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A computer model of the process of polymer materials fatigue destruction

G. Wróbel*
Division of Metal and Polymer Materials Processing, Institute of Engineering Materials and Biomaterials, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: gabriel.wrobel@polsl.pl

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Properties

ABSTRACT

Purpose: In the paper an evolutionary model of fatigue destruction was described. The aim is in as much as possible faithful modeling of processes during constructional materials exploitation observed, particularly progressing of strength ability loss or other useful characteristics changes.
Design/methodology/approach: The MES was choosed as a discretisation method. The model evolution goes sequentialy – chaotic system modification by actual state analysis is preceded. Evolution stage and material state characteristics evaluation give a bases of destruction extend nondestructive evaluation.
Findings: The example gives an evolutionary acoustic properties of polymeric composite change illustration. It points the model diagnostic value.
Research limitations/implications: In order to obtain reliable results, there are many factors to be considered such as real three-dimensional composite structure, type and quality of composite components, particularly reinforcement and others. Further work is needed in this area.
Practical implications: The results obtained would be of considerable importance in the computer aided diagnostic method of polymer composite materials.
Originality/value: A new approach to the problem of investigation of polymeric composite's fatigue destruction has been demonstrated by means of computer simulation procedure. The method developed should be of interest to the industrial quality control applications and forecasting of important mechanical characteristics of composite materials, exploited in fatigue conditions.
Keywords: Non-destructive testing; Fatigue destruction; Chaotic system modification; Acoustic properties

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1. Introduction

Among the many criteria, that the market of products and technologies guided, in both - the consumption and investment spheres – economics and security are the major. Their position is clear from two basic paradigms of social development - the market and value of human life and health. The answer in the field of research methodology to these challenges is to develop non-destructive diagnostics of technical systems to enable an economically rational and safe exploatation of technical systems [1,2,6]. Extending of the set of classical diagnostic methods on simulation techniques, in the field of virtual models, create a new direction for the diagnostic tests, likely to be important in pre-conceptual design.

The basic criteria for quality construction materials are, among many different, the criteria for strength. In Metal and

Polymer Materials Processing Plant of Institute of Engineering Materials and Biomaterials a methodology for non-destructive diagnostic tests, using the technique of ultrasonic and thermal imaging [3-15], is developed. Studies have demonstrated the building possibility of diagnostic relations binding characteristics of acoustic and thermal processes, which are the essence of the methods used with strength characteristics - for example, an immediate strength or residual fatigue strength. Building such relationships in terms of volume requires the implementation of a comprehensive program of basic research of tested material. Research are conducted in the laboratory conditions, they are therefore subjected to the sample material in the contractual conditions of loading. The results are of comparative value, but the generalization of the results for structural components under operating conditions, in the general case is not easy. One way supporting of the diagnostic can be a numerical simulation of the degradation process.

In the further part of the article fatigue tests simulation was described. The evolutionary model of the material was used in. The model structure and properties were shaped in the chaotic process. Quantitative process controllers were defined by the conduct of an experiment in laboratory conditions. The described model allows the simulation of fatigue load-bearing capacity reduction of material with complex geometrical features, subject heterogeneous and unsteady fatigue process.

2. Model of medium

Evolutionary model of fatigue process is the basis for a model of medium, which maps the sequence of the modification process of fatigue destruction. Due to the local nature of evolutionary changes the model of medium divided into small parts, according to the method of finite element method will be used. This model is characterized by geometric structure, resulting from the geometrical features of the medium area and division into finite elements have been accepted. The number of equilibrium conditions and continuity describing the model follows from it. The physical characteristics of the medium image the local physical parameters, such as elastic, describing the defining medium constitutive equation. Fatigue degradation takes place in periodic loads conditions. Extreme conditions of load and strain at the time are connected with the maximum of load in the cycle. In the fatigue loaded medium area the load distribution are created due to active and passive external loads and the distribution of physical properties - stiffness, mass density.

The mechanism of fatigue weakening occurs in conditions when in the loads concentration zones in the extremely load phase the rapidly initiation of evolving discontinuities - in the material - does not occur, however, arise microdamages of an irreversible process. This is due to critical condition at a micro and nanostruktural level, caused by natural matter heterogeneity of the medium. In subsequent cycles of loading the local effects of damage are accumulating and, finally, it can to lead to makrocrack, after reaching a critical number of cycles. The place of the initiation and propagation of fatigue damage, in conditions a heterogeneous state of internal loads, results from the position of the maximum load zone, where the probability of run of damage mechanism of the material is the greatest. In the case where the zone of maximum loads is extensive, in homogeneous area of the load conditions may cover the whole area of the medium, the location of the damage outbreaks initiation will be random.

In the evolutionary model of the characteristic process of the model material elements modification, probability distribution of the modification, corresponding to it's failure mechanism was adopted. It was assumed that the probability of damage depends on the element tension state. For different materials these distributions may be different. Established procedure for the model evolution is carried out in the area of elastic parameters .

3. The fatigue destruction model of medium

According to a general description of the MEDIUM model presented in the previous chapter, the key to simulate the evolutionary process of fatigue destruction is a form of the characteristic for the elements' material of the model, the probability distribution of the changes running corresponding to the damage in the different stages of evolution - the structural modification procedure steps of the model. It was assumed that the probability of damage depends on the tension state of the element.

Was adopted the working hypothesis that the shape of this dependence corresponds to the shape of Wöhler diagram for the material and loading parameters [1] (Fig. 1).

This graph provides information about the dependence of critical number of cycles to destruction of material n_{kr} on the maximum value of stresses in the load cycle $\sigma_{red,max}$. When mapping on the basis of this diagram n_{kr} in the probability of local damage, assuming that p (Re) = 1, p (Z_{rc}) = 0, to determine the probability of element damage for values corresponding to an intermediate amplitude loading is proposed Formula (1).

$$p(\sigma_{red\,\max}) = \frac{\mathrm{Re} - Z_{rc}}{\mathrm{Re} - \sigma_{red\,\max}} \; \frac{\Delta n}{n_{kr}}, \text{ for } \Delta n < n_{kr}, \tag{1}$$

$$p(\sigma_{red\,\max}) = 1, \text{ for } \Delta n \geq n_{kr},$$

where:
Re - the yield limit,
Z_{rc} - the limit of fatigue strength,
n_{kr} - a critical number of load cycles for the cycle with an amplitude $\sigma_{red,max}$
Δn - the number of cycles corresponding to Step of the procedure.

This dependence for maximum stress values $\sigma_{red\ max} \leq Zrc$, against $n_{kr} \to \infty$, excludes the possibility of destroying the element. For $\sigma_{red\ max}$ values, for which $\Delta n \geq n_{kr}$, dependence leads to a value greater than 1, what means the destruction of certain element in the analysis step.

Evolutionary model M_e of fatigue process is a sequence of models (M_i) i = 1,2 ,..., which are Markov chain. Models M_i is another evolutionary phases of the model. Model M_{i+1} is the result of a random modification of the model M_i.

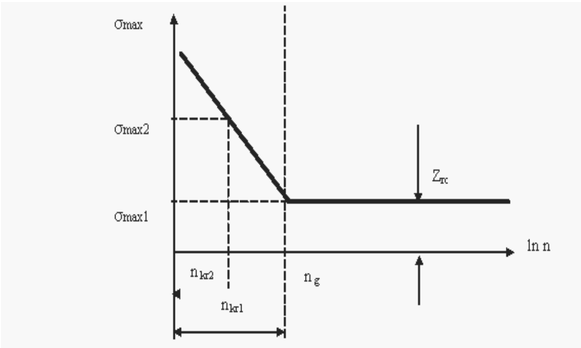

Fig.1. Simplified Wöhler diagram for tension and compression; Z_{rc} - fatigue limit of tensile and compressive strength, n_g - limit the number of cycles

The model M_i is defined by structure S_i of modeled area division and a set of physical parameters E_i characterizing the relations constitutive of the division elements. As a result of the modification is a change in physical parameter values of $E_{e,i}$, and each of the elements e, e = 1,2, ... n at the $E_{e,j}$, with the transition probability p_{ij}, appropriate for the element. The probability of transition is a predetermined probability of local damage to the element. As such, depends on the charges state arising out from model M_i analysis. In the subsequent analysis and modification of the sequences phases of evolution of the model are determined, which create the representation string of the fatigue destruction process of the analyzed medium. The key for the initiation of the evolution of the model is greater than zero probability value (1) for even a single model element. The appearing of a "material defect" in one of the attempts to stimulate the process will accelerate the degradation factor, and the environment defects will act as a stress concentrator.

4. Example of a model of composite with polymer matrix

Methodology of model mapping of the fatigue change processes on the example of a composite with a polymer matrix, reinforced with continuous fibers (eg glass or carbon fibers) will be discussed [11,13]. It is a popular case found in the laminated plates and shells. Knowledge of the mass or volumetric fraction of fibers in the material and structural features of its alignment were assumed. In the example shown uniform distribution of fibers in the composite volume was assumed (on the shell surface and thickness).

In order to model simulation of the fatigue destruction process, quboid, portion of a unit thickness of material was extracted, as a part of a composite shell. Other dimensions correspond to the stretch of the local film thickness and sample size, arbitrarily fixed to allow effective simulation of the fatigue destruction and the acoustic diagnosis (Table 1). Numerical model was built with the disc elements of a unit thickness. The analyzed area is therefore a rectangle equal to the thickness of the shell. Geometrical division of the finite elements and the distribution of material properties of elements allows the mapping of the structural characteristics of the material. In this example, the medium has been homogenized by adopting alternative values of density and elastic parameters (Table 2). Composite model of the dimensions shown divided into 40 898 rectangular finite elements of the disc with two degrees of freedom in the node corresponding to 41 328 nodes, which consequently led to a model with 82 656 degrees of freedom.

5. Results and discussion

The following simulation results concerning the process of diagnosis of acoustic models representing the cut piece of flat panels of epoxy resin laminate, reinforced with fiberglass. The initial, continuous structure of the material has undergone modification, corresponding to degradation process of fatigue, which was simulated. As a result, a string of models, corresponding to different degrees of progress in fatigue degradation was received. These models were then used to analyze the process of propagation of acoustic signal, corresponding to the characteristics of ultrasonic waves. In order to develop a computational model of the composite, computer program called Random using object-oriented programming language C + + was developed. The input to the Random Mesh1.bdf file is generated by a computer system MSC.Patran to calculate the dynamic calculation module using MSC.Nastran.

Below, in Figures 2 to 5 selected images shown instantaneous deformation of the acoustic wave model center.

Figures 6, 7 and 8 show the overview of images of the original and fatigue degradated material acoustic deformation.

Table 1.
Geometric dimensions of the physical model of the composite sample

No.	Dimensions modeled stretch composite	Value [*μm]*
1.	Length *l*	20000
2.	Height *h*	10000
3.	Thickness *g*	1

Table 2.
Material Data

Component	Resin polymer material	Glass fiber	
Elastic module E [MPa]	20	77	
Poisson's Ratio ν	0.35	0.23	
Density ρ [kg/m^3]	1200	2450	
Mass fractions [%]	50	Warp 25	Thread 25

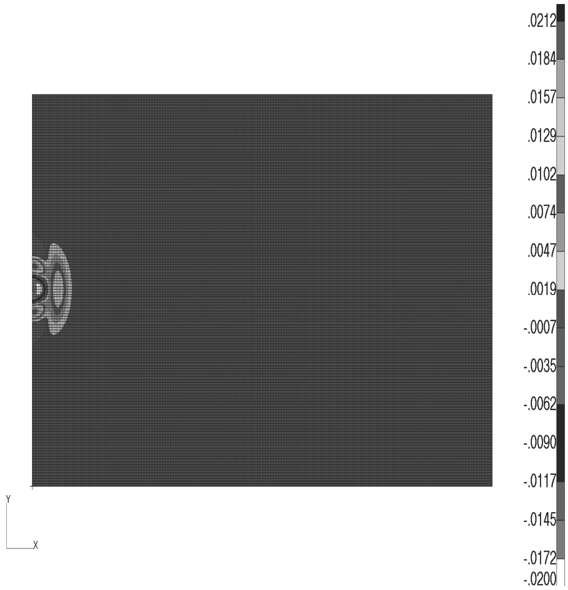

Fig. 2. Displacements map along x-axis of the composite after a period of $5.0 \cdot 10^{-4}$ ms

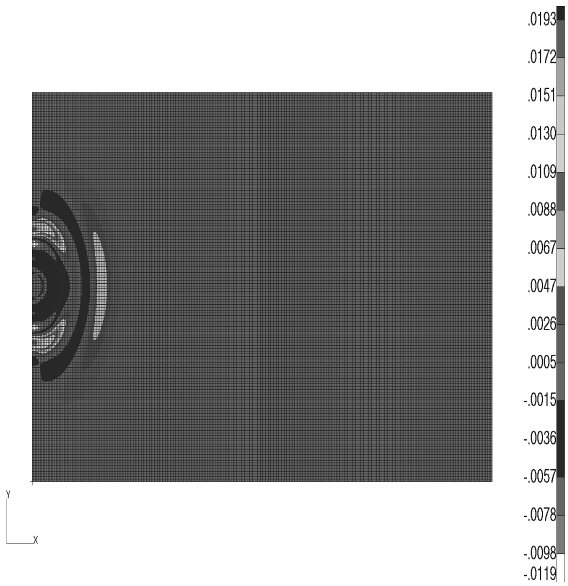

Fig. 3. Displacements map along x-axis of the composite after a period of $1.0 \cdot 10^{-3}$ ms

Based on analysis of selected variants, for each case of the analysis the phase velocity - the velocity of propagation of longitudinal ultrasonic wave front in the modeled medium - was identified. Overview of the speed values, calculated in terms of the speed chart for the ranges of degradation from 1% to 7%, in Figure 9 is shown.

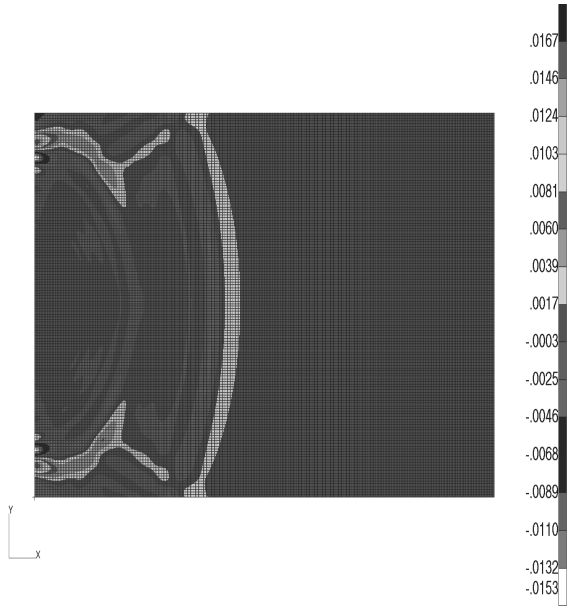

Fig. 4. Displacements map along x-axis of the composite after a period of $2.5 \cdot 10^{-3}$ ms

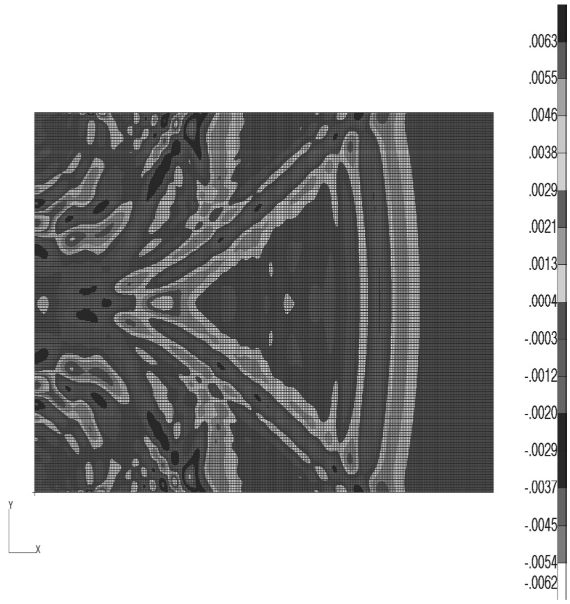

Fig. 5. Displacements map along x-axis of the composite after a period of $4.5 \cdot 10^{-3}$ ms

Comparison of the calculated wave propagation velocity and the degree of fatigue load-bearing capacity exhaustion, the measure of what is the quotient of the simulated, is a prerequisite for evaluation of the material on the basis of diagnostic ultrasound velocity measurements. The value of such an assessment does not depend on the actual history of the loads of the investigated material.

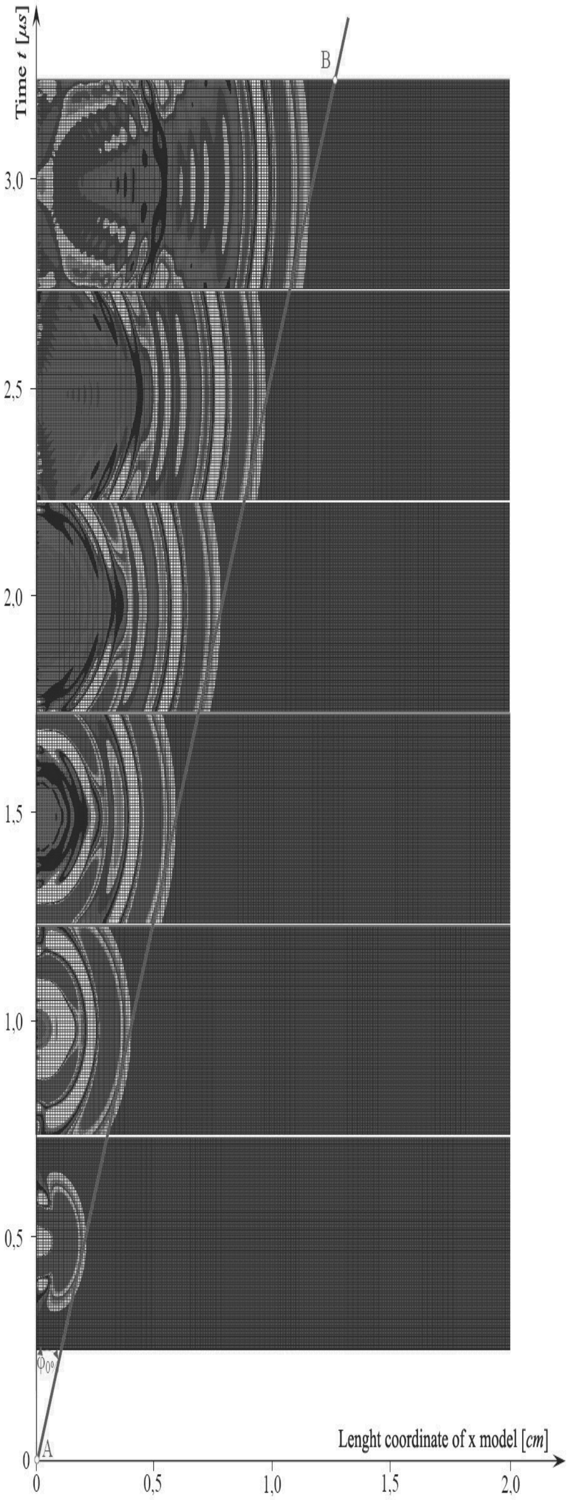

Fig. 6. Overview of images of the original material acoustic deformation

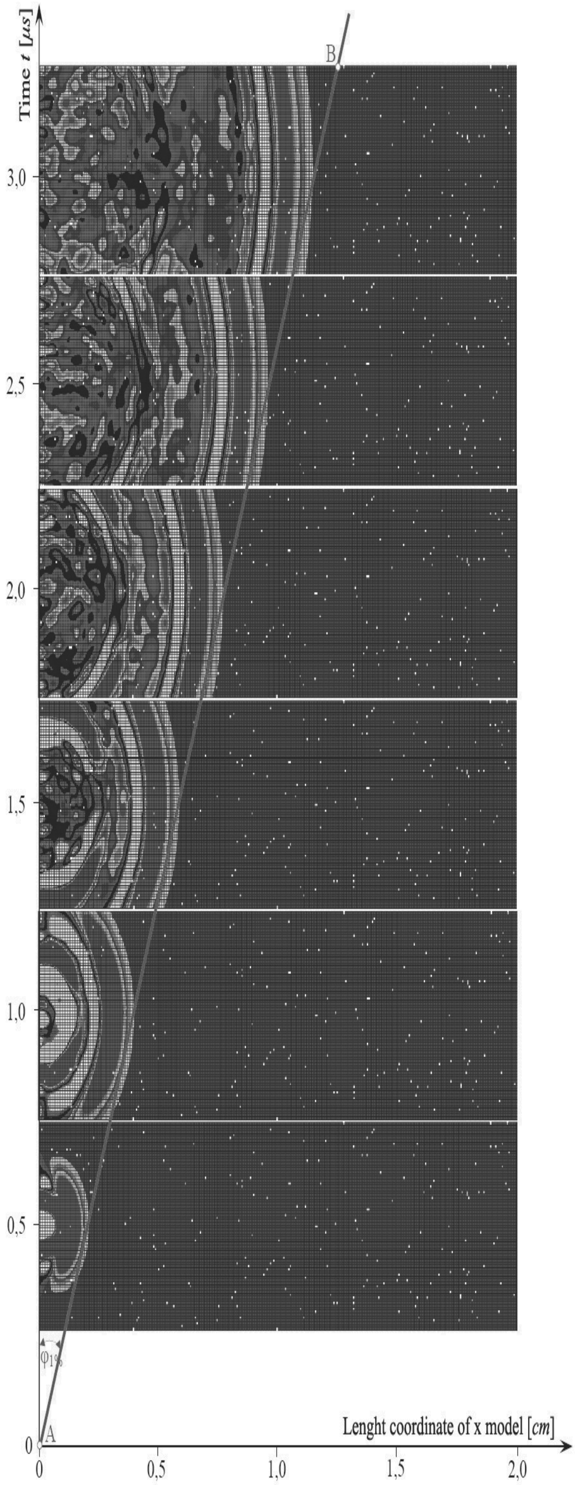

Fig. 7. Overview of images of acoustic deformation of the material in the advanced state of fatigue degradation

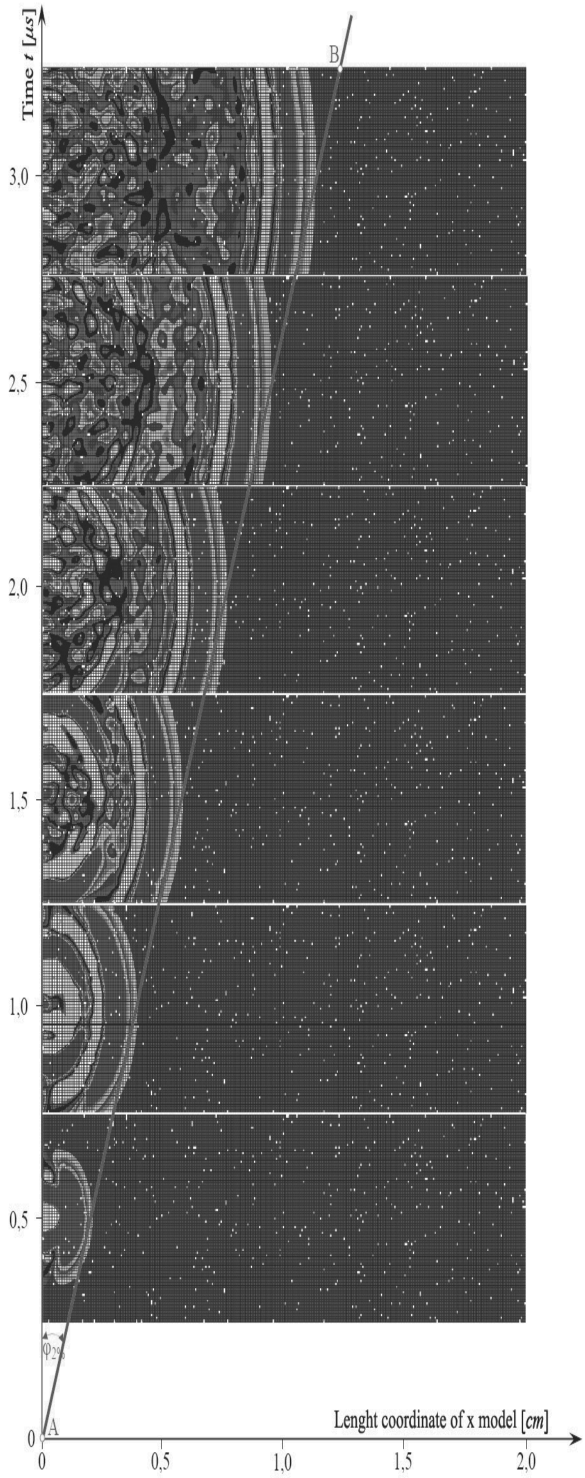

Fig. 8. Overview of images of acoustic deformation of the material in the final state of fatigue degradation

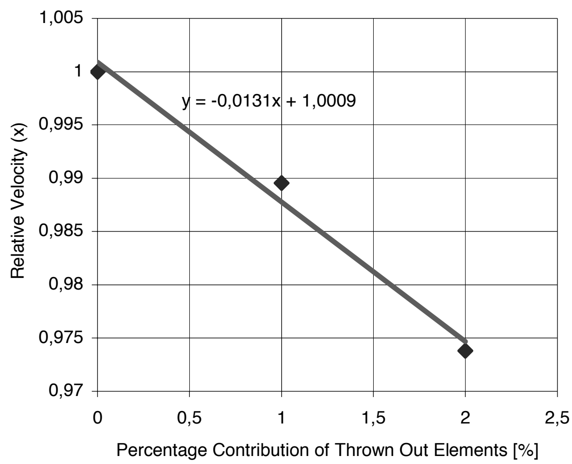

Fig. 9. Dependence of wave velocity on the degree of model fatigue degradation of the material

6. Conclusions

The generality of the model of the evolutionary process of fatigue, presented in the work, includes both homogeneous materials and composites. The developed methodology uses the MES. The evolution of the model is carried out sequentially - a chaotic system modification is preceded by the analysis of current status, the results are used to convert the following parameters. In conditions of discrete space of modified physical parameters the evolutionary sequence of models is a Markov chain. Evaluation of the evolution phases and characteristics of the material provides a basis for non-destructive evaluation of the degree of exhaustion of load-bearing capacity of the material

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Additional information

Selected issues related to this paper are planned to be presented at the 16th International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science CAM3S'2010 celebrating 65 years of the tradition of Materials Engineering in Silesia, Poland and the 13th International Symposium Materials IMSP'2010, Denizli, Turkey.

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