Досліджено закономірності зміни сигналів акустичної емісії в наближенні моделей руйнування композиційного матеріалу у вигляді пучка волокон за критеріями OR і Мізеса. Показано, що із зростанням коефіцієнту, що характеризує відношення розмірів елементів композиційного матеріалу, відбувається наближення закономірності зміни еквівалентних напружень за критерієм OR до закономірності зміни за критерієм Мізеса. При визначеному значенні коефіцієнта за критерієм OR досягається узгодження еквівалентних напружень з мінімальним їх відхиленням один від одного. Однак дане узгодження обмежено визначеним інтервалом часу зміни.

Отримані закономірності зміни кількості елементів, що залишаються,і сигналів акустичної емісії за критерієм OR з наближенням до закономірності зміни за критерієм Мізеса. Показано, що при найкращому наближенні еквівалентних напружень за критеріями спостерігається добре узгодження закономірностей зміни кількості елементів композиту, що залишаються, в часі і параметрів формованих сигналів акустичної емісії з мінімальним їх відхиленням. Визначено, що відхилення параметрів сигналів акустичної емісії обумовлено різницею швидкості зміни еквівалентних напружень з наближенням до моменту часу початку руйнування композиційного матеріалу за критеріями OR і Мізеса.

Визначено, що із зростанням швидкості деформування композиційного матеріалу закономірності наближення зміни еквівалентних напружень за критерієм OR і критерієм Мізеса, кількості елементів композиту, що залишаються, і параметрів сигналів акустичної емісії зберігаються. Однак дані закономірності спостерігаються на менших інтервалах часу. Отримані результати можуть бути використані при дослідженні процесів руйнування композиційних матеріалів, з урахуванням впливу різних факторів

Ключові слова: акустична емісія, композиційний матеріал, параметри сигналів, критерії руйнування, еквівалентні напруження

UDC 620.179:534.6
DOI: 10.15587/1729-4061.2020.204820

STUDYING ACOUSTIC EMISSION BY FITTING THE DESTRUCTION MODELS OF A COMPOSITE ACCORDING TO THE OR CRITERION AND MISES CRITERION

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Received date 01.04.2020
Accepted date 02.06.2020
Published date 26.06.2020

1. Introduction

The high physical and mechanical characteristics of composite materials (CM) have led to their widespread use in various articles, including components that work under severe conditions. However, CMs are prone to fragile destruction. Minor damage can lead to the accelerated destruction of CMs and the loss of carrying capacity by the articles. From the point of view of monitoring, diagnosing, and forecasting the state of CMs, much attention is paid to both theoretical and experimental studies into the processes of their destruction aimed to predict the performance of a material under load.

Theoretical studies of CM destruction processes are carried out using different approaches, concepts, and models. The processes of CM destruction are analyzed both under conditions of stretching and shear. In this case, the regularities of changing the remaining elements of CMs over time are considered, as well as the patterns of changing acoustic emission (AE). If there are common trends in the construction of CM destruction models, the analysis of developing processes is considered using different destruction criteria and statistical distributions of deformable material characteristics by strength. In terms of forecasting a CM approaching total destruction, it is important to analyze the conditions under which the models and patterns of CM destruction processes are aligned, as well as AE for various criteria of destruction.

2. Literature review and problem statement

One of the models that have been widely used in the study of CM damage processes is the fiber bundle model (FBM) [1]. The model assumes that the loss of the composite's carrying capacity is due to the destruction of its fibers (elements). The CM elements are deformed elastically before destruction. The destruction of each element occurs instantly when it reaches a strength limit that follows a certain distribution. In this case, the destruction of CM is considered as a process of consistent destruction of its elements.

Most studies involving FBM address the destruction of CM at uniaxial stretching. The authors of paper [1] considered the process of destruction and derived expressions for the number of remaining elements and the accumulated energy of AE. It was shown that the patterns of their change are described by power laws until the moment close to the time of complete destruction of the CM. Work [2] shows that as the destruction process progresses, the size (quantity) of destruction over time increases, the time between successive destructions decreases, and the distribution rates of destruction change. Similar patterns are considered in paper [3]. Work [4] examines the process of breaking down a two-component system using the FBM model. The distributions of the number of destructible elements were analyzed, determining the transition from fragile to plastic destruction of the material. In [5], the FBM model is used with an analysis of the balance of potential, kinetic, and released energy. It is shown that the accumulated number of AE events and the accumulated energy of AE in the destruction of CM increase by a power law. The advancement of these studies is considered in paper [6]. The basic provisions of the FBM model are considered in [7], with the assumption about the distribution of the strength of CM elements according to Weibull, as evidenced by experimental studies involving AE. It shows that AE allows rapid determination of the distribution parameters according to Weibull. Work [8] examines the destruction process of optical CMs using the FBM model and a local load distribution rule. It was determined that the time of destruction follows a power law with respect to the applied load and the size of CM elements. In this case, the process of destruction is avalanche-like. In [9], under the condition of local distribution of the load, an expression was obtained for the process of accumulation of damage to the material during its loading. Analytical and numerical solutions are shown to have good agreement. The classic FBM model in [10] is complemented by two time-dependent recovery mechanisms: re-recovery of torn fibers and reducing the heterogeneity of local stresses (local loads). The analysis of the fiber rupture statistics showed a change in the distribution of avalanche-like destruction. This allows the transition to the type of developing destruction to predict the complete destruction of the material, which can be registered by using AE. The results obtained are consistent with the results of the experimental studies into AE [11]. In [12], under the condition of uniform load distribution, the energy balance of the entire fracture process was studied using various distributions of threshold levels of fracture In [12], under the condition of uniform load distribution, the energy balance of the entire fracture process was studied using various distributions of threshold levels of fracture. It was determined that in approaching the critical point of destruction elastic energy is always greater than the total energy of damage. That allows predicting the destruction of the material taking into consideration the relationship of the peak of elastic energy with the moment of destruction. Work [13] examines a modified FBM model, under which the load application is accompanied by a random shift of fiber (a material with the random distribution of fibers can be considered). In this case, all fibers have an equilibrium length, which, in the model, is a controlled parameter. The distribution of the number of broken fibers at every step of the iteration of the destruction process was considered. It was shown that at a certain value of the controlled parameter, the distribution at the critical stage of the destruction process is determined. Paper [14] examines the model of a bundle of fibers with thermal noise. The authors analyzed the unbalanced statistical mechanics for the ensembles of state when fibers are loaded. They derived the equations of state, the state balance equations, an expression for the dynamic entropy, and the potential of free energy. Distribution of the system state fluctuations was also determined. Work [15] examines the dynamics of avalanche-like destruction for a high-dimensional FBM model. It was shown that the average time profile of the development of avalanche destruction depends on the dimensionality of the system and varies from a strong asymmetrical shape to a symmetrical parabola. The FBM model was used in [16] to simulate two materials with different mechanical properties that interact with each other.

The FBM models of the destruction process of a heterogeneous material under the action of shear force at the even and local distribution of load were considered, respectively, in papers [17, 18], and of a granular material – in work [19]. Paper [17] examines the patterns of change in the equivalent stresses (according to the OR criterion and Mises criterion), as well as the number of remaining elements in the development of the process of destruction of the material.

Studies into the destruction process of CM using the FBM model are aimed at determining the critical stage of destruction. One of the main parameters is a change in the avalanche-type activity of destruction, which is characterized by a change in the form and parameters of the distribution of destruction dimensionality. In this case, the possibility of applying different variations of the FBM model, taking into consideration the threshold stresses, to analyze the processes of CM destruction is estimated based on the proximity of the parameters of the obtained distributions. At the same time, experimental analysis of theoretical studies is based on the processing of AE, usually an analysis of the energy distribution of AE or the number of events. This is due to the following. It is believed that the elastic energy stored in single fiber is released in the form of AE energy at an event with some proportionality factor, which is a constant. In this case, one considers the ratios for the rate at which the energy of AE events is released, rather than the AE signal formed.

However, the derived ratios characterize the processes of destruction and acoustic emission only approaching the complete destruction of a material as the examined functions are disrupted at a given moment. The presence of such ambiguity did not allow the authors to build a mathematical expression for an AE signal, which is formed when a composite material is destroyed. Based on the parameters of such a signal, it is possible to compile procedures for monitoring and predicting the CM destruction.

An expression for the AE signal generated in the CM destruction was derived in [20] by using the FBM model and the OR criterion. It was shown that the formed AE signal is a continuous pulse signal whose parameters depend on a series of factors – the deformation rate, the physical and mechanical characteristics of a CM, and the size of its elements.

At the same time, when considering the destruction process of a material using the FBM model, as shown in [17], it becomes possible to use other criteria of destruction. Such a criterion is the Mises criterion. According to the OR criterion, it is assumed that the destruction of a CM element under the action of a shear force occurs when its stretching or bending strain reaches a certain level, that is, two modes of the destruction of bending and stretching are independent. In contrast, according to the Mises criterion, the two destruction modes are interconnected via a non-linear function. In this case, the destruction would occur at lower stresses. That should lead to differences in the development of the destructive processes of CM elements and the formed

AE signals. Naturally, in terms of using AE to predict the CM destruction processes, it is interesting to study the patterns of change in the signal parameters in approximating the CM destruction models based on the OR criterion and Mises criterion.

3. The aim and objectives of the study

The aim of this study is to determine the patterns of change in AE signals in the approximation of CM destruction models in the form of a bundle of fibers according to the OR criterion and Mises criterion. This would make it possible to define the conditions for harmonizing AE signals when using the destruction of a CM in the form of a bundle of fibers according to the OR criteria and Mises criterion.

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

– to define the conditions for approaching the destruction of a composite according to the OR criterion and Mises criterion;

– to identify patterns of change in the number of remaining elements when a CM is destroyed according to the OR criterion in approximating to the number of remaining elements when the CM is destroyed according to Mises criterion;

– to determine patterns of change in the AE signals when the CM is destroyed according to the OR criterion in approaching to the AE signal when the CM is destroyed according to Mises criterion.

4. Conditions for modeling the patterns of change in the equivalent stresses, the number of remaining elements, and AE signals, when a composite is destroyed according to the OR criterion and Mises criterion

In work [20], a model of the CM destruction process by a shear force was built under the following assumptions. The sample material was supposed to consist of N_0 elements of the same size. The elements were evenly distributed throughout the sample volume. The influence of the matrix was not taken into consideration. It was believed that under the action of a shear force, the elements were deformed elastically. The distance between the planes of the fixing of the elements did not change. Under such loading of the composite, its elements were exposed to a bending moment and a stretching effort. It was believed that the destruction of the elements occurred in a consistent way when their deformation reached a certain threshold level, that is, destruction occurs through bending or stretching (the OR criterion). In this case, the external load is evenly distributed to the remaining elements. The remaining elements experience the same increasing axial deformity.

Taking into consideration an expression for changing the equivalent stresses on the CM elements for the case of independent uniform distributions of threshold levels with boundaries [0, 1], we derived the expressions for the number of remaining elements over time $N(t)$ when a CM was destroyed by a shear force and the AE formed signal $U(t)$ in the following form

$$N(t)=N_0 e^{-\upsilon_0 \int_{t_0}^{t} e^{r[\alpha t(1-\alpha t)(1-g\sqrt{\alpha t})-\alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})]}\mathrm{d}t}, \tag{1}$$

$$U(t)=U_0\upsilon_0\begin{bmatrix}\alpha t(1-\alpha t)\left(1-g(\alpha t)^{\frac{1}{2}}\right)- \\ -\alpha t_0(1-\alpha t_0)\left(1-g(\alpha t_0)^{\frac{1}{2}}\right)\end{bmatrix}\times$$
$$\times e^{r[\alpha t(1-\alpha t)(1-g\sqrt{\alpha t})-\alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})]}\times$$
$$\times e^{-\upsilon_0 \int_{t_0}^{t} e^{r[\alpha t(1-\alpha t)(1-g\sqrt{\alpha t})-\alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})]}\mathrm{d}t}, \tag{2}$$

where U_0 is the maximum possible offset when a CM sample, consisting of N_0 elements, is destroyed instantly. υ_0, r are the constants, depending on the physical and mechanical characteristics of a CM; α is the CM deformation rate; g is a factor that depends on the geometric size of CM elements; t_0 is the time when the CM elements begin to be destroyed.

The equivalent stresses on CM elements in the linear input of deformation, according to [17], are described in the following form

$$\sigma(t)=\alpha t(1-\alpha t)\left(1-g\sqrt{\alpha t}\right). \tag{3}$$

When using the Mises criterion, equivalent stresses are described, according to [17], in the following form

$$\sigma_m(t)=\alpha t\cdot 0.5\left[\begin{pmatrix}2-2\sqrt{\alpha t}+ \\ +\alpha t^{\frac{3}{2}}\log\left((1+\alpha t)/(1-\alpha t)\right)\end{pmatrix}\right.$$
$$\left.-\alpha t^{\frac{3}{2}}\begin{pmatrix}2\sqrt{\left(1-\sqrt{\alpha t}\right)/\alpha t}+ \\ +\log\left(\left(1+\sqrt{1-\sqrt{\alpha t}}\right)/\left(1-\sqrt{1-\sqrt{\alpha t}}\right)\right)\end{pmatrix}\right]. \tag{4}$$

Once we apply provisions from [20] to build a model of the CM destruction process using the Mises criterion, the expressions for the number of remaining elements over time $N(t)$ when the CM is destroyed by a shear force and the formed AE U signal $U(t)$ take the following form

$$N(t)=N_0 e^{-\upsilon_0 \int_{t_0}^{t} e^{r[\sigma_m(t)-\sigma(t_0)]}\mathrm{d}t}, \tag{5}$$

$$U(t)=U_0\upsilon_0\left[\sigma_m(t)-\sigma(t_0)\right]\times$$
$$\times e^{r[\sigma_m(t)-\sigma(t_0)]}\cdot e^{-\upsilon_0 \int_{t_0}^{t} e^{r[\sigma_m(t)-\sigma(t_0)]}\mathrm{d}t}, \tag{6}$$

where $\sigma_m(t)$, $\sigma(t_0)$ are, respectively, the change in the equivalent stress on CM elements and the threshold stress of the onset of CM elements destruction; t_0 is the moment when CM elements began to be destroyed; U_0 is the maximum possible offset at the instant destruction of a CM sample, consisting of N_0 elements; α is the CM deformation rate; υ_0, r are the constants, depending on the physical and mechanical characteristics of a material.

The expression $\sigma(t_0)$ in (5) and (6) corresponds (4), at $t=t_0$. Expression (4), according to [17], was derived at the parameter value g=1.

We shall simulate patterns of change in the number of remaining elements of CM and AE signals, according to (1), (2), (5), (6), by approximating the conditions for a composite destruction based on the OR criterion and Mises criterion. Underlying this approximation is determining the conditions (parameters) for approximating the patterns of change in equivalent stresses, according to (3) and (4).

The simulation will be carried out in relative units under the following conditions. The rate of deformation, constants υ_0, r that depend on the CM physical and mechanical characteristics, are accepted equal to $\tilde{\alpha}=10$; $\tilde{\upsilon}_0=100{,}000$ and $\tilde{r}=10{,}000$. The U_0 parameter value is accepted equal to $\tilde{U}_0=1$. The moment of the onset of the destruction of the CM elements based on the Mises criterion t_0 is taken equal to $\tilde{t}_0=0.01$. A given point of time corresponds to the threshold stress of the onset of the destruction of CM elements equal to $\tilde{\sigma}(\tilde{t}_0)=0.05862777965495844$. The threshold stress of the onset of CM destruction based on the OR criterion is accepted equal to stress $\tilde{\sigma}(\tilde{t}_0)$ based on the Mises criterion. The magnitude of the g parameter in (3) is to change from $\tilde{g}=0.2$ to $\tilde{g}=1.10231$. For all g values, the stress of the onset of CM destruction when modeling the number of remaining CM elements and AE signals remains constant.

5. Results of modeling the patterns of change in the equivalent stresses, the number of remaining elements and AE signals when a composite is destroyed according to the OR criterion and Mises criterion

To determine the conditions for approaching the destruction of a composite according to the OR criterion and Mises criterion, we shall model patterns of change in the equivalent stresses according to (3) and (4). The results of this simulation, for the accepted conditions, are shown in Fig. 1.

When building dependence 6 in Fig. 1, the value $\tilde{g}=1.10231$ corresponds to the lowest deviation of dependences of change in the equivalent stresses using the OR criterion and Mises criterion over time $\tilde{t}[0, 0.1]$. In this case, the maximum deviation of equivalent stresses, according to (3) and (4), over a given time period for curves 6 and 7 (Fig. 1), as the calculations show, does not exceed 1.27 %, and, at stresses $\tilde{t}=\tilde{t}_0=0.01$, coincide (the deviation in the equivalent stresses equals 0). With the further increase in time, there is a gradual increase in the deviation of equivalent stresses when using the Mises criterion from the equivalent stresses when using the OR criterion. This is well observed in Fig. 2, which shows a fragment of the dependences of change in the equivalent stresses for curves 6 and 7, shown in Fig. 1, in the region of value $\tilde{t}=\tilde{t}_0=0.01$. Fig. 2 also shows that the rate of change in equivalent stresses for the OR criterion is greater than that for the Mises criterion.

Fig. 3, *a* shows the results of the simulation of patterns of change in the remaining elements when a CM is destroyed according to the OR criterion and Mises criterion, in line with (1) and (5). When modeling dependences (1) to (6) (Fig. 3, *a*) with a threshold stress of the onset of CM destruction $\tilde{\sigma}(\tilde{t}_0)=0.05862777965495844$ for the values of $\tilde{g}$, equal to 0.2, 0.4, 0.6, 0.8, 1.0, 1.10231, the time of the destruction onset $\tilde{t}_0$, is, respectively, 0.006619; 0.007058; 0.0076031; 0.008311; 0.0093; 0.01. The time of the onset of CM destruction according to the Mises criterion was 0.01. When building each diagram in Fig. 3, the time is normalized for the relevant time of the onset of CM destruction.

The results of modeling the dependences of change in the amplitude of AE signals over time, according to (2) and (6), are shown in Fig. 3, *b*. When building the diagrams in Fig. 3, *b* for the constant value of the threshold stress of destruction, the times of the onset of CM destruction are similar to the values used in the construction of diagrams in Fig. 3, *a*. As is the case for diagrams in Fig. 3, *a*, when building the diagrams in Fig. 3, *b*, the times are normalized for the appropriate time of the onset of CM destruction.

The results of treating the parameters of AE model signals are given in Table 1. In Table 1 the following designations are adopted: $\tilde{U}_m$, $\tilde{\tau}$, $\tilde{E}$ are, respectively, the maximum amplitude, duration, and energy of the AE signal; $\tilde{g}$ is the coefficient that depends on the geometric size of CM elements.

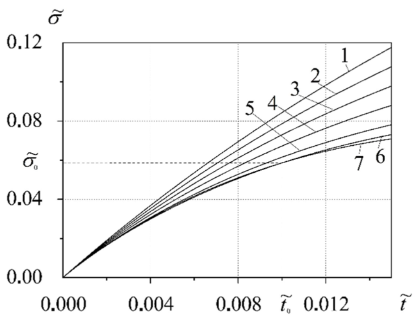


Fig. 1. Patterns of change in equivalent stresses in the linear introduction of CM deformation using the OR criterion (1, 2, 3, 4, 5, 6) and using the Mises criterion (7). The $\tilde{g}$ parameter values when the OR criterion is applied: 1 – 0.2; 2 – 0.4; 3 – 0.6; 4 – 0.8; 5 – 1.0; 6 – 1.0231

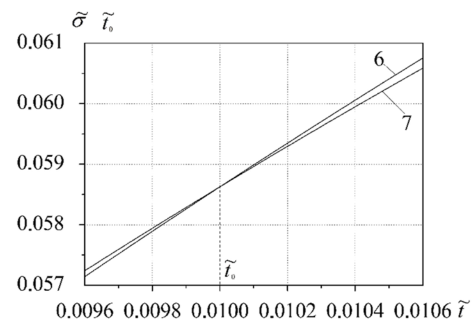


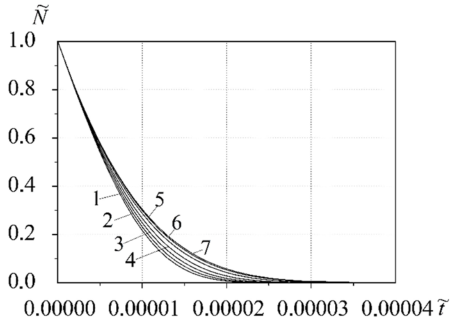
Fig. 2. Fragment of patterns of change in the equivalent stresses for curves 6, 7, shown in Fig. 1, in the region of the value $\tilde{t}=\tilde{t}_0=0.1$

Table 1

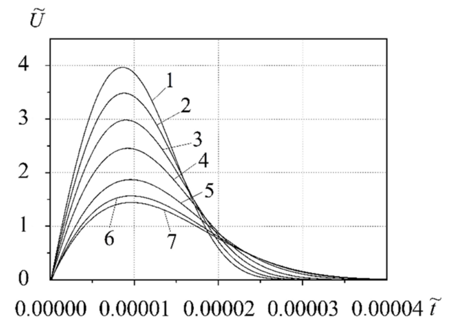
Parameters of the AE model signals when CM is destroyed according to the OR criterion and Mises criterion

Criterion	$\tilde{g}$	$\tilde{U}_m$	$\tilde{\tau}$	$\tilde{E}$
OR criterion	0.2	3.96604	3.1E-5	1.57295E-6
	0.4	3.48453	3.2E-5	1.21419E-6
	0.6	2.98282	3.44E-5	8.89722E-7
	0.8	2.4547	3.75E-5	6.02555E-7
	1.0	1.87097	4.19E-5	3.50053E-7
	1.10231	1.56814	4.52E-5	2.45906E-7
Mises criterion	1.0	1.44489	4.66E-5	2.08771E-7

According to (2) and (6), a change in the amplitudes of the formed AE signal at the rear front is asymptomatic. Therefore, in determining the duration of AE signals, we confined ourselves to the third order of smallness of the amplitude at the rear front. The energy of the signals was determined over the specified duration of the AE signals.



a



b

Fig. 3. Destruction of CM according to the OR criterion (1, 2, 3, 4, 5, 6) and to Mises criterion (7): *a* — patterns of change in the number of remaining elements; *b* — patterns of change in the amplitude of AE signals. The $\tilde{g}$ parameter values when the Mises criterion is applied: 1 — 0.2; 2 — 0.4; 3 — 0.6; 4 — 0.8; 5 — 1.0; 6 — 1.0231

6. Discussion of results of modeling the patterns of change in equivalent stresses, the number of remaining elements, and AE signals, when a composite is destroyed according to the OR criterion and Mises criterion

The results of our simulation show that in the linear introduction of CM deformation the patterns of change in equivalent stresses, both when using the OR criterion and the Mises criterion, demonstrate a non-linear pattern of increase (Fig. 1). The increase in the $\tilde{g}$ parameter leads to a decrease in the rate of increase in the pattern of change in equivalent stresses according to the OR criterion and their gradual approaching the pattern of change in the equivalent stresses according to the Mises criterion. However, at $\tilde{g}=1.0,$ with the increase in time, there is an increase in the deviation of equivalent stresses under the OR criterion from that according to the Mises criterion (curves 5, 7 Fig. 1). Thus, at the point of time $\tilde{t}=0.01,$ this deviation is 5 %, at $\tilde{t}=0.012$ – 7 %, at $\tilde{t}=0.015$ – 9.3 %. At the same time, at $\tilde{g}=1.10231,$ over the time period $\tilde{t}[0, 0.1]$, there is the best match between equivalent stresses according to the OR criterion and Mises criterion (curves 6, 7 Fig. 1). In this case, the maximum deviation over a given time period is 1.27 %, and, at $\tilde{t}=0.01,$ the equivalent stresses are equal. However, as the destruction onset time $\tilde{t}_0=0.01$ approaches, the rate of an increase in the equivalent stresses according to the OR criterion is higher than that according to the Mises criterion (Fig. 2).

The results of the simulation of the CM destruction process at the constant value of the threshold stress of the destruction onset $\tilde{\sigma}(\tilde{t}_0)$ show that the patterns of change in the non-destroyed elements over time demonstrate a continuous nature of descent (Fig. 3, *a*). Increasing the $\tilde{g}$ parameter leads to a decrease in the rate of descent of the patterns of change in the non-destroyed elements according to the OR criterion (curves 1...6, Fig. 3, *a*) and their gradual approaching the pattern of change in the not destroyed elements according to the Mises criterion (curve 7, Fig. 3, *a*). In this case, the duration of the destruction process of CM elements is increasing. Such patterns of change in the number of non-destroyed CM elements are due to a decrease in the rate of increase in the equivalent stresses. At $\tilde{g}=1.10231,$ the best match is observed between the patterns of change in the non-destroyed elements over time according to the OR criterion and Mises criterion (curves 6, 7, Fig. 3, *a*).

Simulation of the patterns of change in the amplitude of AE signals, according to (2) and (6), shows that the signals formed are pulsed signals. Reducing the rate of the destruction process of CM elements with an increase in the $\tilde{g}$ parameter leads to a decrease in the amplitude and energy of the AE signal, as well as to an increase in its duration (curves 1....6, Fig. 3, *b*, Table 1). At the same time, there is a gradual approach by the pattern of change in the signal amplitude to the AE signal when using the Mises criterion (curve 7, Fig. 3, *b*, Table 1). The comparison of AE signals when the CM is destroyed according to the OR criterion at $\tilde{g}=1.10231$ (a value of the best fit parameter) and the Mises criterion shows that with the same value of threshold stress $\tilde{\sigma}(\tilde{t}_0)$ and the same time $\tilde{t}_0=0.01$ of the onset of destruction, the signals parameters differ from each other (Table 1). The maximal AE signal amplitude for the Mises criterion is less than the maximal signal amplitude for the OR criterion by 7.86 %, the signal energy is 15 % lower, and the signal duration is longer by 3 %. This difference in the parameters of AE signals is due to the difference in the rate of change in the equivalent stresses in proportion to approaching the time of destruction onset $\tilde{t}_0=0.01.$ The rate of increase in the equivalent stresses according to the OR criterion is higher than that according to the Mises criterion (Fig. 2). This increase in rate is 7.37 %. However, as the calculations show, at value $\tilde{g}=1.2$ and when all other modeling parameters are constant, approaching the threshold stress of CM destruction onset $\tilde{\sigma}(\tilde{t}_0)=0.05862777965495844,$ the rate of increase in the equivalent stresses according to the OR criterion is 12.7 % lower than that according to Mises criterion. Under such conditions, the amplitude of the AE signal formed when the CM is destroyed according to the OR criterion is 15 % less than that according to the Mises criterion.

Our study also shows that at $\tilde{\upsilon}_0=100000,$ $\tilde{r}=10000,$ $\tilde{g}=1.10231,$ as the speed of the linear introduction of CM deformation increases, the above patterns are preserved. Thus, at $\tilde{\alpha}=20,$ the lowest deviation of equivalent stresses when using the OR criterion and Mises criterion (best-fit approximation) is observed over the time frame $\tilde{t}[0,\ 0.05]$. At the same time, the maximum deviation of equivalent stresses, according to (5) and (6), over a given time period does not exceed 1.27 %. At $\tilde{t}=\tilde{t}_0=0.005,$ the deviation of equivalent stresses is 0. At $\tilde{\alpha}=40,$ similar patterns are observed over the time period $\tilde{t}[0,\ 0.025]$. The maximum deviation of stresses is 1.27 %. In this case, for $\tilde{\alpha}=20$ and $\tilde{\alpha}=40,$ the percentage deviation of the AE signals' parameters is maintained.

A condition for approaching by the patterns of change in the amplitude of AE signals when a CM is destroyed according to the OR criterion and Mises criterion is approaching the patterns of change in the equivalent stresses according to these criteria. The best fit is achieved by changing the coefficient that characterizes the ratio of the linear sizes of CM elements. However, a given fit is limited to a certain period of time for changes in equivalent stresses. AE is sensitive to the speed of change in the equivalent stresses as it approaches the time of the onset of CM destruction. This leads to a certain deviation in the parameters of AE signals when the CM is destroyed according to the OR criterion and Mises criterion. At the same time, the expressions for the number of remaining elements over time and the AE signals include parameters that characterize the CM physical and mechanical properties. This allows us to undertake research aimed at determining the additional conditions for harmonizing AE signals when a CM is destroyed according to the OR criterion and Mises criterion with changes in these parameters.

7. Conclusions

1. The conditions have been determined under which the destruction of a composite according to the OR criterion approaches that according to the Mises criterion. It is shown that the basis for their approaching is approaching the patterns of change in the equivalent stresses. It has been determined that at a certain value of the coefficient characterizing the size of CM elements the best fit between the equivalent stresses and their minimum deviation of 1.27 % is achieved. However, this fit is limited to a specific time interval.

2. We have defined patterns of change in the number of the remaining elements when CM is destroyed according to the OR criterion with approaching to the number of the remaining elements in the destruction of the CM according to the Mises criterion. It is shown that the smallest deviation of the received patterns (no more than 3 %) is observed while approaching a change in the equivalent stresses according to the OR criterion to the equivalent stresses according to the Mises criterion.

3. Patterns of change in the AE signals when the CM is destroyed according to the OR criterion approaching the AE signal, when the CM is destroyed according to Mises criterion, have been determined. It is shown that, with the best approximation of the patterns of change in the equivalent stresses, AE signal parameters deviate when CM is destroyed according to the OR criterion and the Mises criterion (the deviation of the amplitude, duration, and energy of AE signals, is, respectively, 7.86 %, 3 %, and 15 %). Such deviations are due to differences in the rates of change in the equivalent stresses as the CM is approaching the time of the onset of the destruction. In this case, the rate of increase in the equivalent stresses according to the OR criterion is 7.37 % higher than that according to the Mises criterion. In order to determine the additional conditions for harmonizing the AE signals, it is necessary to conduct a study into the influence of parameters that characterize the CM physical and mechanical properties under certain conditions of fitting the patterns of change in the equivalent stresses according to the OR criterion and Mises criterion.

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