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Analysis of damage mechanics of unidirectional composites beams with acoustic emission method

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Abstract

Attempts of evaluation of a composite material strength during any period of its use, with use of acoustic emission method (AE) were taken by many authors. In this paper author also tried to define the parameters of acoustic emission signal, which could univocally define the mechanism of a composite destruction at a given stage of its use.

It seemed that the agreed energy „MARSE" could have been treated as that parameter, but the tests and analysis of the obtained results did not enable to give a univocal evaluation. From the tests were obtained the separate signals coming from resin cracking and the signals created during failure of the fibres. The characteristic of frequency $v=C/D$, where C is the number of counts and D is the signal duration time, was introduced as the basis parameter, which enables to separate the signals. The analysis of the results enables to determine, univocally, the process of composite failure.

Keywords: monotropic composite, acoustic emission, identification, damage.

Introduction

The composites are the materials highly and dynamically applied in modern constructions. It concerns their application in the aircraft industry (35% of the materials applied for Boeing airbuses production are the composite materials), power industry (big wind power stations), building industry (bridge spars, flyovers), oil industry (transfer pipelines), sport equipment (yachts, skis, tennis rackets) and many others, where traditional materials are being replaced by composites. It results from a number reasons. By changing the component materials of a composite (matrix, fibre), their volume fracture, and applying various technologies of performance, we may shape, on a very wide scale, the forecast parameters of the final material, that is its strength, weight, corrosion resistance, fatigue strength and other. An easy mechanical treatment of composite materials simplifies, within a wide range, manufacturing prototypes and repairing construction elements in the case of their failure.

But it requires the development of calculating procedures to apply just at the designing level, researching procedures to apply in the prototypes testing as well as monitoring tests during the period of construction operation. It is in particular important to have the possibility of evaluating the effort condition of an element or of the whole construction, which decides about its further and safe operation and use.

The attempts to evaluate the composite material strength during any period of its use, with the acoustic emission method (AE) were made by many authors [1-3]. The author of this paper also tried, in his former publications, to define the parameters of acoustic emission signal, which could univocally define the mechanism of a composite destruction at a given stage of its use. It seemed that the agreed energy "MARSE" could have been treated as that parameter, but the tests and analysis of final results did not let us give a univocal evaluation. Because of the fact that tests were conducted with the final composites, it was difficult to separate the signals coming from resin cracking from the signals created during failure of the fibres. There were some circumstances (an analysis of energy parameter) but without total certainty.

Thus the tests were performed with the use of AE, of component materials (resin, fibre) together with a full analysis of obtained signals of acoustic emission. The obtained results turned out to be very promising and they made it possible to draw conclusions about real mechanisms of the composites failure.

The subject and methodology of tests

The subject of testing

The tests were conducted with a glass fibre type E, epoxy resin and a composite of the following contents: 28% of EP6 and 72% of glass fibre type E.

The fibre was made of non-alkaline glass E with less than 1% of alkaline oxides. Mechanical and physical properties of the fibre are given in Table 1. The glicyde-epoxysylanic preparation was applied to continuous glass fibres which were applied to reinforce the resins. The fibres of a nominal diameter of an elementary fibre of 10 μm and tex of 1200 were used in the tests. The fibres exist in a form of rowing, i.e. as the bands made of elementary glass, continuous fibres set in parallel in a bundle, without twists. The number of bands in a rowing varies from 1 to 60. A more accurate description of glass fibres is presented in [4].

The tests of a matrix material were performed with the samples of dimensions 200 x 6 x 3.2 mm, made of epoxy resin EP6 with hardener Z-1 produced at chemical works in Nowa Sarzyna. Table 1 shows mechanical and physical properties of the tested resin (advertising brochures of a producer).

The composite samples of dimensions 200x6x3.2mm were produced at Electrotechnical Works in Międzylesie by saturation of glass fibre with epoxy resin. Volume fracture of the fibres is $V_f = 0.72$. Mechanical and physical properties according to the producer data are presented in Table 1.

Table 1. **Mechanical and physical properties of the tested materials**

Properties	Glass fibre type E	Epoxy resin	Composite
Density d [kg/m^3]	2500	1100 – 1200	> 1800
Tensile strength Rm [MPa]	3400	40-55	> 750
Bending strength [MPa]	-------	80 – 120	> 350
Young's modulus E [GPa]	72	2.5 – 4.5	~ 52

Methodology of tests

The tests of the fibres were carried out on a rowing with varying number of fibres in a bundle. They were selected randomly from a band. The measured length of the sample was $l_{\acute{s}r} = 275$ mm. The fibres were tensioned in a tensioning machine type UTS-200 with the speed of holders replacement of $v = 1$ mm/min. The value of force, displacements and the signals of acoustic emission resulting from fibres cracking were registered during tensioning. The samples made of epoxy resin, fixed on an extension arm, were quasi-statically bent while being displaced in a controlled way. Force, displacement and acoustic emission signals were registered during the whole period of loading till the moment of the sample failure. The tests were run similarly with the samples made of a composite. They were fixed on an extension arm and loaded until their failure, registering in a continuous way the force, displacement and AE signals occurring during the failure process. The observed acoustic emission helped analyse the processes occurring in the tested samples during their loading. Such parameters of AE signals as number of counts C, signal duration time D (s), time of signal R increase (s), agreed energy " Marse" E (ev) and other – enabled us to perform the analysis of mechanism of a composite failure. The processor type AE "Mistras 2001" produced by PAC AET firm, AET 2004 and wide-band sensors of the frequency range 20 – 1000 kHz were used in order to register the AE signals.

The detailed description of the method and definitions of the parameters used for the purpose of defining AE signals are given in [1, 5, 6].

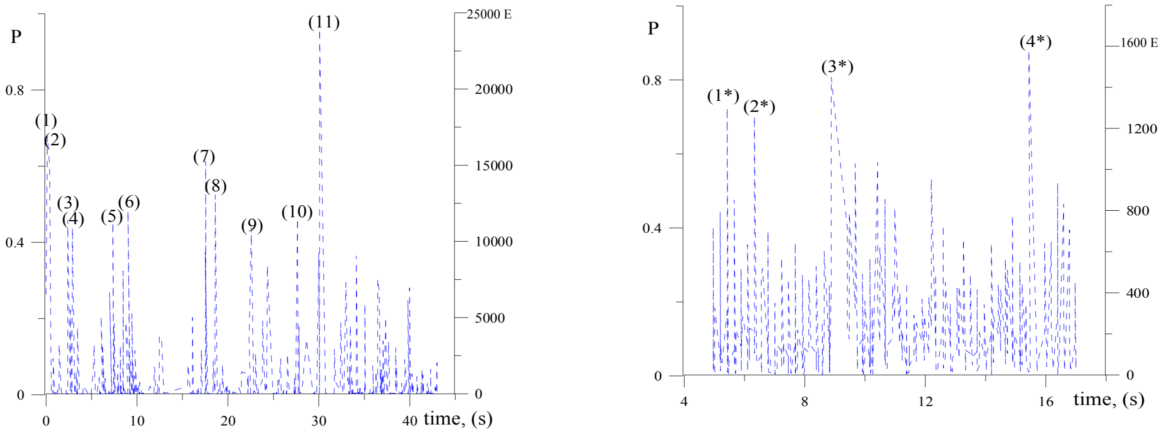
Obtained results and their analysis

Glass fibres

Glass fibres play important role in the composite strength. This section deals with the analysis of AE signals obtained in the tests done by G. Świt [4].

The tests were run on a rowing of glass fibres set in parallel without twists. The fibres were tensioned on a tensioning machine. Acoustic emission signals were registered during tensioning.

Despite the glass fibres are set in rowing rather in parallel, then its breaking does not occur as a single act, but it is extended in some period of time- what shows that the process of failure occurs by breaking one after one of the most loaded fibres. The loading force P is maintained almost at the same level during the cracking process.



a b

Fig.1. **The course of " Energy" characteristic of AE signal registered during loading the glass fibres bundle**.

Fig.1 shows the course of a characteristic "Energy" of AE signals during loading of the glass fibres rowing. The difference between figures (a) and (b) lies in the fact that figure (a) includes the parameter "Energy" for all the signals registered during loading, while figure (b) includes only the signals of low level of " Energy" prameter (E<1600 ev). Table 2 shows the parameters of signals marked on figures with the corresponding numbers.

The figures and data included in Table 2 show that the level of a parameter "Energy" varies within a very wide range from 300 to 25000 ev. Also the changes of parameters of A amplitude vary from 40 to 100, the period of signal D duration from 100 to 250000, the number of countings C- from 900 to 15,000. Such a wide dispersion of parameters of AE signals does not enable us to define a common property characterizing the process of fibre glass cracking. Frequency parameter ***v*** shows little interval of divergence [0.031 – 0.076] and its average value is 0.039.

Resin

Resin is the basic component of a composite. The samples made of resin were tested in a consol bending system and with loading controlled by displacement of its free end [7].

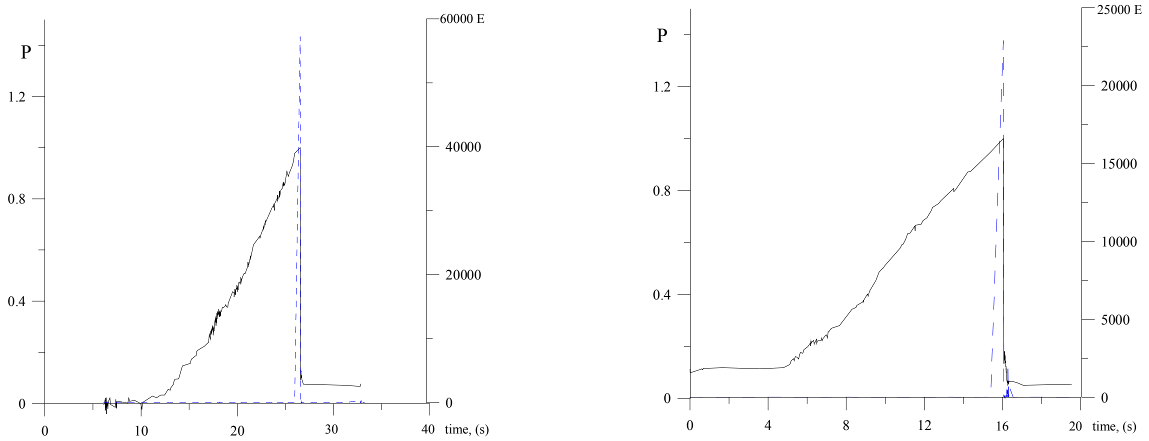


Fig.2. **The graphs of standartised loading of a sample (continuous line) and " Energy" characteristic of AE signal (broken line) in relation to course of time for the samples made of resin during their static loading**

The above diagrams (Fig. 2) of loading *P* change show that a resin cracking mechanism is fragile. The samples failure is a single operating act after a maximum level of loading force *P* has been reached. Single signals *AE* of high parameters were registered during cracking of the samples (Table 2).

For the first sample: $A = 100$, $D = 45500$; $E=57200$; $C = 1134$. For the second sample: $A = 100$, $D = 29000$; $E = 22900$; $C = 607$. Other signals AE registered for both samples till the moment of cracking have low amplitude parameters ($A < 75$), energy ($E<150$) and duration time ($D< 1000$).

For both samples the quotient of signal countings number in relation to its duration time was marked as the frequency $v = C/D$, according to the authors' proposal presented in the study [5]. For both cases it is similar and its value is $v = 0.0249$ for the first and $v = 0.0208$ for the second sample.

The composite

The samples made of a composite the components of which have been analysed above, were tested with the support bending unit, by controlling the process of loading with displacement. Fig. 3a and 3b show the courses of a force loading the composite and the parameters "Energy" and "Amplitude" of AE signals during loading.

The frequency parameter *v* was analysed in the characteristic points, in which the highest values of AE parameters [marked as (1÷14)] were registered. In points 1-3, the value *v* was 0.023÷0.026, which is very close to the frequency of signals occurring during the resin cracking. It can be noticed that duration time of signals *D* in points 1, 2, 3 during cracking of a composite (Fig. 3a) is of the same level as the duration time of signals during cracking of the samples made of resin (see Table 2).

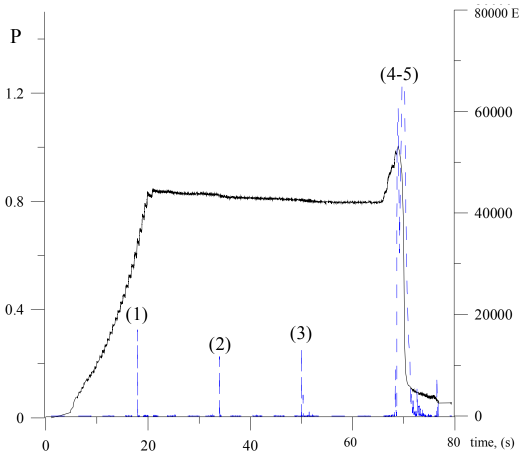


Fig.3a. **The course of standatised force and " Energy" parameter of AE signal during loading the samples made of composite**

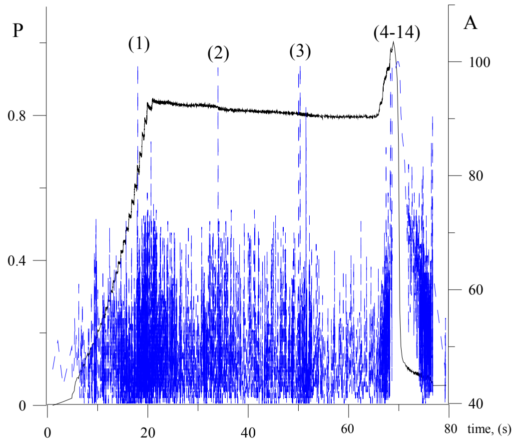
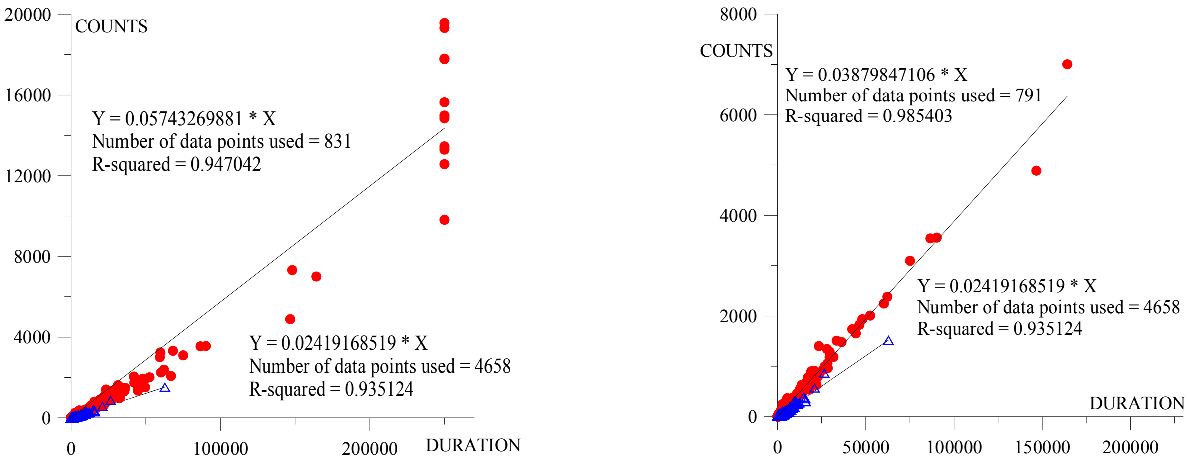


Fig.3b. **The course of standartised force and " Amplitude" parameter of AE signal during loading the samples made of composite**

In points 4÷14 the values of frequency ν parameter reach the level of interval [0.039 – 0.078] to corresponds with the values of frequencies of signals registered during testing of glass fibre (Table 2).

Table 2. **The values of parameters of AE signals**

Sample	Signal number	A	**E**	D	C	ν =C/D
Glass fibre I	1	81	16900	250000	14515	0.058
	2	75	14900	169400	12167	0.072
	3	78	11413	216800	9127	0.042
	4	75	10900	249900	10923	0.044
	5	81	11268	106860	1502	0.037
	6	75	12040	220000	8007	0.036
	7	100	15260	29870	936	0.031
	8	85	13070	215000	10311	0.048
	9	73	10900	247560	9734	0.039
	10	76	11520	78550	5933	0.076
	11	95	23952	47660	1680	0.035
Glass fibre II	1	83	1300	20090	1023	0.051
	2	85	1260	13130	654	0.050
	3	70	1450	18950	799	0.042
	4	61	1581	60600	2391	0.040
Resin I , Resin II	1	100	**57000**	45500	1134	0.0249
	1	100	**22900**	29000	607	0.021
Composite	1	100	17000	14842	387	0.026
	2	99	11740	62800	1520	0.024
	3	99	13560	15740	365	0.023
	4	100	51323	250000	9816	0.039
	5	100	60586	249982	12569	0.050
	6	100	32080	249997	13291	0.053
	7	99	50300	249996	14984	0.06
	8	100	65535	249994	13453	0.054
	9	100	65535	249991	15640	0.039
	10	99	65535	250000	19322	0.077
	11	91	39030	249988	19568	0.078
	12	87	24540	249997	17805	0.071
	13	85	15614	249993	17775	0.071
	14	82	11700	249993	14842	0.061



a b

Fig.4. **Distribution of frequencies of AE signals during static loading of a composite**

Conclusions

The analysis presented above helps identify the separate AE signals, coming from the component elements of a composite. The characteristic of frequency *v* is the basic parameter, which enables us to separate the signals. Fig. 4 shows the distribution of the frequency AE signals during loading the sample made of a composite

Empty triangles show the distribution of frequencies of all AE signals at the point 4. Their average value is 0.024 and corresponds to the parameter of resin cracking. Full circles show the distribution of signals from the point 4 to a total failure of a sample. The average value *v* of all the signals from that interval is 0.057, which corresponds to the values of frequency of signals occurring during glass fibre cracking. Fig. 4b shows the distribution of the frequency after rejection of the signals of the highest energy parameters in relation to the period of their duration. In that case the average value *v* is 0.039 which is also included in the interval of the frequency for cracking fibre.

The analysis of the results helps determine, univocally, the process of a composite failure. At the first stage the resin is almost totally damaged, then the glass fibres failure occurs.

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Kompozitų pažeidimų mechanikos analizė akustinės emisijos metodu

Reziumė

Pateikti sudėtinės materialiosios jėgos poveikio bet kurioje jo stadijoje vertinimai, atlikti naudojant akustinės emisijos metodą. Be to, aptarti tyrimai akustinės emisijos signalo parametrams ir sudėtiniam irimui tam tikroje poveikio stadijoje, nustatyti.

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