UDC 620.179:534.6

S. Filonenko, A. Stakhova
(National Aviation University, Ukraine)

Influence of composite properties dispersity during its destruction according to von Mises criterion on acoustic radiation energy

Abstract. The results of acoustic radiation energy modelling during the composite destruction by shear force according to von Mises criterion are considered. It is shown that for given loading conditions decrease of composite properties dispersion leads to increase of acoustic radiation maximum energy. The patterns of acoustic emission signals maximum and total energy change are determined. It is shown that the regularity of acoustic emission signals maximum energy increase is well described by a power function. The pattern of acoustic emission signals total energy decrease is well described by a linear function. It has been determined that the most sensitive amplitude-energy parameter of acoustic emission to composite properties dispersion decrease is the acoustic emission signals maximum energy. It is shown that the acoustic emission signals maximum energy increase is ahead of acoustic emission signals maximum amplitude increase and total energy decrease.

1. Introduction

In the scientific literature, much attention is paid to study of composite materials (CM) processes destruction. This is due to the tendency of CM brittle fracture. When carrying out theoretical studies of CM destruction, various approaches to represent of CM structure are used. The destruction process is analyzed to determine the parameters characterizing of CM limiting state, or to determine the time of material complete destruction approach. Research is aimed at developing methods for monitoring and predicting of CM destruction.

In experimental studies of CM processes destruction various methods are used. One of such methods is the acoustic emission (AE) method. The method has a low inertia and high sensitivity to submicro, micro and macro processes of materials destruction, including CM. Significant amounts information about the processes occurring in materials structure during their deformation are obtained.

However, different levels in material structure processes lead to the problem of interpreting the recorded information. The problem is further complicated by the fact that various factors is affected on AE, such as deformation rate, material properties dispersion and others. This complicates to using of AE in the development methods of control, monitoring, and diagnostic CM and products made from CM.

From this point of view, theoretical studies of AE during CM development destruction processes are of importance. Such studies make it possible to analyze the various influence factors on the AE signals formation processes under conditions of static and dynamic CM loading. In this case, it is possible to determine the patterns of acoustic radiation parameters changes under the action of various factors.

Such regularities are the basis for interpreting the CM structure developing processes during their loading, as well as the basis for developing methods of control, monitoring and diagnostic the CM and products from CM state.

2. Review of publications

Various concepts and models at CM destruction processes study are used. Thus, in articles [1, 2] a discrete model of CM destruction is considered, in article [3, 4] a diffusion model of destruction, in articles [5, 6] a model of phase field destruction and others. However, in a significant number of studies, representation the fiber bundle model (FBM) is used [7, 8, 9]. In this case, the CM destruction processes under uniaxial tension and shear force are considered. For both types of loading conditions, the main provisions of FBM are preserved. The studies analyze the rate of remaining elements change in time with a local distribution of on the remaining elements or with a uniform distribution of load on all the remaining elements. In this case, analysis of CM full destruction expected time for a given applied load value is also made. In general terms, the FBM model has a modifications number that consider different laws of threshold fracture stresses distribution, different fiber sizes, repeated restoration of fibers with a decrease in local stress inhomogeneity, consideration of thermal noise, and others.

In articles [10, 11], analysis of CM destruction process under the action of shear force using OR rule and von Mises criterion was carried out. Expressions for the patterns of equivalent stresses change for the particular case independent uniform distributions of threshold levels fracture with boundaries [0,1] are obtained. The research results made it possible to obtain a number the analytical and numerical patterns of remaining number elements (fibers) changes over time during the composite material development process destruction. Analysis of acoustic radiation during CM development destruction process [12] is also made. In the studies it is assumed that the elastic energy stored in a single fiber is released as AE event energy with a certain proportionality coefficient, which is a constant. In this case, the AE signals formation process is not considered. The process of acoustic radiation energy accumulation as it approaches in time to complete destruction is analyzed.

Expression for AE signal formation during CM destruction by a shear force using OR criterion is considered in article [13]. It is shown that during of CM destruction elements continuous process a continuous AE signal is formed. The signal is a pulse signal. Its parameters depend on a number of factors – CM loading rate, CM physical and mechanical characteristics and others.

Regularities of various factors influence on the AE signal formation parameters are obtained. In [14], the expression for the AE signal during CM destruction by shear force according to von Mises criterion is considered in the form

$$U(t) = U_0 \upsilon_0 [\sigma_m(t) - \sigma(t_0)] \cdot e^{r[\sigma_m(t)-\sigma(t_0)]} \cdot e^{-\upsilon_0 \int_{t_0}^{t} e^{r[\sigma_m(t)-\sigma(t_0)]} dt}, \qquad (1)$$

where $\sigma_m(t)$, $\sigma(t_0)$ - respectively, CM elements equivalent stress change in time on a linear input deformation $\varepsilon = \alpha t$ (α is the deformation rate) and threshold stress corresponding to the time t_0 of CM elements beginning destruction;

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

$$\sigma(t_0) = \alpha t_0 \cdot 0.5 \Big[\Big(2 - 2\sqrt{\alpha t_0} + \alpha t_0^{\frac{3}{2}} \log((1+\alpha t_0)/(1-\alpha t_0))\Big)$$

$$-\alpha t_0^{\frac{3}{2}}\left(2\sqrt{(1-\sqrt{\alpha t_0})/\alpha t_0}+\log\left(\left(1+\sqrt{1-\sqrt{\alpha t_0}}\right)/\left(1-\sqrt{1-\sqrt{\alpha t_0}}\right)\right)\right)\Bigg]. \quad (3)$$

$U_0 = N_0\, \beta\, \delta_S$ - is the maximum possible displacement during the instantaneous CM destruction, consisting of N_0 elements; β – proportionality coefficient between the fracture stress and single perturbation pulse amplitude during CM single element destruction; δ_s - parameter, the numerical value of which is determined by the shape of single perturbation pulse during CM single element destruction; υ_0, r – are constants depending from CM physical and mechanical characteristics.

As in the case of OR criterion, various factors influence on the AE formation signal parameters. The AE formation signals parameters during CM destruction according to OR criterion and von Mises criterion were compared. The conditions for model approximation and differences in AE signals parameters when using different failure criteria are shown.

In article [15], the simulation of AE signals energy during CM destruction by shear force out using von Mises criterion depending on the parameter characterizing CM properties was carried. It is shown that as this parameter increases, acoustic radiation energy and total energy decrease. The obtained patterns of AE signals maximum and total energy change have a non-linear decrease. Dependencies are well described by power functions. It is also shown that with increasing influencing parameter value, maximum energy decrease is ahead to decrease of AE signals maximum amplitude, and total energy decrease is ahead of AE signals maximum energy decrease.

At the same time, one of the parameters that effects on AE is CM properties dispersion. Undoubtedly, it is of interest to study the influence of CM properties dispersity on AE energy during CM destruction according to von Mises criterion.

3. Statement of the task

The aim of this work is: to modelling of AE signals energy during CM destruction by shear force using FBM and von Mises criterion with composite properties dispersion change; to determine the dependence of AE signals maximum energy and total energy change with CM properties dispersion decrease; to describe the obtained regularities; to determine of AE signals amplitude-energy parameters sensitivity to decrease of composite properties dispersion.

4. Research results

Modelling of acoustic radiation energy will be carried out in two stages. At the first stage, we will simulate the AE signals, according to (1), under the following conditions.

The CM deformation rate α will be taken equal $\tilde{\alpha}$=10. The time $\tilde{t}_0$ of beginning CM destruction will be $\tilde{t}_0$=0.004. This time $\tilde{t}_0$ corresponds to the threshold stress $\tilde{\sigma}_0(\tilde{t}_0)$ of CM beginning destruction equal $\tilde{\sigma}_0$=0.03037385029676163. The value of the parameter $\tilde{\nu}_0$ will be taken equal $\tilde{\nu}_0$=100000. The value of parameter r will be changed in the range of values from $\tilde{r}$=10000 to $\tilde{r}$=26000 with an incremental step $\Delta\tilde{r}$=40000.

At the second stage, according to the results of the first stage, we will carry out calculations and study the patterns of AE signals maximum energy change and AE signals total energy. We will carry out calculations using expressions of the form

$$E(t) = \Delta t_k i U_i^2 \quad (4)$$
$$E_{sum} = \Delta t_k i \sum_i U_i^2 , \quad (5)$$
where i = 0,…., k – number of AE signal amplitude calculated value on its durationτ; Δt_k – time interval between the calculated values of AE signal amplitudes (Δt_k=const).

When modelling, according to (4) (5), the time interval Δt_k between AE signal amplitudes calculated values will be $\Delta \tilde{t}_k = 1 \cdot 10^{-7}$.

The results of calculations AE signals energy dependences change in time in relative units, according to (4), are shown in Fig. 1. The processing obtained data in the form of AE signals maximum and total energy dependences change in relative units with increasing of parameter value $\tilde{r}$ is shown in Fig. 2.

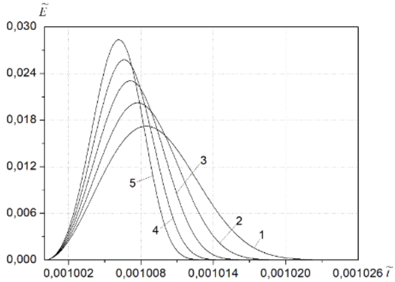
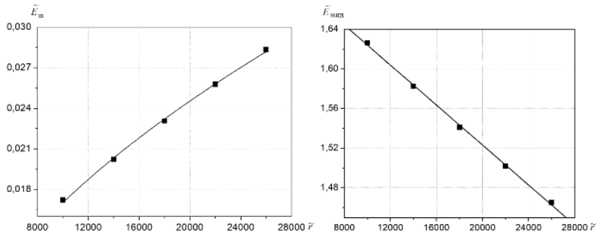


Figure 1. Graphs of AE signal energy changes in relative units during of CM elements destruction by shear force with a composite property's dispersion change. Parameter value r: 1 - $\tilde{r}$=10000; 2 - $\tilde{r}$=14000; 3 - $\tilde{r}$=18000; 4 - $\tilde{r}$=22000; 5 - $\tilde{r}$=26000. $\tilde{\upsilon}_0$=100000, $\tilde{\alpha}$=10. $\tilde{\sigma}_0$= 0.008897277688462064. Beginning destruction time $\tilde{t}_0$ = 0.001



a *b*

Figure 2. Dependences of AE signals maximum energy change (a) and AE signals total energy with change of composite property dispersion in relative units during the CM destruction by shear force. Simulation parameters: $\tilde{\alpha}$=10, $\tilde{\upsilon}_0$=100000, $\tilde{\sigma}_0$= 0.008897277688462064

Analysis dependencies shown in fig. 2 showed the following. Dependence fig. 2, but is well described by a power function of the form

$$\tilde{E}_m = a\tilde{r}^b , \quad (6)$$

where $\tilde{E}_m$ – maximum energy of AE signals; a and b are the approximating expression coefficients.

The values of approximating expression coefficients (6) are: - a =0.00013, b= 0.52763. When describing the dependence in Fig. 2, a determination coefficient R^2 was R^2=0.99867.

Dependence Fig. 2, b is well described by a linear function of the form

$$\widetilde{E}_{sum} = d\tilde{r} + c, \tag{7}$$

where $\widetilde{E}_{sum}$ – AE signals total energy; d and c are approximating expression. coefficients

The values of approximating expression coefficients (7) are: - d =-1,00932$\cdot 10^{-5}$, c= 1,72493. When describing the dependence in Fig. 2, b, the correlation coefficient R was R=-0,99936.

The criterion for choosing expressions (6) and (7) to describe of AE signals maximum and total energy dependences change with increasing $\tilde{r}$, shown in Fig. 2, was the minimum value of residual variance and standard deviation.

Let us compare of AE signals amplitude-energy parameters sensitivity to composite property's dispersion change during its destruction according to von Mises criterion. To do this, we will process of AE signals maximum amplitude, maximum energy and total energy change in relation to their initial values at $\tilde{r}$ =100000 as a percentage. The results of the performed processing are shown in Fig. 3.

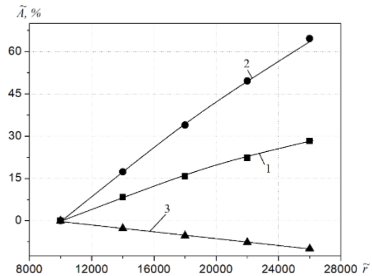


Figure 3. Dependences of AE signals maximum amplitude (1), maximum energy (2) and total energy (3) change in percentage terms with a change of composite properties dispersion

On Fig. 3, the following notation is adopted: $\widetilde{A}$,% – AE signals analyzed parameter – maximum amplitude, maximum energy or total energy of AE signal.

5. Discussion of research results

The studies show that at CM destruction by shear force according to von Mizes criterion with increase of parameter $\tilde{r}$ (decrease of composite properties dispersion), increase of AE signals energy (Fig. 1) is observed. The dependence of maximum energy change increases non -linear (Fig. 2, a). In this case, the total energy is reduced (Fig. 2, b).

The approximation of obtained dependencies showed that the pattern of AE signals the maximum energy change is well described by the degree function. The pattern of AE signals total energy change is well described by a linear function.

A comparison of AE signals amplitude-energy parameters sensitivity (Fig. 3) with decrease of composite properties dispersion showed following. With increase the value of parameter $\tilde{r}$ increase of AE signals maximum energy is ahead to increase of

AE signals maximum amplitude. In this case, increase of AE signals maximum amplitude and maximum energy is ahead to decrease of AE signals total energy of the of the AE.

Thus, at increasing $\tilde{r}$ in 1.4 times (from 10000 to 14000) AE signals maximum amplitude increase by 8,34 %, AE signal maximum energy increase by 17.36%, and AE signal total energy decreases by 2.69 %. At increasing $\tilde{r}$ in 2.2 times (from 10000 to 22000) AE signals maximum amplitude increase by 22,32 %, AE signal maximum energy increase by 49.59 %, and AE signal total energy decreases by 7.67 %. At increasing $\tilde{r}$ in 2.6 times (from 10000 to 26000) AE signals maximum amplitude increase by 28,28 %, AE signal maximum energy increase by 64.58 %, and AE signal total energy decreases by 9.92 %.

The results of performed studies show that the most AE signals sensitive parameter to decrease of composite properties dispersion during its destruction by shear force according to von Mises criterion is the AE formation signal maximum energy. According to obtained data, increase of AE signals maximum energy significantly outstrips the increase of AE signal maximum amplitude and decrease its total energy. The results of conducted studies can be used in the development the methods of control, monitoring and diagnostics CM and products from composite materials, as well as in the development the methods of monitoring CM properties uniformity.

6. Conclusion

The results of modelling acoustic radiation energy during CM destruction by shear force according to von Mises criterion with decrease of composite properties dispersion are considered. It is determined that for the given CM loading conditions, decrease of composite properties dispersion leads to increase of AE formation signal maximum energy. Such increase of maximum energy is due to composite development destruction process acceleration. However, the total energy of acoustic radiation decreases, which is associated with a decrease of destruction process in time. The patterns of AE signals maximum energy and total energy change with decrease of composite properties dispersion are determined. It is shown that increase of maximum energy has a non-linear nature, while a decrease of total energy has a linear nature. The description of obtained regularities is carried out. The sensitivity of AE signals amplitude-energy parameters to decrease of composite properties dispersion is compared. It is shown that with decrease of composite property's dispersion (increase the value of parameter $\tilde{r}$), increase of AE signals maximum energy outstrips increase of AE signals maximum amplitude and decrease of AE signals total energy.

Thus, at increasing $\tilde{r}$ in 2.2 times AE signals maximum amplitude increase by 22.32%, AE signals maximum energy increase by 49.59%, and AE signal total energy decrease by 7.67%. At increasing $\tilde{r}$ in 2.6 times AE signals maximum amplitude increase by 28,28 %, AE signals maximum energy increase by64.58 %, and AE signal total energy decrease by 9.92 %.

The obtained results showed that for given CM loading conditions, the most AE sensitive parameter to decrease of composite properties dispersity is the AE signal maximum energy.

In further works, it is of interest to determine the factors that have greatest influence on AE signals amplitude-energy parameters during composite destruction by shear force according to von Mises criterion.

References

1. Barbero E. J., and Cosso F. A. 2014 Determination of material parameters for discrete damage mechanics analysis of carbon-epoxy laminates. Composites Part B: Engineering 56 pp 638-646.
2. Jin W., and Arson C. 2018 Micromechanics based discrete damage model with multiple non-smooth yield surfaces: Theoretical formulation, numerical implementation and engineering applications. International Journal of Damage Mechanics 27(5) pp 611-639.
3. Oliver J. 1989 A consistent characteristic length for smeared cracking models. International Journal for Numerical Methods in Engineering 28(2) pp 461-474.
4. Heinrich C., and Waas A. 2012, April Investigation of progressive damage and fracture in laminated composites using the smeared crack approach. In 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference 20th AIAA/ASME/AHS Adaptive Structures Conference 14th AIAA (p. 1537).
5. McAuliffe C., and Waisman H. 2016 A coupled phase field shear band model for ductile–brittle transition in notched plate impacts. Computer Methods in Applied Mechanics and Engineering 305 pp 173-195.
6. Dzepina B., Balint D., and Dini D. 2019 A phase field model of pressure-assisted sintering. Journal of the European Ceramic Society 39(2-3) pp 173-182.
7. Danku Z., and Kun F. 2014 Record breaking bursts in a fiber bundle model of creep rupture. Frontiers in Physics 2 p 8.
8. Hader A., Boughaleb Y., Achik I., and Sbiaai K. 2013 Failure kinetic and scaling behavior of the composite materials: Fiber Bundle Model with the local load-sharing rule (LLS). Optical Materials 36(1) pp 3-7.
9. Capelli A., Reiweger I., Lehmann P., and Schweizer J. 2018 Fiber-bundle model with time-dependent healing mechanisms to simulate progressive failure of snow. Physical Review E 98(2) p 023002.
10. Kun F., Hidalgo R., Raischel F., and Herrmann H 2006 Extension of fibre bundle models for creep rupture and interface failure. International journal of fracture 140(1) pp 255-265.
11. Raischel F., Kun F., and Herrmann H. 2005 Simple beam model for the shear failure of interfaces. Physical Review E 72(4) p 046126.
12. Shcherbakov R. 2002 On modeling of geophysical problems. Cornell University. 209 P.
13. Filonenko S., Kalita V., and Kosmach A. 2012 Destruction of composite material by shear load and formation of acoustic radiation. Aviation 16(1) pp 1-9.
14. Filonenko S., and Stakhova A. 2020 Studying acoustic emission by fitting the destruction models of a composite according to the OR criterion and Mises criterion. Восточно-Европейский журнал передовых технологий 3(9-105) pp 39-45.
15. Filonenko S., and Stakhova A. 2021 Acoustic Emission at Properties Change of Composite Destructed by von Mises Criterion. Electronics and Control Systems 1(67) pp 54-60.