



## TWO APPROACHES TO THE DESCRIPTION OF ACOUSTIC EMISSION SIGNALS IN THE KINETIC MODEL OF COMPOSITE DESTRUCTION

Sergey Filonenko<sup>1</sup>, Viktor Kalita, Tatiana Nimchenko

National Aviation University, Kyiv, Ukraine. E-mail: <sup>1</sup>files01@mail.ru (corresponding author)

Received 14 March 2010; accepted 24 May 2011



**Sergey FILONENKO**, Prof. Dr Habil

Date and place of birth: 1954, Echmiadzin, Armenia.

Education: Kiev Polytechnic Institute. Affiliation and functions: Director of the Institute of Information Diagnostic Systems at the National Aviation University since 2008. Research interests: diagnostics of technological processes, automatic diagnostic systems. Publications: over 190 books and articles, 31 patents.



**Viktor KALITA**, Prof. Dr Habil

Date and place of birth: 1962, Chernigov, Ukraine.

Education: Rostov on Don State University.

Affiliation and functions: Professor of physics, National University of Ukraine since 2008. Research interests: solid-state physics, technical diagnostics. Publications: over 80 articles.



**Tatiana NIMCHENKO**

Date and place of birth: 1980, Kiev, Ukraine.

Education: National Aviation University.

Affiliation and functions: assistant at National Aviation University since 2007. Research interests: diagnostics of technological processes, signal processing. Publications: over 50 articles.

**Abstract.** Acoustic emission signals in non-coherent addition of waves and coherent addition of displacement were analysed. It is shown that for non-coherent addition of waves the area under a curve of a temporary course of acoustic emission intensity does not depend on the entry speed of the load. For an acoustic emission, which is calculated by addition of displacement impulses, the area under a curve of change of effective amplitude in time does not depend on the entry speed of the load.

**Keywords:** acoustic emission, stress, loading, signal of acoustic emission, intensity of acoustic emission, fracture, composite material, fibre bundle model, acoustic waves.

### 1. Introduction

Much attention is given to the research of the acoustic emission (AE) phenomenon, which can be observed at the destruction of different materials (Hadjab 2007; Chandra *et al.* 2004; Bocchieri *et al.* 2003; Rajendraboopathy *et al.* 2008; Malcharczikova *et al.* 2006; Babak *et al.* 2005; Filonenko *et al.* 2009). It is caused by the

fact that AE is a corollary of internal processes that take place in materials when they are loading. The analysis and processing of AE information have practical application and are used for diagnostics of the technical condition of different products. At the same time, description of the origin of acoustic emission and its connection with

the processes of plastic deformation and destruction of materials are difficult tasks.

It is accepted (Wadley, Scruby 1983; Shibata 1984; Grosse *et al.* 2008; Андрейкив, Лысак 1989) that AE is considered as a wave process because the acoustic emission which is formed in the wave zone (that is a relaxation zone for stresses) of the deformed area of solid, for example, in an area that is circumferential to the crack (Андрейкив, Лысак 1989). In this case the wave equalizations, which are a stream of unmonochromatic waves with a casual phase, are acceptable for the AE description. However, AE, which is observed in an experiment, in most cases is a stream of impulses (Filonenko *et al.* 1985; Novikov, Filonenko 1995; Kharoubi *et al.* 2007; Иванов, Белов 1981). Such an approach answers the statement that decoupling is generated by the impulse of displacement spreads in the solid as AE (Иванов 1986; Бабак и др. 2002; Babak *et al.* 2006).

These two approaches contradict each other in the description of AE spreading. However, the role of AE source varies in these approaches. Unfortunately, at the formation of a crack in classic solids (including crystals), the discovery of details and distinctions of AE for these two approaches is very difficult because it requires a solution of the dynamic task of the crack's formation and the description of the generated AE.

If the composite is examined, the FBM (Fiber Bundle Model) is widely used for its destruction. It is based on the fact that the material appears as a bunch of fibers (elements), and its destruction is considered to be a process of the sequential destruction of the elements (Curtin 1991; Newman, Phoenix 2001; Lyakhovsky *et al.* 1997; Turcotte *et al.* 2003; Guarino *et al.* 1998). The application of such an approach allows the AE, that accompanies the destruction of composite. It arises from the connection of AE and the speed of the destruction of elements of the composite (Turcotte *et al.* 2003; Филоненко и др. 2009а, 2010).

In this work we shall analyze the AE signals that are generated both in the case of non-coherent addition of acoustic waves and in the case of the presentation of AE as a stream of impulses of displacement within the framework of the relaxation model. We shall consider the model of AE signal formed at the destruction of composite, based on its representation as a bunch of fibers. The features of AE signals will be researched by the approach of non-coherent acoustic radiation that is induced at the destroyed fibers. In this case we consider that there is no interaction between fibers, and the life duration of every fiber will be defined in accordance with the kinetic theory of resistibility. Within the framework of the examined approach the AE will be calculated in the representation of the stream of displacement impulses.

## 2. Energy of acoustic emission

Let us suppose that we have a composite (a specimen), which consists of several fibers (copulas). By loading such material with stretching we shall examine its destruction from positions of the FBM model (Curtin 1991; Newman, Phoenix 2001; Lyakhovsky *et al.* 1997). In accordance with the model, the basic loading is with stood by fibers or elements, and the destruction of composite happens at the expense of the destruction of the elements. Such an assumption is possible under the following conditions. If a matrix is elastic or has less strength, its destruction does not conduce to the complete destruction of material; that is, the external loading is stood by a copula. If the matrix's strength is more than the copula's strength, by resilient deformation the destruction of composite is begun with the destruction of the copula. In this case, the gradual accumulation of the amount of the blasted fibers or sub (micro) cracks causes the complete destruction of the material. In general, the destruction of the copula is the basic process of the destruction of the composite. Thus, the properties of a matrix, the influence of the interphase of the matrix-copula and the interaction between separate elements (by fibers) are not examined.

Let us suppose that by the loading of composite the act of destruction of every element happens independently and is accompanied by acoustic radiation. Thus, we shall examine two cases. For the first case we shall suppose that the generated acoustic wave perturbations are identical, but they happen usually with a casual phase. Let us also consider that waves radiated at the destruction of elements of composite are spread without fading. In this case the intensity of the resulting signal will be equal to the total intensity of waves generated by the blasted elements. Then it is possible to determinate for the intensity  $I_{NC}$  of the resulting signal

$$I_{NC}(t) = I_1(t) \left| \frac{dN_P}{dt} \right|, \quad (1)$$

where  $I_1(t)$  is the intensity of the wave which appears at the destruction of one element;  $\left| \frac{dN_P}{dt} \right|$  is the speed of the destruction of the elements of composite; and  $dN_P$  is the number of elements, destructed of which for elementary time  $dt$ .

We shall consider that load on the elements of composite increases with time by the linear law,  $\sigma(t) = \alpha t$ , where  $\alpha = const$ , i.e. load on a composite has direct ratio to time. Undoubtedly, the amplitude of the wave  $\dot{A}_1$  radiated at the destruction of one element will be proportional to the value of destructive stress. Therefore, we shall consider that  $\dot{A}_1(t) \sim \sigma(t)$  or

$$A_1(t) = k_E \alpha t, \quad (2)$$

where  $k_E$  is a coefficient of proportion.

Taking into account (2), by non-coherent addition of waves arising from the destruction of elements of composite, the intensity of total acoustic indignation, concordantly (1), will be described by the expression

$$I_{NC}(t) = k_{NC} \alpha^2 t^2 \left| \frac{dN_P}{dt} \right|, \quad (3)$$

$k_{NC}$  is the coefficient which is proportional to the multiplication of the speed of sound and the square of coefficient  $k_E$ .

In the second case, we shall consider that by the destruction of the elements of composite, generated acoustic indignations form identical coherent impulses of displacement. We shall suppose that they spread without fading. The amplitude of displacement will also be proportional to the value of destructive. In this case, the resulting displacement  $U_C$  will be described by the expression

$$U_C(t) = k'_E \alpha t \left| \frac{dN_P}{dt} \right|, \quad (4)$$

where  $k'_E$  is a coefficient of proportion, the value of which depends on the duration of impulses.

Then, taking into account (4), the intensity of acoustic radiation for the case of addition of displacements (coherent addition) will look like

$$I_C(t) = k_C \alpha^2 t^2 \left| \frac{dN_P}{dt} \right|^2, \quad (5)$$

where  $k_C$  is a coefficient which is proportional to the multiplication of the speed of sound and the square of coefficient  $k'_E$ .

Note that in writing the expressions (3) and (5), we ignored the geometrical features of the distribution of radiation, including polarization.

In accordance with (3) and (5) the intensity of AE at the destruction of composite depends on the speed of the destruction of fibers  $\left| \frac{dN_P}{dt} \right|$ .

### 3. The relaxation model of the destruction of composite

As in (Филоненко и др. 2009a), we shall examine a specimen of composite which consists of  $N_0$  elements. We shall consider that by application of load to such a specimen every element is deformed resiliently, up to its destruction. We suppose that all of the elements possess identical strength. Thus, the process of the specimen's destruction is the process of the consistent destruction of the elements with the continuous redistribution of loads on the remaining elements. Taking into account these conditions, at the development of the destruction process of the specimen, in accordance with (Turcotte *et al.* 2003), the speed of change of remaining elements is described by the expression

$$\frac{d}{dt}[N_0 - N_P(t)] = -v(t)[N_0 - N_P(t)], \quad (6)$$

where  $N_0$  is an initial amount of elements;  $N_P(t)$  is the number of collapsing elements dependent on time;  $[N_0 - N_P(t)]$  is the number of remaining elements; and  $v(t)$  – is the speed of the development of the destruction process, which depends on the attached stress  $\sigma(t)$ .

To make it more convenient we shall accept that the number of remaining elements is equal to  $N = [N_0 - N_P(t)]$ . Then expression (6) can be written down in this way:

$$\frac{dN}{dt} = -v(t)N. \quad (7)$$

Thus, in the relaxation model, in accordance with (7), the process of the destruction of the elements of composite at the applied loading to the specimen is a kinetic process. Thus, the basic problem of the relaxation model of the destruction is the definition of  $v(t)$ .

Let us use Zhurkov's formula (Регель и др. 1974), in accordance with which the state of every element of composite before the destruction is characterized by the time of the expectation of destruction

$$\tau = \tau_0 \dot{a} \left( \frac{U_0 - \gamma \sigma(t)}{kT} \right), \quad (8)$$

where  $\tau_0$  – is a parameter in order of the value where the order is equal to the period of vibrations of atoms in the grate of solid;  $U_0$  – is energy, related to formation of free-form by the formation of cracks;  $\sigma(t)$  – is stress in the material, conditioned by the mechanical loading and activating of the process of destruction, setting its orientation;  $k$  – is Boltzmann constant;  $T$  – is temperature; and  $\gamma$  – is structurally sensible coefficient, characterizing the concentration of stress on a crack at its formation.

Obviously, the speed of development of the destruction process will be equal to  $v \approx \tau^{-1}$ . Then it is possible to write down

$$v = \frac{1}{\tau_0 \dot{a}} \left( \frac{U_0 - \gamma \sigma(t)}{kT} \right). \quad (9)$$

The next expression will be used to make the further letups more convenient

$$\chi = \frac{\gamma \alpha}{kT} \text{ and } t_0 = \frac{U_0}{\gamma \alpha}. \quad (10)$$

We shall consider that the time of the development of the whole destruction process is less than the time of load change, applied to the specimen. Taking into account (9) and the accepted denotations (10), expression (7) will be

$$\frac{dN}{dt} = -\frac{1}{\tau_0 \dot{a}} \chi (t_0 - t) N. \quad (11)$$

We shall rewrite expression (11) in the following way

$$\frac{dN}{N} = -\frac{1}{\tau_0 \dot{a}} \chi (t_0 - t) dt. \quad (12)$$

Having calculated the expression (12), taking to account that by the initial conditions at the moment of time  $t = 0$ , the value  $N_p(t)$  is equal to zero, i.e.  $N_p(0)=0$ , we shall get the expression for the amount of elements remaining in the process of loading of composite

$$N(t) = N_0 e^{-\frac{1}{\tau_0 \chi} (\hat{a}^{-\chi(t_0-t)} - \hat{a}^{-\chi t_0})} \quad (13)$$

It follows from expression (13) that in the accepted model the speed of the destruction of elements of the composite will be

$$\left| \frac{dN_p}{dt} \right| = \left| \frac{dN}{dt} \right| = \frac{N_0}{\tau_0} e^{-\chi(t_0-t)} \chi \frac{1}{\tau_0 \chi} (\hat{a}^{-\chi(t_0-t)} - \hat{a}^{-\chi t_0}) \quad (14)$$

Taking into account (14), expression (3) for the intensity of AE, as a stream of non-coherent waves, will look like

$$I_{NC}(t) = k_{NC} \alpha^2 t^2 \frac{N_0}{\tau_0} e^{-\chi(t_0-t)} \chi \frac{1}{\tau_0 \chi} (\hat{a}^{-\chi(t_0-t)} - \hat{a}^{-\chi t_0}) \quad (15)$$

Taking into account (14), the intensity of acoustic radiation (5) for the case of addition of displacements (coherent addition) will be

$$I_C(t) = k_C \alpha^2 t^2 \frac{N_0^2}{\tau_0^2} e^{-2\chi(t_0-t)} \chi \frac{2}{\tau_0 \chi} (\hat{a}^{-\chi(t_0-t)} - \hat{a}^{-\chi t_0}) \quad (16)$$

Note that in expressions (15) and (16) coefficients  $k_{NC}$  and  $k_C$  have a different dimension.

#### 4. The results of modelling

Let us make the modeling of the time history of the amount of remaining elements by the development of the destruction process, the intensity of AE at a non-coherent and coherent radiation, and similarly effective amplitude of AE at non-coherent and coherent radiation.

Results of calculations of the dependencies of the time history amount of remaining elements, according to (13), are given in Fig. 1 as graphs  $\tilde{N}(\tilde{t}) = N(\tilde{t}) / N_0$ ; that are in relative units. When making calculations the parameters from expression (13) are brought to non-dimensional value, but the time is normalized to  $t_0$ , which corresponds to the time of the maximum speed of the load's application. The correlation of the values  $\chi t_0$  and  $1/\chi \tau_0$  were chosen due to the fact that the period of atom oscillatory motion material takes far less the time of the development of the destruction process and the

time of the load's application, i.e.  $(\chi t_0 / \chi \tau_0) = (t_0 / \tau_0) \gg 1$ . For example, calculations were conducted under the following values  $1/\chi \tau_0$ . 100 000; 200 000; 400 000. Under given constant value  $\tau_0$ , increasing of the value  $(1/\chi \tau_0)$  corresponds to the reduction of speed of the load's application (look at (10)). For  $1/\chi \tau_0 = 200 000$  and  $1/\chi \tau_0 = 400 000$  the speed  $\alpha$  decreases, accordingly, by two and four times.

The results of the calculations (Fig. 1) show that by the increase of speed of the load's application (diminishing of value  $1/\chi \tau_0$ ) there is displacement of curves on the axis of time towards less values. By the increase of speed of the load's application the destruction of elements begins earlier. Thus, there is an increase of module  $d\tilde{N}(\tilde{t})/d\tilde{t}$ , i.e. the steepness of curves increases notably  $\tilde{N}(\tilde{t})$  (Fig. 1).

The dependences of the change of intensity of AE signals for non-coherent addition of waves, in accordance with (15), are showed in Fig. 2 the graphs  $\tilde{I}_{NC}(\tilde{t}) = I_{NC}(t)\tau_0 / k_{NC}\alpha^2 t_0^2 N_0$  are relative units. By making calculations we took the same parameters from (15), by calculations of the graphs in Fig. 1.

The results of modeling (Fig. 2) show at the diminishing of speed of the load's application the intensity of AE diminishes as well. The maximum of the intensity is displaced in the area of fewer values  $\tilde{t}$  that matches with the results of calculations  $\tilde{N}(\tilde{t})$ .

The processing of modeling shows the diminishing of the intensity at a peak-point of the dependence  $I_{NC}(\tilde{t})$  in order to the value is inversely proportional to the speed of the load's application  $\alpha$ . Thus, the diminishing of the speed  $\alpha$  by 2 and 4 times results from the diminishing of the maximum intensity, accordingly, by 2 and 4 times. At the same time, the total intensity (area under intensity curve) is identical for different speeds of the load's appli-

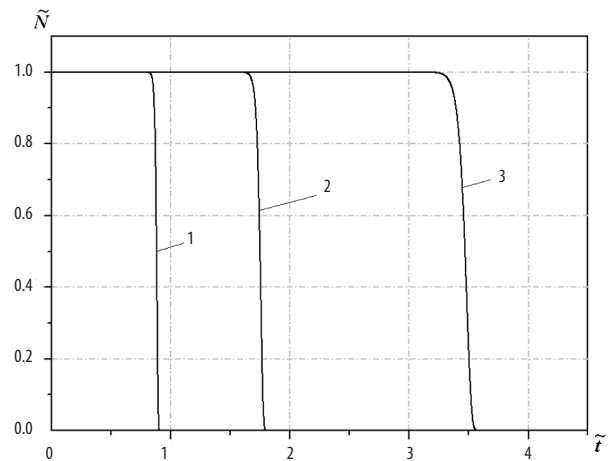
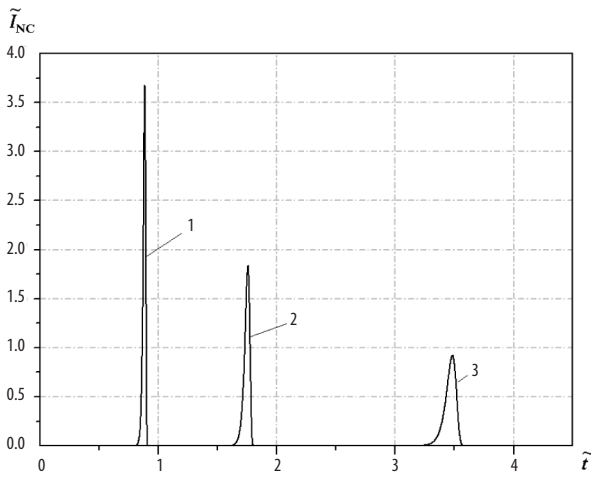


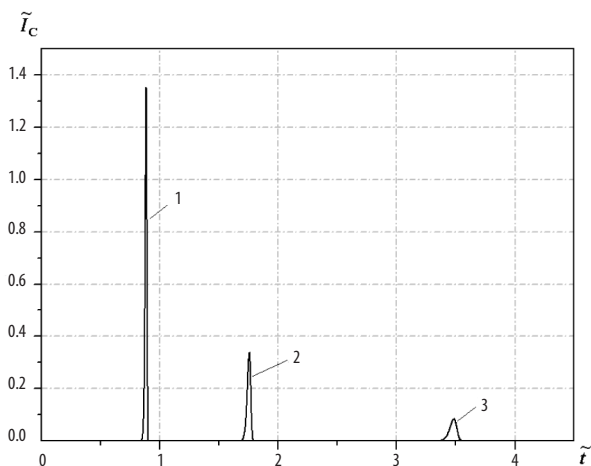
Fig. 1. Dependence of the number of unbroken elements  $\tilde{N}(\tilde{t})$  on the different values of the speed of the load's application during time. Values of  $1/\chi \tau_0$ : 1 -  $1/\chi \tau_0 = 100 000$ ; 2 -  $1/\chi \tau_0 = 200 000$ ; 3 -  $1/\chi \tau_0 = 400 000$ ;  $\tau_0 = 10^{-7}$



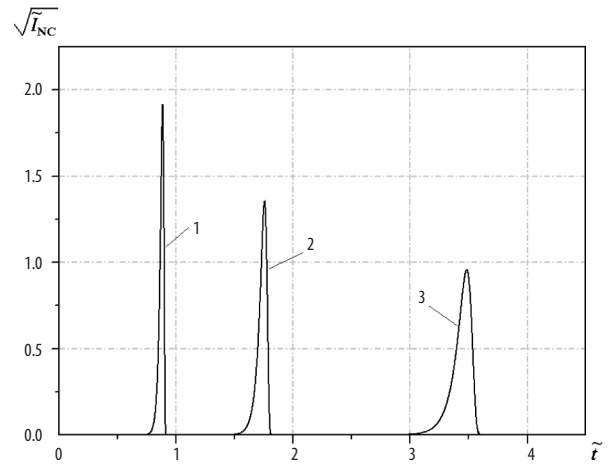
**Fig. 2.** Dependence of the intensity of acoustic emission  $\tilde{I}_{NC}(\tilde{t})$  of  $\times 10^{-6}$  during time on different values of the speed of the load's application  $\chi$  for non-coherent addition of waves. Values  $1/\chi\tau_0$ : 1 -  $1/\chi\tau_0=100\ 000$ ; 2 -  $1/\chi\tau_0 = 200\ 000$ ; 3 -  $1/\chi\tau_0 = 400\ 000$ .  $\tau_0 = 10^{-7}$

cation. Dependencies of change of the intensity of AE signals for the case of addition of displacements described in the expression (16) are given in Fig. 3 as the graphs  $\tilde{I}_C(\tilde{t}) = I_C(t)\tau_0^2 / k_C\alpha^2 t_0^2 N_0^2$  in relative units. By making calculations we took the same parameters from (16) as in calculations of the graphs given in Fig. 1.

The results of modeling (Fig. 3) show that for the case of the addition of displacements at the diminishing of speed of the load's application  $\alpha$  the intensity of AE diminishes similarly. However, its change is considerably stronger than the change of the intensity in the case of non-coherent addition of waves. Calculations show that the maximum of intensity  $[\tilde{I}_C(\tilde{t})]_{\max}$  (Fig. 3) is back proportional to the square of speed of the load's application. Indeed, diminishing of the speed  $\alpha$  by 2 and 4 times results in the diminishing of the maximum



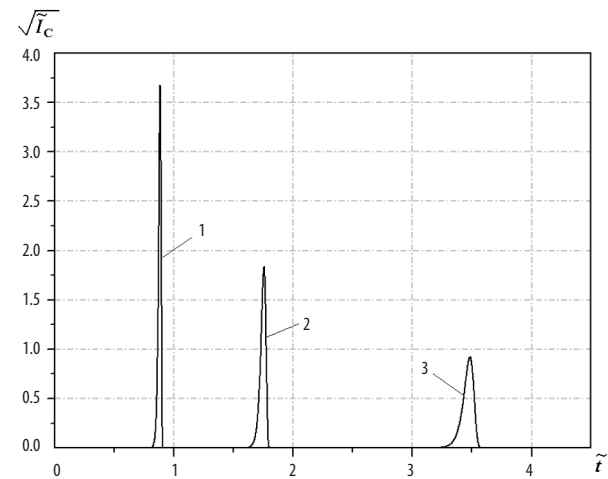
**Fig. 3.** Dependence of the intensity of acoustic emission  $\tilde{I}_C(\tilde{t})$  of  $\times 10^{-11}$  during time on different values of speed of the load's application  $\chi$  for summarizing of displacements. Values  $1/\chi\tau_0$ : 1 -  $1/\chi\tau_0=100000$ ; 2 -  $1/\chi\tau_0 = 200000$ ; 3 -  $1/\chi\tau_0 = 400000$ .  $\tau_0 = 10^{-3}$



**Fig. 4.** Dependence of change of the effective amplitude of acoustic emission  $\sqrt{\tilde{I}_{NC}(\tilde{t})}$  of  $\times 10^{-3}$  during time on different values of speed of the load's application  $\chi$  for non-coherent summarizing of waves. Values of  $1/\chi\tau_0$ : 1 -  $1/\chi\tau_0=100\ 000$ ; 2 -  $1/\chi\tau_0 = 200\ 000$ ; 3 -  $1/\chi\tau_0 = 400\ 000$ .  $\tau_0 = 10^{-7}$

of intensity  $[\tilde{I}_C(\tilde{t})]_{\max}$  at the addition of displacements, in 4 and 16 times accordingly. Thus, total intensity (area under intensity curve) appears back proportional to the speed of load's application. So, by diminishing the speed of the load's application in times 2 and 4, the total intensity diminishes in times 2 and 4 accordingly.

During of the experiment the amplitude of AE signal is registered. Thus, the value of measurable amplitude is proportional to the mechanical displacement of points of material of the tested specimen in the place of the location of the AE sensor. We shall take into account that the value of the effective amplitude is proportional to a square root of the intensity. In Figs 4 and 5 dependencies of the temporal motion of the effective AE amplitude, that were received from the dependencies  $\sqrt{\tilde{I}_{NC}(\tilde{t})}$  and  $\sqrt{\tilde{I}_C(\tilde{t})}$  are given. We took the same as in Figs 2 and 3.



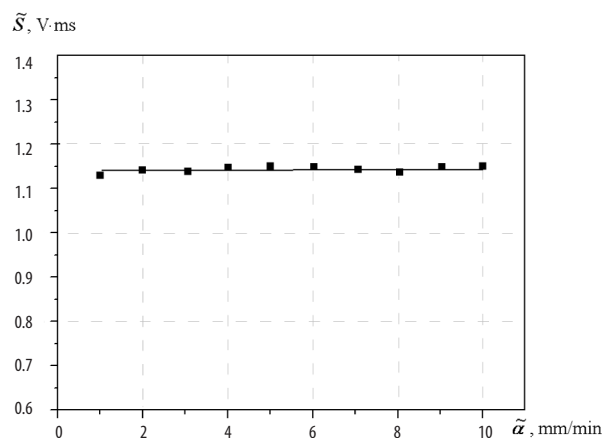
**Fig. 5.** Dependence of change of the effective amplitude of acoustic emission  $\sqrt{\tilde{I}_C(\tilde{t})}$  of  $\times 10^{-6}$  during time on different values of speed of the load's application  $\chi$  for summarizing of displacements. Values of  $1/\chi\tau_0$ : 1 -  $1/\chi\tau_0=100\ 000$ ; 2 -  $1/\chi\tau_0 = 200\ 000$ ; 3 -  $1/\chi\tau_0 = 400\ 000$ .  $\tau_0 = 10^{-7}$

Processing of the received data (Fig. 4) showed that the peak of the effective amplitude  $(\sqrt{\tilde{I}_{NC}(\tilde{t})})_{\max}$  by the non-coherent addition of waves diminishes inversely, proportionally to the square root of the speed of the load's application. Thus, the area under the curve  $\sqrt{\tilde{I}_{NC}(\tilde{t})}$  increases with the load's application with diminishing the speed. At the same time, in the case of AE, calculated by the addition of impulses, the maximum value of the effective amplitude  $(\sqrt{\tilde{I}_C(\tilde{t})})_{\max}$  appears to be back proportional to the speed of the load's application (Fig. 5). Besides, in the case of the addition of impulses the area under the curve  $\sqrt{\tilde{I}_C(\tilde{t})}$  for the effective amplitude does not depend on the speed of the load's application.

We note similar results for the model of AE signal by the prevailing mechanical destruction of composite considered in research (Filonenko *et al.* 2010). Besides, the effect of the independence of the area under the curve and the temporal dependence of the effective amplitude of AE signal are observed in a number of experiments.

The results of processing of the area  $\tilde{S}$  under the curve of experimental signals of AE, which were received (Филоненко и др. 2009b) by loading of the identical specimens of composite at different speeds of the speed of the load's application, are given in Fig. 6.

It is evident from fig. 6 that for the specimens of composite with identical size the area under the curve of the registered signals of AE does not depend on the speed of loading. Thus, all other parameters of AE signals (amplitude, energy, duration) change with the change of the speed of loading of composite.



**Fig. 6.** Dependence of change of the area under the curve of experimental signals of AE from the speed of loading of specimens from VK4, got on the base method, that is described in work (Филоненко и др. 2009)

## 5. Conclusions

The modeling of AE signals got by employing the approach of FBM model and with the application of the kinetic approach for the description of destruction of fibers of composite has shown the following. On the whole, the temporal dependence of the intensities and the effective amplitudes, both in the case of non-coherent addition of waves and in the case of addition of displacements, appeared similar in quality. In both cases the assumption connected with the application of Zhurkov's formula is executed, so that at more rapid load application to the material, time of its destruction diminishes. However, it is important to get the quantitative difference of AE modeling signals. So, for non-coherent addition of waves, the area under the curve of temporal motion of intensity of AE does not depend on the speed of the load's application. For AE, calculated by the addition of impulses of displacement, the area under the curve of the change of the effective amplitude during time does not depend on the speed of the load's application either. This important difference of the theory can be tested experimentally, and, as the experiments' data (Филоненко и др. 2009b), got at the destruction of composite at different speeds of loading, show, it is necessary to consider the AE signal as a signal of addition of impulses of the displacement.

## References

- Babak, V. P., *et al.* 2006. Research of acoustic emission signals at destruction of graphite, *Aviation* 10(1): 10–16.
- Babak V. P., *et al.* 2005. Model of acoustic emission signal at self-accelerated crack development, *Aviation* 9(20): 3–8.
- Bocchieri, R. T., *et al.* 2003. Time-dependent Microcracking Detected in a Rubber-toughened Carbon-epoxy Composite by the Modal Acoustic Emission Method, *J. of Composite Materials* 37(5): 421–451. doi:10.1177/0021998303037005058
- Chandra, B. P., *et al.* 2004. Dislocation unpinning model of acoustic emission from alkali halide crystals, *Pramana J. Phys* 62(6): 1281–1292. doi:10.1007/BF02704440
- Curtin, W. A. 1991. Theory of mechanical properties of ceramic-matrix composites, *J. Am. Ceram. Soc.* 75: 2837–2845. doi:10.1111/j.1151-2916.1991.tb06852.x
- Filonenko, S. F., *et al.* 2009. Definition of contact stress in friction units on the basis of the acoustic emission method, *Aviation* 13(3): 72–77. doi:10.3846/1648-7788.2009.13.72-77
- Filonenko, S. F., *et al.* 1985. Characteristics of Acoustic Emission Signals During the Plastic Deformation and Brittle Fracture of Materials, *Fiz. Khim. Mekh. Mater.* 6: 105–106.
- Filonenko, S. F., *et al.* 2010. Model of acoustic emission signal at the prevailing mechanism of composite material mechanical destruction, *Aviation* 14(4): 95–103. doi:10.3846/aviation.2010.15
- Grosse, C. U., *et al.* 2008. *Acoustic Emission Testing*. Springer-Verlag Berlin Heidelberg. 403 p.
- Guarino, A., *et al.* 1998. An experimental test of the critical behavior of fracture precursors, *Europ. Phys. J.* 6: 13–24.
- Hadjab, H. S., *et al.* 2007. The use of acoustic emission to investigate fracture process zone in notched concrete beams, *Current Science* 93(5): 648–653.

- Kharoubi, M., *et al.* 2007. Study of the damage by acoustic emission of two laminate composites subjected to various levels of loading in three points bending, *Mechanika* 5(67): 48–52.
- Lyakhovskiy, V., *et al.* 1997. Distributed damage, faulting and friction, *J. Geophys.* 102(27): 635–649.
- Malcharchikova, J., *et al.* 2006. Impact of conditions of directional crystallization by Bridgman method on physical and metallurgical characteristics of Ni<sub>3</sub>Al, *Acta Metallurgica* 12(4): 427–435.
- Newman, W. I.; Phoenix, S. L. 2001. Time dependent fiber-bundles with local load sharing, *Rev. E.* 63: 021507.
- Novikov, N. V.; Filonenko, S. F. 1995. Effect of parameters of acoustic path on the criterion estimation of acoustic emission signal generation from the crack, *Technical Diagnostics and Nondestructive Control* 1: 47–52.
- Rajendraboopathy, S., *et al.* 2008. Neural network prediction of failure strength of composite tensile specimens using acoustic emission counts, *J. of Non Destructive Testing & Evaluation* 7(2): 21–26.
- Shibata, M. A. 1984. A theoretical evaluation of acoustic emission signals the rise-time effect of dynamic forces, *Mater. Eval.* 42(1): 107–116.
- Turcotte, D. L., *et al.* 2003. Micro and macroscopic models of rock fracture, *Geophys. J. Intern.* 152(3): 718–728. doi:10.1046/j.1365-246X.2003.01884.x
- Wadley, H. N. G.; Scruby, C. B. 1983. Elastic wave radiation from cleavage crack extension, *Int. J. Fracture* 23: 111–128.
- Андрейкив, А. Е.; Лысак, Н. В. 1989. *Метод акустической эмиссии в исследовании процессов разрушения*. Киев: Наукова думка. 176 с.
- Бабак, В. П. и др. 2002. Модели формирования сигналов акустической эмиссии при деформировании и разрушении материалов, *Технологические системы* 1(12): 26–34.
- Иванов, В. И. 1986. Акустическая эмиссия в процессе когерентного разрушения, *Доклады АН СССР* 287(2): 302–306.
- Иванов, В. И.; Белов, В. М. 1981. *Акусто-эмиссионный контроль сварки и сварных соединений*. Москва: Машиностроение. 184 с.
- Регель, В. Р. и др. 1974. *Кинетическая природа прочности твердых тел*. Москва: Наука. 560 с.
- Филоненко, С. Ф. и др. 2009а. Модель формирования сигнала акустической эмиссии при разрушении композиционных материалов, *Технологические системы* 2(46): 17–25
- Филоненко, С. Ф. и др. 2009б. Информативность параметров сигналов акустической эмиссии при разрушении композиционных материалов, *Технологические системы* 4(48): 22–28.
- Филоненко, С. Ф. и др. 2010. Модель сигнала акустической эмиссии при разрушении композиционного материала под действием поперечной силы, *Технологические системы* 2(51): 45–53.

## DU POŽIŪRIAI APIBŪDINANT AKUSTINĖS EMISIJOS SIGNALĄ KOMPOZITINĖS MEDŽIAGOS DESTRUKCIJOS KINETINIAME MODELyje

S. Filonenko, V. Kalita, T. Nimchenko

**Santrauka.** Atlikta akustinės emisijos signalų analizė, kai bangų sumavimas yra nekoherentinis, o poslinkių sumavimas – koherentinis. Parodyta, kad plotas žemiau kreivės, rodančios akustinės emisijos intensyvumo kitimą laikui bėgant, nepriklauso nuo apkrovos įvedimo greičio, kai bangų sumavimas nekoherentinis. Akustinėje emisijoje, kuri apskaičiuojama sumuojant impulsų poslinkį, plotas žemiau kreivės, rodančios efektyvios amplitudės kitimą bėgant laikui, nepriklauso nuo apkrovos įvedimo greičio.

**Reikšminiai žodžiai:** akustinė emisija, įtempimas, apkrova, akustinės emisijos signalas, akustinės emisijos intensyvumas, įtrūkimas, kompozitinė medžiaga, pluošto modelis, akustinės bangos.