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ACOUSTIC ENERGY AT CHANGE OF TREATED COMPOSITE MATERIAL DISPERSION PROPERTIES

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Abstract

Purpose: *The aim of this study is to investigate the influence of treated composite material dispersion properties on acoustic radiation energy, which appears during composite material machining.* ***Methods:*** *The researches were grounded on simulation of acoustic radiation energy at change of mechanically treated composite material properties dispersion for the mechanical model of its surface layer destruction. The data processing with definition of acoustic radiation statistical energy parameters was conducted. The analysis of acoustic emission energy parameters sensitivity to change of composite material properties dispersion, and as the analysis of influencing of composite material properties dispersion on AE amplitude and energy parameters was conducted.* ***Results:*** *Were obtained that at decreasing of composite material properties dispersion there is increasing an average level of acoustic radiation energy and value of its deviation. Is determined, that at decreasing of composite material properties dispersion the greatest increasing there is an acoustic emission energy average level dispersion. It is show that the increasing of acoustic radiation energy parameters advances increasing its amplitude parameters.* ***Discussion:*** *The simulation of acoustic radiation energy at composite material machining for the mechanical model surface layer destruction at decreasing of composite material properties dispersion (spread) is conducted. It is shown, that the decreasing of composite material properties dispersion does not influence on acoustic radiation energy nature change. At the same time, the ascending parameter, that describing of composite material properties dispersion decreasing, results in increase of acoustic radiation signal energy parameters. The obtained outcomes can be used at mining methods of verification, diagnostic and monitoring of composite material machining technological processes. Thus during the composite material machining is possible to control and to determine of composite material properties rejection by analysis of acoustic emission signal energy average level dispersion.*

Keywords: acoustic emission; composite material; dispersion properties; distraction; energy; machining; Signal.

1. Introduction

At mining of composite materials (CM) machining technological processes the researches are carried out, which one are connected with optimization of their parameters, and creation the verification and monitoring methods of these processes. The researches carry out with usage as conventional, and not of conventional methods.

The conventional methods are measurement of cutting forces and temperature. However these methods have a high lag effect to dynamics processes of treated materials surface layers deformation and destruction. It reduces veracity the control and monitoring with definition the incipient states of machining conditions change. Consequent of such change is the loss of the made item quality.

One of the not conventional methods is the acoustic emission (AE) method. As against conventional methods, the AE method has a sharp response to the deformation and destruction processes of treated materials surface layers. However it to result in to the problem of interpretation information, that registered. As demonstrate researches, the problem is aggravated by that on AE parameters have influence the technological parameters (machining CM speed,

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feed rate, cutting depth) and physical-mechanical characteristics treated and treating materials.

With given the points of view, the simulation of acoustic radiation at change of the influential factors is relevant. It allows determining the AE amplitude and energy parameters regularity change, which matters for the monitoring and control methods of CM machining technological parameters veracity increase. Thus it is possible to conduct estimations of AE sensitivity with definition conditions for optimization technological parameters. One of the influential factors is the dispersion of treated CM properties. The definition of its influencing on acoustic radiation parameter stability, unconditionally, introduces scientific and practical concern.

2. Analysis of the latest researches and publications

For optimization and controls of CM machining technological processes are carried out researches with usage of different methods. One of such methods is the AE method [1, 4]. Its application is conditioned by a high sensitivity to the deformation and destruction processes of the materials. It allows receiving the information on internal processes, which one flow past in the materials structure.

The researches carry out with the analysis of influencing different technology factors on AE parameters. Such factors are: machining speed [5, 6]; feed rate [6]; cutting depth [6, 7]; cutting tool wearing [8] and number of other parameters. At researches the analysis of AE amplitude parameters is carried out. The outcomes researches demonstrate existence of AE amplitude parameters relations at ascending the influential factors. However they have composite nature of change. Obtained regularity has not high stability. Some of them contradict one another. It is handicapped interpretation the obtained outcomes from stands of existing representations about the CM machining processes. Their usage for monitoring and control of technological processes is hindered.

One of the influential factors is the CM treated properties dispersion. However practically there are no data about influencing of CM properties disperse on AE. The main publications in the given direction are connected to the analysis of influencing CM properties dispersion (hardness) on cutting forces [9 - 11].

In articles [12, 13] the analytical investigations of AE amplitude parameters are conducted at change of CM properties dispersion. The researches are conducted for the model of acoustic radiation at prevailing mechanical destruction CM surface layer. Considered, that the CM machining implements with constant technological parameters without cutting tool wearing. On small periods of time is destruction the CM surface layer elementary areas. Elementary areas have the identical sizes and are destructed sequentially. The destruction of each elementary area is accompanied by formation of single AE pulse signal. The sequentially destruction of elementary areas results in sequentially formation of AE pulse signals. They in aggregate reshape a resultant AE signal

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

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; $j = 0,\ldots\ldots, n$ – the number of consequently destructed areas; δ - random component in a moment of occurrence of each subsequent AE pulse signal (is conditioned by possible instability of CM machining technological parameters.

For the prevailing mechanical destruction of CM surface layer AE pulse signal [12] is described by expression of kind

$$U_j(t) = u_0 t\alpha \upsilon_0 e^{r\alpha t} e^{-\frac{\upsilon_0}{r\alpha}(e^{r\alpha t} - 1)}, \qquad (2)$$

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 speed; υ_0 – parameter, which is determined by the physical-mechanical characteristics of CM; r – parameter, which is determined by the CM properties dispersion.

The outcomes of conducted researches [12] have shown that the decreasing of CM properties dispersion descends ascending an AE signal amplitude average level and value of its deviation. The relations of AE amplitude parameters change at decreasing of treated CM properties dispersion were determined. It is show [13] that at given and constant of CM machining technological parameters decreasing of its properties dispersion results in increasing statistical AE amplitude parameters. Thus the AE signal amplitude average level has linear nature of increasing, and its standard deviation and dispersion increase not by a linear mode. However greatest sensitivity there is AE signal amplitude average level dispersion, i.e. she has a maximum speed of change.

At the same time, most capacious parameter of AE signals is their energy. In article [14] the model and the results of acoustic radiation energy simulation is reviewed at an alteration of CM machining speed. The researches are conducted for a case of prevailing mechanical destruction CM surface layer. At simulation the conditions were adopted, as well as in article [12]. Thus the energy of resultant acoustic radiation is shown by the way

$$E_p(t) = \sum_j E_{jM}(t - t_j), \qquad (3)$$

where $t_j = j\Delta t_j \pm \delta$ - moments of time when AE signals appear with energy E_{jM}, which appear during sequential mechanical destruction of CM *j-th* areas; j – number of CM destructed area or a number of formed AE pulse signal (j=0, 1,…, n); Δt_j - is time interval between the beginning of the next AE impulse signal generation in regard to the previous one; δ – random component in a moment of time when each next AE pulse signal appear; $E_{jM} \sim U_{jM}^2$; U_{jM} - the current value of amplitude *j-th* AE signal, which one is described by expression (2).

The outcomes researches have shown, that with ascending of CM machining speed is watched increasing of AE signal average level energy and value of its deviation. The calculations of AE signals energy parameters as have shown, that the greatest increasing is watched in a dispersion of AE signal energy average level.

Outcomes of researches [14] are possible to use for research of influencing the treated CM properties dispersion on acoustic radiation energy. It will allow comparing sensitivity AE amplitude and energy parameters to change of CM properties dispersion at its machining. The results of such researches are introduced by scientific and practical concern for mining verification and control methods of CM machining processes.

3. Research tasks

The aim of this study is to investigate the influence of CM treated dispersion properties on acoustic radiation energy, which appears during CM machining for prevailing mechanical destruction its surface layer. As the statistical processing of acoustic radiation energy parameters with definition the energy average level, its standard deviation and dispersion for set values of parameter, that describing CM properties dispersion, will be conducted. The sensitivity of AE energy parameters to change of CM properties dispersion will be showed. As matching influencing of CM properties dispersion on AE amplitude and energy parameters will be conducted.

4. Researches results

Let's esteem process of CM machining with usage turning operation. Conditions of CM machining we shall accept same, as well as in article [14]. The treated CM has the given physical-mechanical characteristics. The CM machining technological parameters (cutting speed, feed rate, cutting depth) are constants. Wearing of cutting tool is misses. The sequentially destruction of CM elementary areas results in acoustic radiation energy formation, which one is described by expression (3). Thus the reshaped AE pulse signals are described by expression (2). Energy of AE pulse signal, according to article [14], is described by expression

$$E_{jM}(t) = \Delta t_k \sum_i U_{jiM}^2(i \cdot \Delta t_k), \qquad (4)$$

where i = 0,…., k – number of calculated amplitude value of *j-th* AE signal on its duration; Δt_k – time interval between two calculated amplitude values of *j-th* AE signal (Δt_k =const).

Let's conduct simulation of acoustic radiation energy, which one is reshaped during CM machining, agrees (3), with allowance for (2) and (4). Simulation we shall conduct under following conditions. The parameters, which are included in expressions (2), (3) and (4), we shall put to non-dimensional values. Energy of AE pulse signals we shall set norms on value u_0^2. At simulation of acoustic radiation energy the value of parameters υ_0 and α in expression (2) we shall accept equal: $\tilde{\upsilon}_0$ = 100000; $\tilde{\alpha}$ =20. The value r we shall change in range of sizes from $\tilde{r}$ = 10000 up to $\tilde{r}$ = 26000 with a step of increment 40000. The increase of value $\tilde{r}$ means decreasing of CM dispersion or its properties deviation.

Time period between appearance of AE pulse signals (between sequentially destruction of CM areas) $\widetilde{\Delta t}_j$ and range of random component δ change in time we shall set outgoing from to duration reshaped AE pulse signals for a preset machining speed $\tilde{\alpha}$. Pursuant to calculation results, duration of AE pulse signal for given value $\tilde{\alpha}$ = 20, $\tilde{\upsilon}_0$ = 100000 and $\tilde{r}$ = 10000, value $\widetilde{\Delta t}_j$ we shall accept equal $\widetilde{\Delta t}_j$ = 0,0000092. Thus value $\tilde{\delta}$ we shall change in range of sizes from 0 up to 0,0000082 arbitrarily. At a solving of acoustic radiation energy, agrees (4), the value Δt_k will make: $\Delta\tilde{t}_k$ =0,0000005.

According to the conducted calculations, the increase of value $\tilde{r}$ results in decreasing of AE pulse signal duration. For all other parameter values $\tilde{r}$ values $\widetilde{\Delta t}_j$ and $\tilde{\delta}$ we shall reduce proportionally to decreasing of AE pulse signals duration.

The conducted calculations results by the way of resultant AE signals energy relations change in time in relative units for the different parameter values, that describing CM properties dispersion, are shown in a fig. 1. At construction of the graphs fig. 1 time is set norms on time of CM destruction process development at its machining for mechanical model surface layer destruction. At calculations the processing 5000 values of amplitudes, and, accordingly, energies for each AE pulse signal was conducted.

The simulation results of acoustic radiation energy have shown following (fig. 1). At CM machining with prevailing mechanical destruction its surface layer and given simulation conditions the energy of acoustic radiation in time is continuous. At constant CM machining technological parameters (cutting speed, feed rate and cutting depth) decreasing) of CM properties dispersion does not influence of acoustic radiation nature. However, visible from fig. 1, increasing of parameter, that describing CM properties dispersion decreasing, is results in increasing an AE signals energy average level and value of its deviation.

Let's conduct calculations of statistical AE signals energy parameters for set values of parameter $\tilde{r}$, describing CM properties dispersion. The results of the conducted calculations demonstrate, that at $\tilde{r}$ =10000 values of statistical acoustic radiation energy parameters in relative units make: energy average level - $\tilde{\tilde{E}} = 3{,}24977 \cdot 10^{-4}$; energy average level standard deviation - $s_{\tilde{\tilde{E}}} = 2{,}8945 \cdot 10^{-4}$; energy average level dispersion - $s^2_{\tilde{\tilde{E}}} = 8{,}37812 \cdot 10^{-8}$.

Let's consider increasing of AE signals energy parameters in relation to their values at $\tilde{r}$ =10000. At increasing value $\tilde{r}$ in 1,4 times (from $\tilde{r}$ =10000 up to $\tilde{r}$ =14000) there is an increase of AE signal energy average level of $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, accordingly, in 1,11786 times, in 1,02415 times and in 1,04888 times. At ascending value $\tilde{r}$ in 1,8 times (from $\tilde{r}$ =10000 up to $\tilde{r}$ =18000) there is an increase of AE signal energy average level of $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, accordingly, in 1,26521 times, in 1,14732 times and in 1,31635 times. At ascending value $\tilde{r}$ in 2,2 times (from $\tilde{r}$ =10000 up to $\tilde{r}$ =22000) there is an increase of AE signal energy average level of $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, accordingly, in 1,4371 times, in 1,32429 times and in 1,75375 times. At ascending value $\tilde{r}$ in 2,6 times (from $\tilde{r}$ =10000 up to $\tilde{r}$ =26000) there is an increase of AE signal energy average level of $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, accordingly, in 1,62367 times, in 1,49048 times and in 2,22153 times.

The obtained results demonstrate, that at decreasing of CM properties dispersion the increasing of AE signal energy average level advances increasing an energy average level standard deviation. However increasing of AE signal energy average level dispersion advances an increasing of energy average level and its standard deviation.

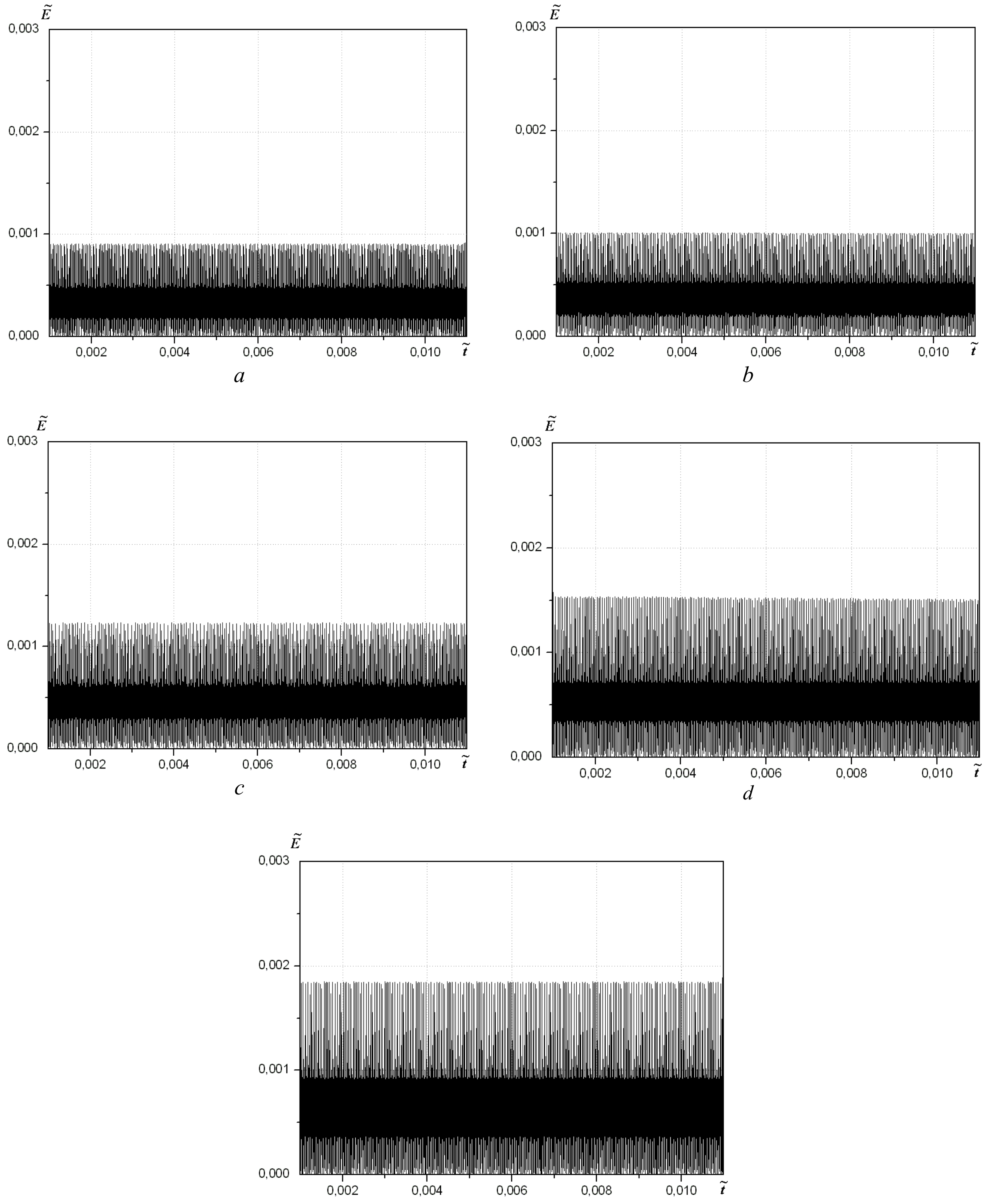

Fig. 1. Graphs of the AE resultant signals energy change in time, agrees (3), in relative units at CM machining for the mechanical destruction its surface layer for its different properties dispersion. The simulation parameters: $\tilde{\upsilon}_0$ = 100000, $\tilde{\alpha}$ = 20. Initial values $\widetilde{\Delta t}_j$ = 0,0000092, $\tilde{\delta}$ ranges of values from 0 up to 0,0000082 with arbitrary mode. The value of parameter, that describing CM properties dispersion, in relative unit: *a* - $\tilde{r}$ =10000; *b* - $\tilde{r}$ =14000; *c* - $\tilde{r}$ =18000; *d* - $\tilde{r}$ =22000; *e* - $\tilde{r}$ =26000

Let's conduct matching ascending of AE signals amplitude and energy parameters at decreasing of CM properties dispersion. According to the data of article [12], at the same simulation parameters for value $\tilde{r}$ =10000 of AE resultant signal amplitude average levels, its standard deviation and dispersion, accordingly, are equal: $\tilde{\tilde{U}}$=11,63615, $s_{\tilde{\tilde{U}}}$=5,66525 and $s^2_{\tilde{\tilde{U}}}$= 32,0951. The outcomes of statistical AE signals amplitude parameters ascending at decreasing of CM properties dispersion in relation to their values at $\tilde{r}$ =10000 are adduced in tab. 1.

The obtained outcomes demonstrate, that at decreasing of CM properties dispersion increasing the acoustic radiation energy parameters advance increasing its amplitude parameters. So, at increase $\tilde{r}$ in 2,6 times (with $\tilde{r}$ =10000 up to $\tilde{r}$ =26000) the ascending of AE signal energy average level $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$ advances ascending an signal amplitude average level of $\tilde{\tilde{U}}$, its standard deviation $s_{\tilde{\tilde{U}}}$ and dispersion $s^2_{\tilde{\tilde{U}}}$, accordingly, in 1,2824 times, in 1,2344 times and in 1,5237 times. Thus the greatest ascending there is a dispersion of AE signal energy average level.

Table 1

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

	Increasing of AE signal amplitude parameters		
Value $\tilde{r}$	$\tilde{\tilde{U}}$	$s_{\tilde{\tilde{U}}}$	$s^2_{\tilde{\tilde{U}}}$
10000	1	1	1
14000	1,0514	1,01431	1,02882
18000	1,12393	1,05522	1,11349
22000	1,19032	1,1219	1,25866
26000	1,26609	1,20744	1,4579

6. Resume

The simulation of acoustic radiation energy at CM machining for the mechanical model surface layer destruction at decreasing of CM properties dispersion (spread) is conducted. It is shown, that the decreasing of CM properties dispersion does not influence on acoustic radiation energy nature change. At the same time, the ascending parameter, that describing of CM properties dispersion decreasing, results in increase of acoustic radiation signal energy average level and value of its deviation. The statistical data processing of simulation has shown ascending all energy parameters of acoustic radiation. However greatest ascending is watched in AE signal energy average level dispersion. The matching of acoustic radiation amplitude and energy parameters at decreasing of CM properties dispersion is conducted. It is shown, that the ascending of AE signals energy parameters advances ascending their amplitude parameters.

The outcomes of the conducted researches can be used at mining verification, diagnostic and monitoring methods of CM machining technological processes. Thus during CM machining is possible to control and to determine the CM properties deviation. As parsed parameter it is possible to use the AE signal energy average level dispersion. At the same time the concern introduces research of legitimacies AE energy parameters change at change of treated CM properties dispersion.

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Акустична енергія при зміні дисперсності властивостей оброблюваного композиційного матеріалу

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Мета: Метою цього дослідження є вивчення впливу дисперсності властивостей оброблюваного композиційного матеріалу на енергію акустичного випромінювання, що виникає в процесі механічної обробки композиційного матеріалу. **Методи дослідження:** Дослідження були засновані на моделюванні енергії акустичного випромінювання при зміні дисперсності властивостей механічно оброблюваного композиційного матеріалу для механічної моделі руйнування його поверхневого прошарку. Була проведена обробка даних з визначенням статистичних енергетичних параметрів акустичного випромінювання. Був проведений аналіз чутливості енергетичних параметрів акустичної емісії до зміни дисперсності властивостей композиційного матеріалу, а також аналіз впливу дисперсності властивостей композиційного матеріалу на амплітудні та енергетичні параметри. **Результати:** Було отримано, що при зменшенні дисперсності властивостей композиційного матеріалу відбувається зростання середнього рівня енергії акустичного випромінювання і величини його розкиду. Визначено, що при зменшенні дисперсності властивостей композиційного матеріалу найбільше зростання має дисперсія середнього рівня енергії акустичної емісії. Показано, що зростання енергетичних параметрів акустичного випромінювання передує зростанню його амплітудних параметрів. **Обговорення:** Проведено моделювання енергії акустичного випромінювання при механічній обробці композиційного матеріалу для механічної моделі руйнування його поверхневого прошарку при зменшенні дисперсності його властивостей. Показано, що зменшення дисперсності властивостей композиційного матеріалу не впливає на зміну характеру випромінювання акустичної енергії. У той же час, зростання параметру, що описує зменшення дисперсності властивостей композиційного матеріалу, приводить до зростання енергетичних параметрів сигналів акустичного випромінювання. Отримані результати можуть бути використані при розробці методів контролю, діагностики і моніторингу технологічних процесів механічної обробки композиційного матеріалу. При цьому в процесі механічної обробки композиційного матеріалу можливо контролювати і визначати нерівномірність властивостей композиційного матеріалу за аналізом дисперсії середнього рівня енергії сигналів акустичної емісії.

Ключові слова: акустична емісія; дисперсність властивостей; енергія; композиційний матеріал; механічна обробка; руйнування; сигнал.

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Акустическая энергия при изменении дисперсности свойств обрабатываемого композиционного материала

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Цель: Целью исследования является изучение влияния дисперсности свойств обрабатываемого КМ на энергию акустического излучения, которое возникает в процессе механической обработке композиционного материала. **Методы исследования:** Исследования были основаны на моделировании энергии акустического излучения при изменении дисперсности свойств механически обрабатываемого композиционного материала для механической модели разрушения его поверхностного слоя. Была проведена обработка данных с определением статистических энергетических параметров акустического излучения. Был проведен анализ чувствительности энергетических параметров акустической эмиссии к изменению дисперсности свойств композиционного материала, а так же анализ влияния дисперсности свойств композиционного материала на амплитудные и энергетические параметры. **Результаты:** Получено, что при уменьшении дисперсности свойств композиционного материала происходит возрастание среднего уровня энергии акустического излучения и величины его разброса. Определено, что при уменьшении дисперсности свойств композиционного материала наибольшее возрастание имеет дисперсия среднего уровня энергии акустической эмиссии. Показано, что возрастание энергетических параметров акустического излучения опережает возрастание его амплитудных параметров. **Обсуждение:** Проведено моделирование энергии акустического излучения при механической обработке композиционного материала для механической модели разрушения его поверхностного слоя при уменьшении дисперсности его свойств. Показано, что уменьшение дисперсности свойств композиционного материала не влияет на изменение характера излучения акустической энергии. В тоже время, возрастание параметра, который описывает уменьшение дисперсности свойств композиционного материала, приводит к возрастанию энергетических параметров сигналов акустического излучения. Полученные результаты могут быть использованы при разработке методов контроля, диагностики и мониторинга технологических процессов механической обработки композиционного материала. При этом в процессе механической обработки композиционного материала возможно контролировать и определять неравномерность свойств композиционного материала по анализу дисперсии среднего уровня энергии сигналов акустической эмиссии.

Ключевые слова: акустическая эмиссия; дисперсность свойств; композиционный материал; механическая обработка; разрушение; сигнал; энергия.

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