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ESTIMATION OF MECHANICAL PROPERTIES OF THE ANISOTROPIC REINFORCED PLASTICS WITH APPLICATION OF THE METHOD OF ACOUSTIC EMISSION

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In this paper the results of the estimation of composite material's (the anisotropic reinforced plastics type) mechanical properties are presented.

The test loadings are applied on specimens with the longitudinal in one case and cross-section in another case of the reinforced fibres orientation in relation to the load direction. The specimens for static tension tests are presented as squared shape band with the moulding fixed plates on the both ends for mounting into the test rig's gapping jaws. The static test program consists of three - or six time specimen's loading to the level making 20% of the ultimate load; after that the loading goes non-stop to the collapse of specimen.

The possibility of the character and level of fibres and a matrix of composite specimen's damages estimation by acoustic emission signals' analysis is shown.

The test performed have shown that the acoustic emission method can be used in practice to carry out the probes of responsible avia/space devices designed of anisotropic reinforced plastics.

Keywords: composite materials, static tests, acoustic emission, ultimate loads

1. Introduction

Aero-Space branch produces the rigid requirements to working capacity and reliability of constructional materials. Recently more and more wide application is found by composite materials which possess variety of unique properties. That defines composites choice instead of metal alloys.

While metals are isotropic, composite materials are extremely isotropic. Composite pattern's strength along a direction of fibres may more than in 20 times to exceeds the strength of a matrix, the strength across fibres or the strength between layers. Thus, many kinds of destruction are possible; such as a tension, a compression, a shift in a sheet plane, an inter-laminar bonding shift, a flat tension and their combinations. But if the metal under the effect of the compression may only to be distorted rather than to be destruct, the polymer composite material may completely destroy, to divide or split the matrix parallel to the fibres.

Besides, composite materials are non-uniform. The pattern has various structures in various directions within a layer or on a thickness. In this connection if the classical approach is used to an estimation of the weariness, the creep and the growth of cracks, it is necessary to take into consideration various elements of a material (a fibre and a matrix), the orientation of fibres in relation to the loading and also their interaction. Even the static strength may be changed under the influence of the sequence of packing of layers, i.e. due to order in which identical layers have been kept within on a thickness.

Other prominent feature of compositions is their small deformations.

Inside the metal the local plastic deformation unloads the stress concentration and redistributes it in places of abrupt changes in geometry, defects and cut-outs. So the stress concentration factors K and Kf ratios of fatigue strength of metals have not been directly used for composite materials. Residual stresses, such as thermal, arising from the curing, become more significant than in metals, and may contribute to premature failure.

It should seriously look into the nature of the degradation of the matrix in composite materials. While the matrix is not exposed to the classical corrosion or the corrosion under stress, like metals, it may degrades from the aging, the exposure of the ultraviolet radiation, the humidity, lightning strikes, mechanic shocks and the environment erosion etc.. These phenomena should be taken into account when it comes to the pattern's long life time.

The degree of an admissible damage is various at compositions and metals and strongly depends on the design. For the reliability estimation it is necessary to understand, how damages influence the static and fatigue strength, the creep and the residual strength.

At last, unusual character of composite patterns and their joints causes of non-destructive testing complexity.

Composite materials such as fibrous composites keep the unique properties of the high strength and the low firmness, have good fatigue properties. So they may be applied in designs of any appointment.

Mechanics of composites studies their mechanical behaviour under the applying loads: the distribution of stresses and strains, by which the kinematics characteristics and the structural strength may be calculated. This investigation may be divided to macro-mechanics or micro-mechanics, depending on the scope of the observation. In the first case the material is considered to consist of homogeneous anisotropic layers, and the unknown quantities are the average stress, strain and tensile strength. This layered composite is characterized by two of Young modulus, two Poisson's ratios, shear modulus and the three values of the ultimate stress limits.

The micro-mechanical viewpoint is based on the fact that the behaviour of the composite material or the pattern is closely related to the level and distribution of internal stresses and load transferring from one component to another. In micro-mechanics these internal stresses, as well as the internal reaction and the interaction of individual pattern's parts, which are caused by applied forces, are studied. This data obtained are the basis for calculating and predicting the macroscopic behaviour of the material, determining the type of the destruction and establishing a criterion of strength limit.

Among the possible types of damage are distinguished the abruption of the matrix, the abruption at the interface between the fibre and matrix and the fibres abruption. These types of fracture are not independent, and may interact and stimulate each other. The beginning of the destruction is obviously determined by the internal stress state, which depends on the current applied load, the geometrical structure of the composite and the properties of its components. It may be that a stress distribution is very complex, and define it analytically is extremely difficult. Therefore experimental studies have a significant importance and even necessary sometimes.

The experimental methods what are applied to studying the mechanics of composites, engage a photo elasticity method, a stress measuring method, a Moire method, a holography and a method of an acoustic emission (AE). AE-method is applicable as a method of non-destructive inspection and is especially effective at the studying of micro-mechanics of the destruction.

When the unidirectional composite pattern is loaded across fibres, there the critical situation takes place. Thus pattern's ruggedness reaches a minimum and the criterion of the strength is defined by the stress and deformations level in a matrix. Concerning this case micro-mechanical and macro-mechanical probes mostly have the analytical character [1].

In some studies the average (macroscopic) mechanical properties have considered and give expressions for the modules in the transverse direction and the coefficients of thermal expansion of the composite. Some of these works are based on energy considerations, using variation principles, in others there is apply approximate empirical expressions.

The stresses in the matrix are important in the case where the load is applied in the direction along to fibres, as in this case the beginning of the destruction is depend on concentration of stresses and strains in the matrix. Due to the numerical method the growth of strain on the border of the matrix and fibres has been calculated [2]. Using numerical methods of the theory of elasticity the exact solution have been obtained [3]. Analytical methods were also developed to account for the influence of anisotropy an exact solution [4], viscoelastic properties, plasticity, and random packing of fibres.

Other important problem of micro-mechanics of composites is a studying of the loading transmission from a matrix to a fibre (or from a fibre to a matrix), when external force is applied in parallel fibres or at an angle to them. The large number of the experimental photo elastic probes is known devoted to the stress investigation inside a matrix, to distributions of stress at borders of the section of a matrix and a fibre, the stress concentration near the ends of fibres and their breaks, as well as kinds of the damage and its progress.

Most of these studies are qualitative in nature. Load transferring and especially the distribution of stresses and their concentration near the end of the fibre has been the subject of many studies that used two-dimensional model.

To date, the application of acoustic emission method to study dynamic phenomena has been very limited. This industry employs S. Huguet, N. Godin, R. Gaertner, L. Salmon, D. Villard [5].

In this article determinate the possibility of assessing the nature and level of damage to the fibres and matrix composite patterns due to analyses the parameters of AE in the course of the tests. It is assumed that the MAE can be used in practice during the test runs of important structures of aerospace vehicles, made of anisotropic reinforced plastics.

2. Methods of Testing

The methodology of the test trials were conducted in accordance with the requirements of ГОСТ 25.601-80 and ГОСТ 24778-81. Composite materials test samples with the longitudinal and transverse orientation of fibres relative to the direction of the applied load have been investigated. The test samples were rectangular plates with clamped ends lining for tensile testing (Fig. 1).

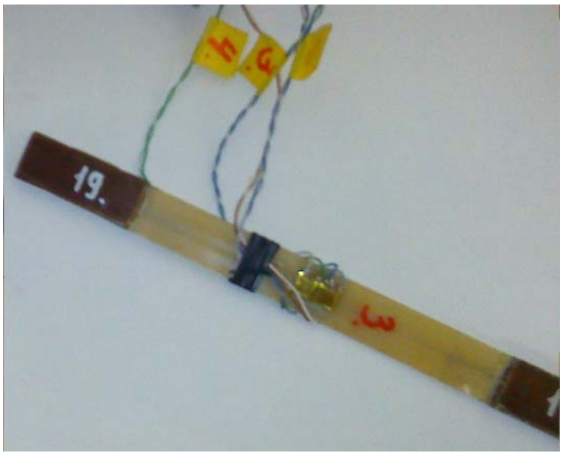


Figure 1. The test sample

The testing program included the as loading the sample only once to the destruction, and as samples incurring to three-and six-times loads of 10–30% of the fracture load and after that loading up till destruction.

Tests were performed on the thermo-stated branch, which is equipped with a hydraulic cylinder and a strain-gauge acquisition system. The loading process was monitored with the loading control system "Aviatest". The bench was modified on base of a test machine WPM, (Germany), (Fig. 2).

Under the testing of samples the ambient temperature within t = + 22 ... 24 º C was maintained as a mandatory requirements.

The strain gauges were glued on each tested sample. The testing data were recorded with the acquisition system HBM MGCplus on tenso-metric module CANHEAD. This data contain information about the strength of loading, the displacement of the piston's actuator, the strain of the sample.

These AE data were fixed with measuring system based on ГСП АРГУС-7 АФ-15 and the processor LCard L-783, under control of the program "Acoustic"; and device firms PAC POCKET AE-2.

a) b)

Figure 2. The test bench:
a) the test sample is attached to the bench; b) the thermostatic box stand

The Acoustic-Emission devices ГСП АРГУС-7 АФ-15 is a 2-channel recorder, which measures the total number of AE impulses and intensity of AE (bandwidth 20 kHz – 2.0 MHz).

The device of the Firm PAC POCKET AE-2 is a portable two-channel acoustic emission device, allowing fixing the parameters of acoustic emission. During the experiment one acoustic emission channel and a channel of a parametric input were activated. The following data were recorded: the time, the voltage on a parametric input, values of AE parameters (the intensity, the energy, the amplitude, the duration, the average frequency of AE signals).

The frequency response of the AE channel device "Pocket - AE2": from 1.0 kHz to 1.0 MHz + / – 1.5 dB.

As an AE sensor the piezo-converter П113 – (0,2-0,8) with a frequency range from 200 kHz to 800 kHz was chosen.

For the AE signals pre-amplification П113 (device АФ-15) with a constant 40 dB gain in frequency bands from 20 kHz to 2 MHz, and IL-LP-WS (PAC POCKET AE-2) with a constant 26 dB gain in frequency bands between 100 kHz up to 1 MHz were used.

AE sensors were attached to the sample with Cyanoacrylate-glue (Fig. 3).

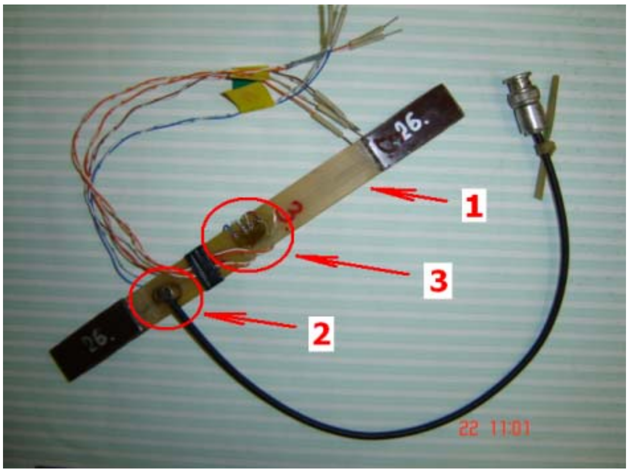


Figure 3. The attachment of the AE sensor on the sample: 1 – an AE sensor, 2 – a sample 3 – tenzogauge

The scheme of switching the measuring equipment is shown on Figure 4.

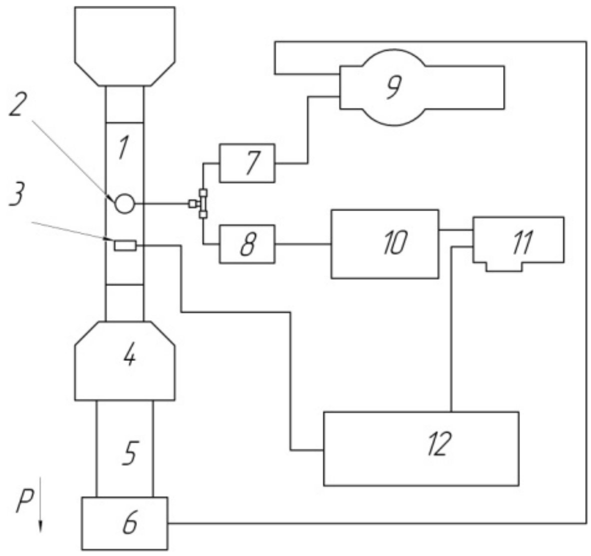


Figure 4. The scheme of switching the measuring equipment: 1 – a sample, 2 – an AE sensor, 3 a tenzogauge, 4 – a clip, 5 – a cylinder, 6 – a dynamometer, 7, 8 – preamps, 9 – PAC POCKET AE – 2, 10 – ГСП АРГУСб 7 АФ-15, 11 – LCard L-783, 12 – a strain gauge system

Loading of samples was carried out due to the following program:

- the three-fold pre-loading to a value of 10 kN or 22 kN for specimens with a longitudinal direction of the fibres and up to 2 kN for specimens with a transverse direction of the fibres, with a subsequent increase in load to destruction the specimen;
- the six-fold pre-loading to value of 6 kN, with a subsequent increase in load to the specimen destruction (Fig. 5.);
- the loading to sample destruction, without pre-loading.

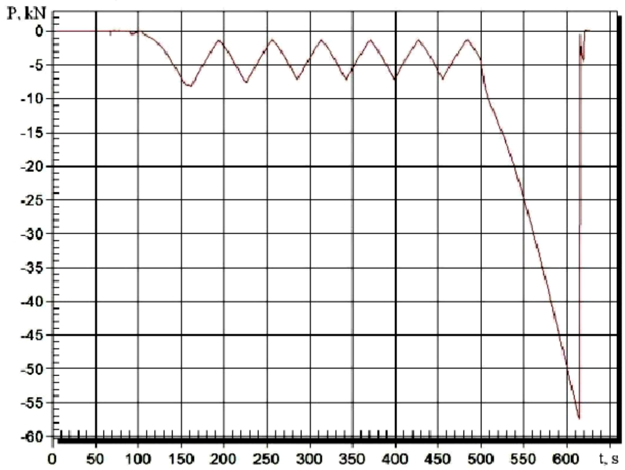


Figure 5. Schedule of sample loading with longitudinal fibres preliminary six-fold loading

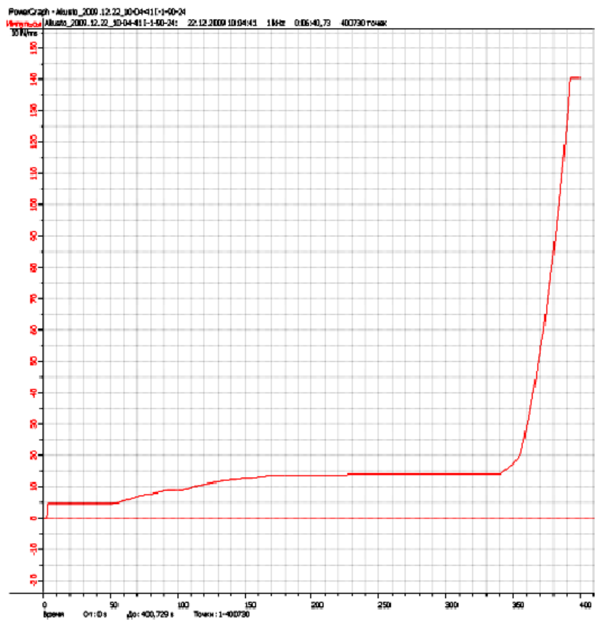


Figure 6. The total of AE signals account versus the time when the specimen was loads with a transverse arrangement of fibres with a preliminary three-times loading

After processing the obtained data were plotted as a function of AE parameters versus load times, as well as the dependence of the parameters of AE on the magnitude of the load (Fig. 6.).

The following relationships were found:

1. During the loading process the amplitude, the duration, the intensity and the energy of AE signals changes its character for the different stages of loading.

2. The relations for each group of samples have a general nature.

The relationships obtained using PAC POCKET AE-2, for ГСП АРГУС-7 АФ-15 show that the nature of the dependences of the intensity of time and loading wore the same character are represented below.

Specimens with longitudinal fibres

At the beginning of the loading process the level of the signal amplitude may achieve for the separate signals of 100 dB, but generally do not exceed 50 dB.

After reaching a load of 60% of the fracture load, the AE amplitude increases to 70 dB, but at the last stage of loading till specimen destruction it reaches 100 dB.

The duration of the AE signal increases from 100 microseconds to 200 mks at the initial stage of loading. After that it increases from 500 mks to 800 mks during 60% of the fracture load, but at the stage of destruction duration of the AE signal reaches 2000 mks.

The intensity of the signals at the initial stage up to 50 after which the signal intensity decreased. At the stage of 15% of the fracture load the intensity is near 10 ms, and with further loading to 60% of the fracture load, it increases to 50. During the destruction of the specimen its value achieves 80.

The values of energy on the initial stage up to 40, at the stage of loading up to 15% of the destructive load the energy reduced to 25, but upon reaching 60% of failure load value of the energy increases to 300, during the destruction of a specimen of its value reaches 5000.

Specimens with transverse arrangement of fibres

The values of the amplitude of the signal the beginning of the loading process may reach for the individual signals 75 dB, but generally does not exceed 50 dB, after reaching a load of 75% of the fracture load the amplitude increases to 70 dB, but at the last stage of loading to the specimen fracture it reached 80–90 dB.

The duration of the signal increases with 50 mks to 200 mks on the initial loading stage, after which increases to 600 during 75% of the fracture load, but at the stage of the destruction the duration of the signal reaches 1000 mks.

The intensity of the signals at the initial stage up to 20, after which at the stage of 10% to 30% of the fracture load the signal intensity decreased of up to 10, with further loading, it rises to 30 at the 75% of the fracture load and at the stage of the specimen failure of its value reaches 60.

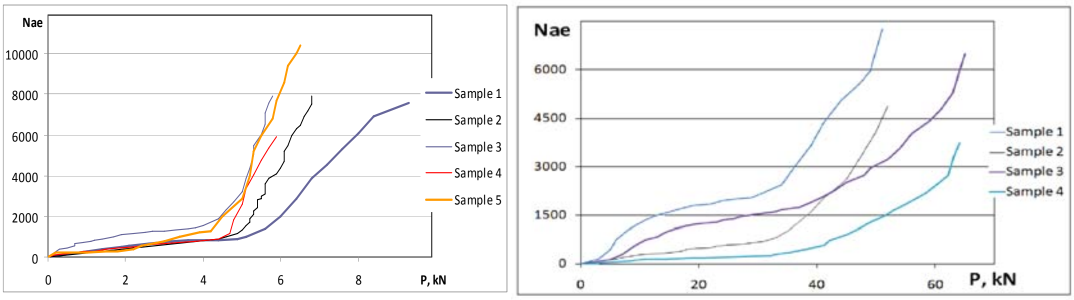
The values of energy at the initial stage is from 40 to 60, at the stage of 30% of the fracture load the energy is reduced to 10, upon reaching 75% of the fracture load value of the energy increases 30–40, and at the stage of destruction of the specimen its value reaches 200.

A clear differentiation processes of loading and fracture in amplitude as in [5], was not found. At the initial stage of loading the values of individual impulses may reach significant values (up to 100 dB), which probably is associated with mounting in the device jaws, specimen clearance (removal of gaps in the jaws with specimens) and the movement of dislocations. During arising the loading the amplitude decreases and do not increases till 60% of the fracture load for specimens with longitudinal fibres and up to 75% for specimens with transverse arrangement of fibres. It's explained by the fact that the acoustic emission signals are formed due to movement of dislocations at this stage. When the load level reach of 60% of the fracture load for the former and 75% for the second, the process of the matrix destruction begins, this is accompanied by signal amplitude from 40 to 60. The next phase is accompanied by the delamination, and is characterized by increasing of the signal amplitude level to 80 dB, the last stage at which the fibre failure is accompanied by the amplitudes of 80 dB to 100 dB. In this case at the last two phases the AE signals with amplitudes characteristic of the matrix destruction are presented.

The destruction of the matrix, the delamination and rupture of fibres are accompanied by increasing AE signals of intensity, duration and energy, while the destruction of the matrix is corresponded to AE signals of lower intensity, duration and energy. During the fracture of fibres AE signals have a maximum intensity, duration and energy, and AE signals during delamination are much greater intensity, duration and energy than that at the destruction of the matrix, but somewhat less than the destruction of the fibres.

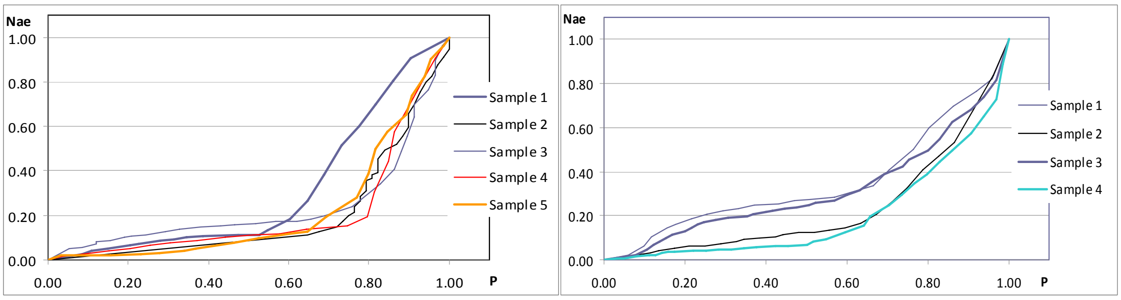
This is most clearly the process of destruction of fibres is characterized by a change in the energy of AE signals as the AE signals at the beginning of the loading process have a small duration.

The obtained dependences of total AE impulses summing versus loading have the same variation of total AE summing for each of the tested specimens: the areas of slow AE signals growth replaced parts of its sharp growth. The intersection of nthese sections forms an angle α, such an angle α, shown in the work of Banov M. and Troenkin D [6].



a) b)

Figure 7. The graph of the AE impulses summing growth versus the loading:
a) specimens with transverse arrangement of fibres, b) specimens with longitudinal fibres



a) b)

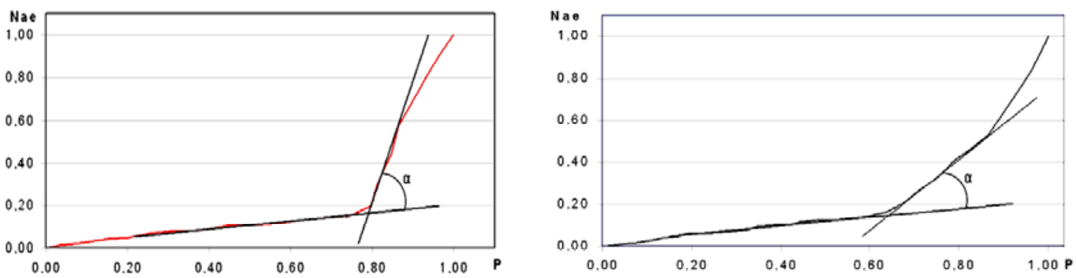
Figure 8. The graph the AE impulses summing growth versus the relative loading:
a) specimens with transverse arrangement of fibres, b) specimens with longitudinal fibres

The formation of this angle α characterizes the beginning of a process of degradation and persists until the fracture.

For specimens with longitudinal orientation of fibres α – change begins from 60 to 70% of the fracture load, describing what the matrix destruction is happens, followed by delamination and finished with the destruction of bearing fibres. Then specimen is completely destroyed.

It is characteristic that for specimens with transverse orientation of fibres that *α*-change begins near 75–80% of fracture load. That characterizes what the matrix material destruction is happened, followed by delamination and finished with the destruction of connecting fibres, after which the specimen is completely destructed.

Thus the method of acoustic emission allows determining the start of an irreversible failure of unidirectional composite material.



a) b)

Figure 9. The graph of the relative the AE impulses summing growth versus the relative loading:
a) specimens with transverse arrangement of fibres, b) specimens with longitudinal fibres

Conclusions

In the specimens with longitudinal orientation of fibres relative to the applied load the beginning of destruction observed under 60% of the destructive load values is exceeded.

In the specimens with transverse orientation of fibres relative to the applied load the beginning of destruction observed under 75% of the destructive load values is exceeded.

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