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ACOUSTIC EMISSION AT PROPERTIES CHANGE OF COMPOSITE DESTRUCTED BY VON MISES CRITERION

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Abstract*—The results of theoretical studies influence the parameter characterizing the composite properties on acoustic emission signals parameters during composite material fracture by a shear force using von Mises criterion are considered. It has been determined that with increase of influencing parameter, there is decrease the maximum amplitude and duration of generated acoustic emission signals. In this case, a decrease the maximum amplitude of acoustic emission signals is ahead of decrease in their duration. It has been determined that the regularities of acoustic emission signals maximum amplitude and duration decrease with an increase the parameter characterizing the composite material properties are well described by power functions.*

Index Terms—Acoustic emission; amplitude of acoustic emission; signal duration; destruction criterion; composite material.

I. INTRODUCTION

Investigations of composite materials (CM) destruction processes are given much attention in the scientific literature. Research is aimed at finding parameters for predicting the critical stages that lead to CM destruction and the loss of product bearing capacity.

Theoretical and experimental studies of CM fracture processes are carried out under conditions of uniaxial tension and the action of shear force. Herewith various concepts of CM representation and methods of studying the processes of their destruction are used. Experimental studies of CM destruction processes show that one of the most sensitive methods is the method of acoustic emission (AE). The method has low inertia to the processes that take place in the CM structure during its deformation. It allows to obtain significant amounts information about the dynamics processes at sub micro, micro and macro levels. However, the interpretation of the obtained experimental results presents significant difficulties. This is due not only to the high sensitivity of the method, but also to the complexity in constructing models and modeling the processes of AE radiation.

Conducted theoretical studies are mainly aimed at analyzing the processes of CM destruction elements in time – study of patterns the number remaining or destroyed CM elements change. Herewith various criteria for CM destruction are used. Assuming that the destruction of composite each element is accompanied by acoustic radiation, it is not the processes of AE signal formation are considered. The processes of AE energy accumulation are considered. The processes are considered only in the approximation to the CM complete destruction, which is due to the existence of discontinuities in the analyzed functions.

At the same time, the use of the FBM model, taking into account the criteria and kinetics of CM destruction, allows to consider the processes of AE signal formation. Herewith it is possible to analyze the regularities of AE signals parameters changes under the action of various factors. Such studies are interest in the development of methods for control, diagnostics and monitoring the state of CM products, both during their production and during operation.

II. STATEMENT OF THE TASK

The aim of this work is analyzing the effect of CM properties on generated AE signals parameters upon composite fracture by shear force according to von Mises criterion.

For achievement the purpose of article the following problems were put: – to simulate the process of CM destruction by shear force according to von Mises criterion in time and AE signals when changing the composite properties; – to process the data to determine the patterns of generated AE signals maximum amplitude and duration change when changing the CM properties, which is destroyed by shear force according to von Mises criterion.

III. REVIEW OF PUBLICATIONS

At studying the processes of CM destruction, the model representing material, including CM, in the form of fibers bundle (FBM) is widely used [1] – [7]. The FBM model allows to study the influence of local microscopic mechanisms on entire composite destruction.

The FBM model assumes that the composite consists of set fibers (elements) that break brittle and consistent manner. The failure load of element is a random variable and is characterized by a certain probability density and distribution function. To study the process of composite destruction, certain rules for redistributing the applied load to the remaining elements are used. The local distribution of the load on adjacent elements that are adjacent to the destroyed element is considered. Equal distribution of the load on all the remaining elements is also considered. The research results are presented in the form of remaining number CM elements dependences change over time for the adopted conditions. At the same time, they strive to determine the critical time for the possibility predicting CM destruction. In a number of works [8] – [10] also analyze acoustic radiation. However, as a rule, it is not considered formation of acoustic signal upon destruction the composite, but release the energy of acoustic radiation. This approach is aimed at analyzing the process of acoustic energy accumulation in the approach to composite destruction complete.

In a number of works [10] – [15], the process of heterogeneous materials destruction under the action of shear force is considered. Herewith various criteria for CM destruction are used. Such in work [11] under the action of shear force, the basic relations for the case of independent uniform distributions material destruction threshold levels with boundaries [0,1] are considered. Are obtained expressions for equivalent stresses change at linear input of deformation at Young's modulus equal to 1:

- for the rule OR

$$\sigma_m = \alpha t\left(1-\alpha t\right)\left(1-g\sqrt{\alpha t}\right), \qquad (1)$$

where g is a coefficient depending on material element geometric dimensions (cross-sectional area and length); α is the rate of material deformation;

- for von Mises criterion:

$$\sigma_m = t\cdot 0.5\left[\left(2-2\sqrt{\alpha t}+\alpha t^{\frac{2}{3}}\log\left(\frac{(1+\alpha t)}{(1-\alpha t)}\right)\right)\right.$$
$$\left.-\alpha t^{\frac{3}{2}}\left(2\sqrt{\frac{\left(1-\sqrt{\alpha t}\right)}{\alpha t}}+\log\left(\frac{\left(1+\sqrt{1-\sqrt{\alpha t}}\right)}{\left(1-\sqrt{1-\sqrt{\alpha t}}\right)}\right)\right)\right]. \qquad (2)$$

Ratios are received and analysis the number of destroyed (remained) elements change at development of CM destruction processes carried out.

In article [16] for the rule OR, taking into account kinetics of CM destruction process at action of shear force, expressions for number of CM remained elements in time and the created AE signal are received. The conducted researches showed that at CM destruction by shear force the curve of remained elements change in time has continuous nature of falling. The continuity of CM elements destruction process is followed by formation of continuous AE signal. For AE signal accelerated increase amplitude of the forward front and relaxation reduction amplitude of the back front is characteristic. Also it was shown that increase of deformation speed leads to increase the steepness falling curves of number remained elements change in time and to reduction time of CM destruction process course. Such increase of destruction process course speed is followed to increase amplitude and reduction duration of formed AE signals.

Expressions for of CM remained number elements in time and the formed AE signal when using von Mises criterion, taking into account kinetics of CM destruction process at action shear force, are considered in article [17] in a look:

- for the CM remained elements number

$$N\left(t\right) = N_0 e^{-v_0\int_{t_0}^{t} r[\sigma_m(t)-\sigma_0(t_0)]dt}; \qquad (3)$$

- for the formed AE signal

$$U\left(t\right) = U_0 v_0\left[\sigma_m\left(t\right)-\sigma(t_0)\right]$$
$$\cdot e^{r\left[\sigma_m(t)-\sigma_0(t_0)\right]}\cdot e^{-v_0\int_{t_0}^{t} e^{r[\sigma_m(t)]-\sigma_0(t_0)]}dt}, \qquad (4)$$

where $\sigma_m(t)$, $\sigma_0(t_0)$ is the respectively, equivalent tension change on CM elements in time and threshold tension corresponding to a time point t_0 of CM beginning destruction; U_0 is the greatest possible shift at instant destruction CM, that consisting from N_0 elements; v_0, r are constants depending from CM physical-mechanical characteristics.

Expression for $\sigma(t_0)$ corresponds (2) at $t = t_0$, i.e.

$$\sigma_0\left(t_0\right) = \alpha t_0\cdot 0.5\left[\left(2-2\sqrt{\alpha t_0}+\alpha t_0^{\frac{2}{3}}\log\left(\frac{1+\alpha t_0}{1-\alpha t_0}\right)\right)-\alpha t_0^{\frac{2}{3}}\left(2\sqrt{\frac{1-\sqrt{\alpha t_0}}{\alpha t_0}}+\log\left(\frac{1+\sqrt{1-\sqrt{\alpha t_0}}}{1-\sqrt{1-\sqrt{\alpha t_0}}}\right)\right)\right]. \qquad (5)$$

Researches were conducted and conditions approach of composite destruction on OR criterion and von Mises criterion are defined, and also comparison destruction processes and formed AE signals parameters is carried out. It is defined that a basis of such approach is approach of equivalent tension regularities change. Thus it is shown that the smallest deviation of remained elements number regularities change at development CM destruction process is observed in approach of equivalent tension regularities change by OR criterion and von Mises criterion. However, researches of AE signals show that the deviation of AE signals parameters at CM destruction by OR criterion and von Mises criterion under such circumstances is observed. It is defined that such deviations are caused by distinctions in speeds of equivalent tension change with approach by the moment of CM destruction beginning time.

In article [18] research influence of composite deformation speed by shear force and its destruction using von Mises criterion on formed AE signals parameters is conducted. Researches showed that to increase of CM deformation speed there is an increase the steepness falling curves of CM remained elements in time change and reduction time of course destruction process. Thus there is increase of formed AE signals amplitude and reduction of their duration. It is also shown that to increase of CM deformation speed there is a gradual transformation of AE signal to a signal of a triangular form. Regularities of AE signals amplitude and duration change at increase of CM deformation speed by shear force are defined and described.

At the same time, one of parameters in expressions (3) and (4) who will influence on CM destruction processes and formation of AE signals, is parameter v_0 – characterizes CM properties.

Certainly, research of CM properties influence on CM destruction processes be Mises criterion and formed AE signals parameters is interest to development the methods and monitoring systems, monitoring and diagnostics of composite.

IV. Results of Researches

Modeling of equivalent tension change at CM destruction by shear force using von Mises criterion, of CM remained number elements changes and formed AE signals at change of composite properties (parameter v_0), we will carry out according to expressions (2), (3), (4) and (5). We will carry out calculations in relative units.

For modeling of equivalent tension regularity change we will accept value of deformation speed α equal $\tilde{\alpha} = 10$. Results of equivalent tension calculation, it agrees (2), are shown in Fig. 1.

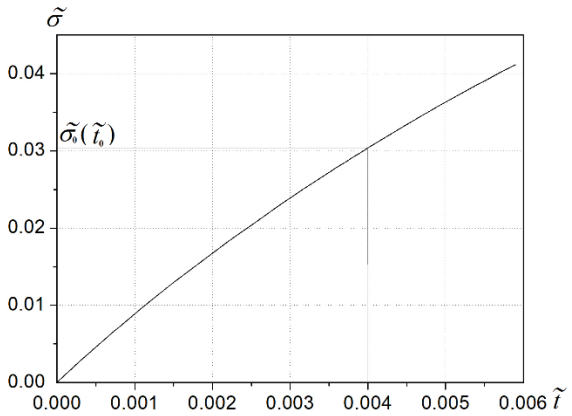


Fig. 1. Dependence of equivalent tension change in time by von Mises criterion, it agrees (2), at a speed deformation $\tilde{\alpha} = 10$

For modeling $\tilde{N}(\tilde{t})$ and $\tilde{U}(\tilde{t})$ it agrees (3) and (4), we will accept the beginning destruction time $\tilde{t}_0$ equal $\tilde{t}_0 = 0.004$.

To this time $\tilde{t}_0$ there corresponds tension $\tilde{\sigma}_0(\tilde{t}_0)$ of the beginning destruction which size, according to calculations for expression (5), is equal $\tilde{\sigma}_0 = 0.03037385029676163$ (Fig. 1).

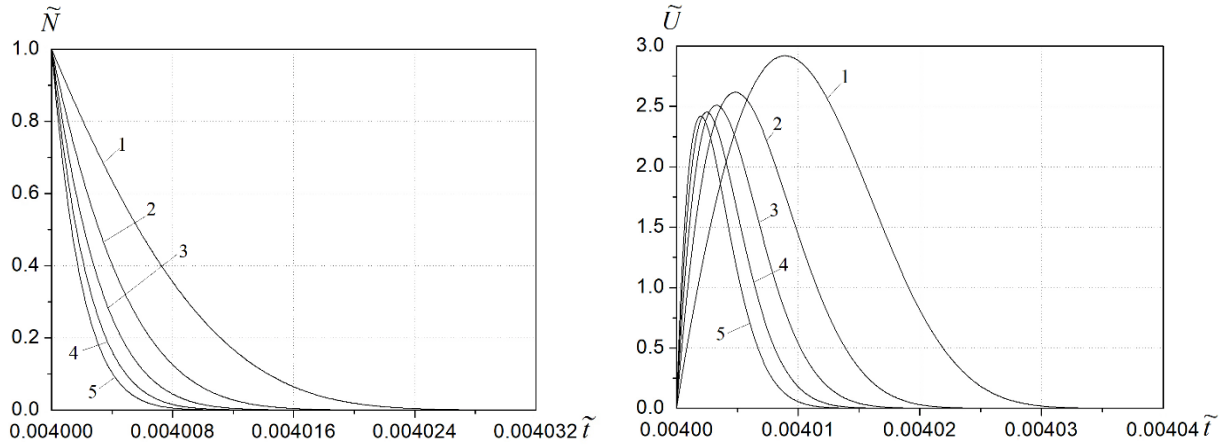
At modeling the number $\tilde{N}(\tilde{t})$ of CM remained elements and AE signals amplitudes $\tilde{U}(\tilde{t})$ in time we will accept value of parameter $\tilde{r}$ equal $\tilde{r} = 10000$. We will change value of parameter $\tilde{v}_0$ from =100000 to =500000 with an increment step $\Delta\tilde{v}_0 = 100000$.

Results of modeling remained number elements at CM destruction by shear force on von Mises criterion with increase of value $\tilde{v}_0$ are shown in Fig. 2a.

Results of modeling AE signals amplitude change at CM destruction by shear force on von Mises criterion with increase of value $\tilde{v}_0$ are shown in Fig. 2b.

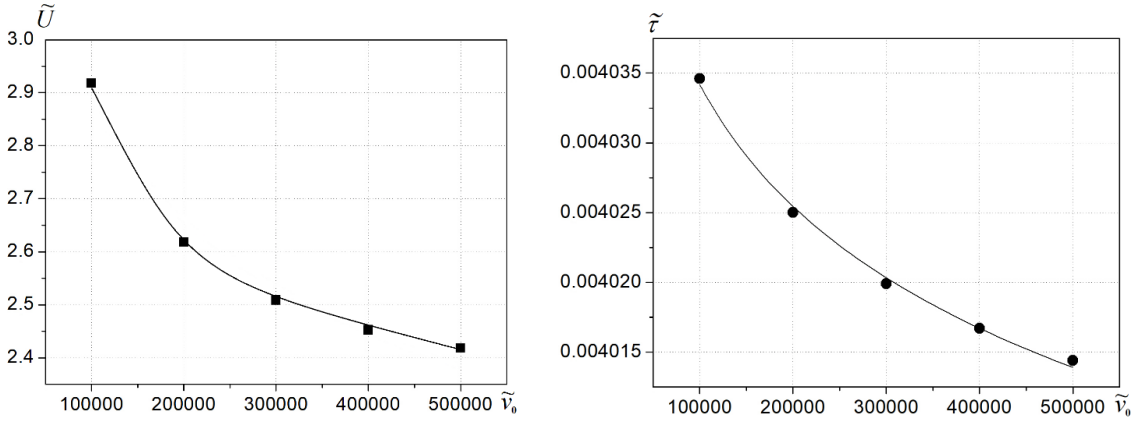
Results obtained data processing in the form of AE signals maximum amplitude and duration dependences change in relative units at increase of value parameter $\tilde{v}_0$ are shown in Fig. 3.

As AE signal amplitude on the back front has asymptotic nature change in time, duration of AE signals determined from condition of restriction the relation amplitudes $\tilde{U}\left(\tilde{t} = \tilde{\tau}\right) \ll \tilde{U}_{\max}(\tilde{t} = \tilde{\tau}_0)$ with the third order a trifle, where $\tilde{\tau}$ is the AE signal duration; $\tilde{\tau}_0$ is the duration of the forward front of AE signal.



a) b)

Fig. 2. Schedules of remained number elements change (a) and AE signals amplitudes AE (b) in time in relative units at CM destruction by shear force on Mises criterion. Value of parameter $\tilde{v}_0$: 1 – $\tilde{v}_0$ = 100000; 2 – $\tilde{v}_0$ = 200000; 3 – $\tilde{v}_0$ = 300000; 4 – $\tilde{v}_0$ =400000; 5 – $\tilde{v}_0$ = 500000. Deformation speed $\tilde{\alpha}$ = 10. Time of beginning destruction $\tilde{t}_0$ = 0.004



a) b)

Fig. 3. Dependences of AE signals maximum amplitude (a) and duration (b) change at increase of parameter $\tilde{v}_0$

The analysis of received AE signals maximum amplitude and duration dependences change at increase of parameter $\tilde{v}_0$ (Fig. 3) showed that they are well described by a power function of a look

$$A = av_0^b, \qquad (6)$$

where A is the analyzed parameter of the AE signals (the maximum amplitude or duration); a and b are approximating expression coefficients.

Values of approximating expression coefficients (6) make: for the AE signals maximum amplitude (Fig. 3a) is the a = 11.43512, b = – 0.11949; for the AE signals duration (Fig. 3b) is the a = 0.00418, b = –0.00314. At description dependence in Fig. 3a the determination coefficient R^2 made R^2 = 0.97269, and dependences in Fig. 3b is the R^2 = 0.99692. Thus residual dispersion SD^2 made: for the AE signals maximum amplitude – SD^2 = 0.00148; for the AE signals duration – $SD^2 = 5.2492 \cdot 10^{-6}$.

Results of obtained data processing in the form of AE signals maximum amplitude and duration dependences change in percentage terms at increase of value parameter $\tilde{v}_0$ are shown in Fig. 4.

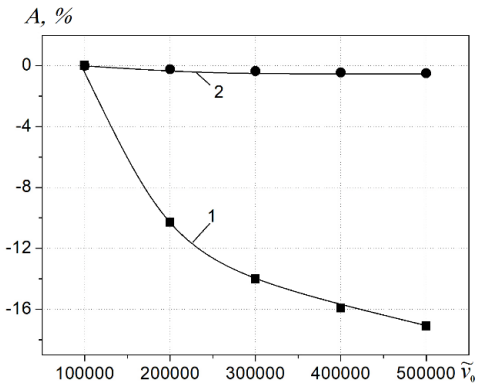


Fig. 4. Dependences of AE signals maximum amplitude (1) and duration (2) change in percentage terms at increase of value parameter $\tilde{v}_0$

In Figure 4 the following designation is accepted: *A* is the AE signals parameter, either the maximum amplitude or duration of AE signal.

V. Discussion of Researches Results

Results of conducted researches show that at CM destruction by shear force on von Mises criterion at linear input deformation dependence of equivalent tension change has nonlinear character (Fig. 1).

Calculations show that for the accepted modeling conditions dependence of CM remained number elements change in time has continuous nonlinear nature reduction. At increase of parameter which characterizes CM properties, there is an increase the steepness falling of remained number elements dependences change in time and reduction of course destruction process time (Fig. 2a). Thus at the initial stages of increase parameter $\tilde{v}_0$ sharp increase the steepness falling of remained number elements dependences change in time is observed. However, at great values of parameter $\tilde{v}_0$ there is an insignificant gain steepness falling of remained number elements dependences change in time (Fig. 2a).

At continuity of CM elements destruction process there is formation of continuous AE signal (Fig. 2b). The formed AE signal has sharp increase of amplitude forward front and asymptotic nature reduction amplitude of back front. At increase of value parameter $\tilde{v}_0$ there is reduction of formed AE signal amplitude and reduction of its duration (Fig. 2b).

Obtained data processing showed that AE signals maximum amplitude and duration dependences change at increase of value parameter $\tilde{v}_0$ have nonlinear nature reduction. Approximation of received dependences showed that they are well described by power functions.

At the same time as show calculations results at increase value $\tilde{v}_0$ by more AE sensitive parameter is the AE signals maximum amplitude (Fig. 4). Really, at increase $\tilde{v}_0$ in 2 time from 100000 to 200000 AE signals amplitude decreases by 10.29%, and AE signal duration decreases by 0.238%. At increase $\tilde{v}_0$ in 4 times from 100000 to 400000 AE signals amplitude decreases by 15.95%, and AE signal duration decreases by 0.444%. At increase $\tilde{v}_0$ in 5 time from 100000 to 500000 AE signals amplitude decreases by 17.11%, and AE signal duration decreases by 0.5%.

VI. Conclusion

Results of modeling CM elements destruction process by shear force with using von Mises criterion and AE signals depending from parameter characterizing CM properties are considered. It is defined that to increase of this parameter there is increase steepness falling of CM remained number elements curves change in time. Thus the AE signals maximum amplitude and duration decrease. Regularities of AE signals maximum amplitude and duration change with increase of parameter characterizing CM properties are received. It is shown that regularities have nonlinear nature of reduction. Statistical data processing with approximation of received regularities showed that dependences of AE signals maximum amplitude and duration reduction are well described by power functions.

It is also defined that reduction of formed AE signals maximum amplitude advances reduction of AE signals duration at increase parameter characterizing CM properties. So at increase of this parameter in 2 time the AE signal maximum amplitude decreases by 10.29%, and AE signal duration decreases by 0.238%. At increase of parameter characterizing CM properties in 5 times the AE signal maximum amplitude decreases by 17.11%, and AE signal duration decreases by 0.5%.

Conducted researches results can be used when developing methods and systems for control, diagnostics and monitoring condition products from CM by their production and operation. Further research influence of CM properties on formed AE signals energy parameters is interest.

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С. Ф. Філоненко, А. П. Стахова. Акустична емісія при зміні властивостей композита, який руйнується за критерієм Мізеса

Розглянуто результати теоретичних досліджень впливу параметра, що характеризує властивості композита, на параметри сигналів акустичної емісії при руйнуванні композиційного матеріалу поперечною силою з використанням критерію Мізеса. Визначено, що зі зростанням впливаючого параметру відбувається зменшення максимальної амплітуди і тривалості сигналів акустичної емісії, що формуються. При цьому зменшення максимальної амплітуди сигналів акустичної емісії передує зменшенню їх тривалості. Визначено, що закономірності зменшення максимальної амплітуди і тривалості сигналів акустичної емісії із зростанням параметра, що характеризує властивості композиційного матеріалу, добре описуються степеневими функціями.
Ключові слова: акустична емісія; амплітуда акустичної емісії; тривалість сигналу; критерій руйнування; композиційний матеріал.

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С. Ф. Филоненко, А. П. Стахова. Акустическая эмиссия при изменении свойств композита, разрушаемого по критерию Мизеса

Рассмотрены результаты теоретических исследований влияния параметра, характеризующего свойства композита, на параметры сигналов акустической эмиссии при разрушении композиционного материала поперечной силой с использованием критерия Мизеса. Определено, что с возрастанием влияющего параметра происходит уменьшение максимальной амплитуды и длительности формируемых сигналов акустической эмиссии. При этом уменьшение максимальной амплитуды сигналов акустической эмиссии опережает уменьшение их длительности. Определено, что закономерности уменьшения максимальной амплитуды и длительности сигналов акустической эмиссии с возрастанием параметра, характеризующего свойства композиционного материала, хорошо описываются степенными функциями.
Ключевые слова: акустическая эмиссия; амплитуда акустической эмиссии; длительность сигнала; критерий разрушения; композиционный материал.

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