes. In this case, as an informative parameter it is necessary to analyze patterns of change dispersion the average level of AE resultant signal amplitude. At the same time, the study of agency CM machining speed on the generated AE parameters is of interest.

References

[1] *Giriraj B.; Raja V.P.; Gandhinadhan R.; Ganeshkumar R.* Prediction of tool wear in high speed machining using acoustic emission technique and neural network. Indian Journal of Engineering and Materials Sciences. – 2006. – V.13. – P. 275–280

[2] *Lu P.; Kevin C.Y.; Tomthpson R.G.* Short-time Fourier transform method in AE signal analysis for diamond coating failure monitoring in machining application. Proceedings of the ASME 2010 Int. Manufacturing Science and Engineering Conf. MSEC 2010 (12–15 October 2010 Erie Pennsylvania USA). – P. 1–8

[3] *Karimi N.Z., Heidary H., Minsk G., Ahmad M.* Effect of the drilling process on the compression behavior of glass/epoxy laminates. Composite Srtuctures. – 2013. – V.98. – P.59–68

[4] *Ren Q.* Type-2 Takagi-Sugeno-Kang Fuzzy logic system and uncertain in machining. Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy of Ecole Polytechnique de Montreal (Monreal Canada 2012). – 111 p.

[5] *Sudha A. J.; Sampathkumar B. S.; Vijaya C.A.* AE Waveform analysis of Delamination in GFRP Composite materials during drilling. Int. J. of Engineering and Technology. – 2009. – V.1. – No.1. – P. 63–66

[6] *Fadare D.A.; Sales W.F.; Bonney J.; Ezugwu E.O.* Influence of cutting parameters and tool wear on acoustic emission signal in high-speed turning of Ti-6Al-4V alloy. Journal of Emerging Trends in Engineering and Applied Sciences. – 2012. – V.3 (3). – P. 547–555

[7] *Qin F.; Hu J.; Chou Y.K.; Thompson R.G.* Delamination wear of nano-diamond coated cutting tools in composite machining. Wear. – 2009. – v.267. – P. 991–995

[8] *Teti R.; Dornfeld D.A.* Modeling and experimental analysis of acoustic emission from metal cutting. ASME J. of Eng. for Indu. – 1989. – V.111. – P. 229–237

[9] *Liu J. J.; Dornfeld D. A.* Modeling and analysis of acoustic emission in diamond turning. J. of Manu. Sci. and Eng. – 1996. – V.118. – P. 199–207

[10] *Filonenko S.F.; Nimchenko T.V.* Acoustic emission at machining of materials by turning. Technological systems. – 2011. – № 3 (56). – С. 50–56

[11] *Filonenko S.* Acoustic emission model with themoactivative destruction of composite material surface. Proceedings of the National Aviation University. – 2015. – N1 (62). – P. 57–62

[12] *Filonenko S.F.; Nimchenko T.V.; Kosmach A.P.* Model of acoustic emission signal at the prevailing mechanism of composite material mechanical destruction. Aviation. – 2010. – v.14. – № 4. – P. 95–103

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С.Ф. Філоненко. Зв'язок акустичної емісії з дисперсністю властивостей оброблюваного композиційного матеріалу

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Розглянуто результати моделювання сигналів акустичної емісії при механічній обробці композиційного матеріалу для механічної моделі руйнування поверхневого прошарку матеріалу в залежності від дисперсності його властивостей. Показано, що зміна дисперсності властивостей композиційного матеріалу не впливає на характер акустичного випромінювання. Визначено вплив дисперсності властивостей композиційного матеріалу на амплітудні параметри акустичної емісії. Показано, що при загальному зростанні амплітудних параметрів акустичної емісії найбільшу чутливість має дисперсія середнього рівня амплітуди результуючого сигналу акустичної емісії.

Ключові слова: акустична емісія; амплітуда; енергія; композиційний матеріал; механічна обробка; модель; результуючий сигнал; статистичні характеристики

С.Ф. Филоненко. Связь акустической эмиссии с дисперсностью свойств обрабатываемого композиционного материала

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Рассмотрены результаты моделирования сигналов акустической эмиссии при механической обработке композиционного материала для механической модели разрушения поверхностного слоя материала в зависимости от дисперсности его свойств. Показано, что изменение дисперсности свойств композиционного материала не влияет на характер акустического излучения. Определено влияние дисперсности свойств композиционного материала на амплитудные параметры акустической эмиссии. Показано, что при общем возрастании амплитудных параметров акустической эмиссии наибольшую чувствительность имеет дисперсия среднего уровня амплитуды результирующего сигнала акустической эмиссии.

Ключевые слова: акустическая эмиссия; амплитуда; композиционный материал; механическая обработка; модель; результирующий сигнал; статистические характеристики; энергия

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