PCM Bearing Capacity Prediction Criteria Development Based on Registered AE Parameters

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Abstract. In this paper a result of the registered acoustic emission (AE) signals during static deformation and destruction of the polymer composite material (PCM) study is presented. Analysis of the total AE accumulation, changing of the Ib-value and probability densities of peak amplitudes and median frequencies of the AE signals was done. An approach for the PCM destruction stages identification and the bearing capacity determination based on the energy and frequency analysis of the AE signals wavelet decomposition is proposed.

1. Introduction
Polymer composite materials (PCM) found wide application in industry [1]. It is worth noting use of fiberglass reinforced plastics (FGRP) in the manufacturing of buildings and transport systems [2]. However, complex structure of these materials makes difficulties at products engineering from them and assess their state during exploitation [3]. At that regard non-destructive testing (NDT), which makes possible to investigate the accumulation of different types of damages in the PCM structure under loading are of interest [4].

Acoustic emission (AE) technique – one of NDT, which allows investigating the damage development in material [5]. Analysis of the registered AE signals descriptors makes it possible to define the nature of occurring damages and their scale. The most used AE descriptors are count [6,7], peak amplitude [8,9], energy [10,11], frequency [12] of and other. The complex analysis of AE allows assessing the damages evolution in material, characterizing the stages of destruction process [6].

2. Materials and Methods
For the experiments FGRP samples was produced from a plate molded by vacuum infusion technique with use of DION 9300 FR resin and T-11-GVS9 fiberglass fabric. For testing of the samples static three-point bend by the standard [13] was chosen.
The AE signals, recorded during the experiments with use of the software-hardware complex [14] and the two wideband transducers Globaltest GT301, was grouped into sets. These sets present the signals, registered every five second of the mechanical testing.

The bearing capacity evaluation was performed by analyzing of the exponent index $n_i$ of the total AE accumulation on the loading parameter dependence [15]. The exponent index calculated by the formula:

$$n_i = \frac{N_{AE} \cdot \sigma_i}{(\Delta \sigma \cdot N_i)},$$

(1)

where $N_{AE}$ – total AE accumulation on loading step; $\sigma_i$ – sample stress, MPa; $\Delta \sigma$ – sample stress on loading step, MPa, $N_i$ – total AE.

The scale of damages occurring in the material was assessed by a slope of the frequency-magnitude distribution – the $I_b$-value. Large values of this parameter point to the microscopic defects occurring in the material’s structure and small values to the macroscopic defects occurring [16]. The $I_b$-value calculated by the formula [1]:

$$I_b = \frac{\log_{10}(N(\mu-a_2 \sigma)/N(\mu+a_1 \sigma))}{\log_{10}(\sigma_{1+a_2} \sigma)},$$

(2)

where $N$ – number of signals greater than specified amplitude; $\mu$ – mean amplitude; $\sigma$ – standard deviation; $a_1$ and $a_2$ – empirical constants.

Including the data of the AE signals frequencies to analysis provides obtaining information not only about the scale, but also about the nature of damages. Previously, authors made a complex analysis of the peak amplitudes and median frequencies distributions for another FGRP [15]. For calculation of the parameters, the normal distribution formula used:

$$p(x) = f(x|\mu,\sigma) = e^{-(x-\mu)^2/2\sigma^2}/(\sigma \cdot \sqrt{2 \cdot \pi}),$$

(3)

where $\mu$ – mean value; $\sigma$ – standard deviation.

In addition, for the characterizing of recorded AE the wavelet decomposition found wide application. In this work was used a method from the work [6], where for the signals was applied the 14th order discrete Daubechies wavelet with transforming to seven decomposition levels. Then for analysis was calculated the peak frequency and part of the energy relative to the total signal of each decomposition level.

3. Results and Discussion

3.1. Exponent Index $n_i$

The choice of the exponent index value of the total AE accumulation on the loading parameter dependence based on the experimental data of the material testing. At that, the estimated values of bearing capacity relative to the maximal stress are in the range from 70 to 80% (Fig. 2). In this work, the exponent index equal to six was accepted and the values of bearing capacity were in range 72-86%, what is appropriate.
3.2. Ib-value
PCM have complex structure, which characterizes by the mixed destruction process with predominance of the macroscopic either microscopic structure defects. On basis of this at the Ib-value analysis attempts to develop the criteria for the determination of the bearing capacity by the scale of the material structural damages was done.

On the plot (Fig. 3) seemed two characteristic peaks of the Ib-value after begins of material testing. Therefore, an initial microdamages with the followed increasing and decreasing of their scale can be characterizes as a relaxation process of stress, formed during the FGRP molding. Consequently, next damages occurring (the second peak of the Ib-value) characterizes the achieving of the maximal bearing capacity period.

The estimated values of the bearing capacity, relative to the maximal stress, are in the range from 72 to 90%, and this result is less appropriate, than in case with the exponent index $n_i$.

3.3. Probability Density Functions
At the analysis of the probability densities of peak amplitudes and median frequencies (Fig. 4) was found a tendency for the stepwise growth of both parameters, when loads greater the bearing capacity, and decreasing of the values closer to the moment of samples failure.
3.4. Wavelet Decomposition.

In researches of the PCM destruction processes highlights the types of damages, which occurring in the material under loading, and the characteristic frequency bands associated with them. In [10] the destruction of FGRP was described by matrix cracking (90-120 kHz), fibers pull-outs (130-200 kHz), fibers debonding (220-245 kHz), delamination (260-295 kHz) and fibers breakage (300-450 kHz). In [6] the process of FGRP sample destruction presented by matrix cracking (70-150 kHz), delamination (168-190 kHz), fibers debonding (210-270 kHz) and breakage (300-400 kHz).

In this work after the wavelet decomposition of the signals, the 3rd (312.5 to 625 kHz), the 4th (156 to 312.5 kHz), the 5th (78 to 156 kHz) and the 6th (39 to 78 kHz) levels were accepted as informative (Fig. 5). By the high values of the energies of the 3rd and the 6th levels, it was assumed that these frequency bands characterize the fibers breakage and the matrix cracks. Therefore, the 3rd level corresponds to fibers breakage, the 4th to fibers debonding, the 5th to fibers pull-outs and the 6th to matrix cracks. In addition, if the mean values of the level’s energies relative to the total signal energy were greater 15%, these values was accepted as important for analysis.

The initial destruction stages (before the loads achieved the value of the bearing capacity) characterize by high values of the energy of the 3rd (18 to 39%) and the 6th (25 to 39%) levels. At the moment, when the loads were closer to the bearing capacity value most damages were matrix cracks. Then the destruction mainly presented by a mixed damaging of fibers and matrix with predominance one or then another. At the sample failure the energy part of the 5th level (fibbers debonding) increased.

For the peak frequencies (Fig. 5) taken into account the influence of signals path length on frequency [17]. It was accepted, that on local occurring of damages the peaks frequencies of registered signals are in small band, and on global in wide band. Also was taken into account the difference of maximal and minimal values, and if this difference is greater 15% relative to the mean value, it points to the process of global destruction.

Before loads achieved the value of bearing capacity, matrix cracks in material bulk with part of the preloaded fibers breaks occurred. Loads equal the bearing capacity characterizes by increasing of the matrix damaging scale. Then the intensity of matrix cracking decrease and begin to alternates with the global failure of the fibers. At samples failure fibers debonding and sample delamination.
Figure 5. Changes of minimal, mean and maximal values of energy parts (left) and peak frequencies (right) for 3rd to 6th decomposition levels (up to down).

4. Conclusion

As a result of research, the assessment of the bearing capacity determination methods based on one parameter (the exponent index \( n_i \), the Ib-value) and based on some parameters of AE (the density probabilities distributions of peak amplitudes and median frequencies, the wavelet decomposition) was done. Established that the analysis only of one AE parameter does not allow fully assessing the damages occurred on each stage of loading. However, the complex analysis of AE parameters allows identifying the types of damages, which characterize loss of the material bearing capacity, their evolution and basing on this data to determine the bearing capacity value.
5. References
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