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Thermographic method of fatigue assessment of polymeric materials

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Materials

ABSTRACT

Purpose: The article presents the adoption of thermal imaging techniques in assessing methodology of the fatigue degradation degree of the polymeric materials.
Design/methodology/approach: Epoxy composites reinforced with glass fiber have been subjected to three point method fatigue bending. The degraded materials were then tested using thermovision method.
Findings: In experiments the temperature changes velocity of the samples was determined in the conditions of infrared radiation. The dependence between speed up of temperature and the number of fatigue cycles was determined. With an increasing a number of fatigue cycles drop in temperature speeds up was observed.
Research limitations/implications: Restriction is a condition of loading state - as homogeneous as possible, and hence the homogeneous degradation state of the material.
Practical implications: Designated diagnostic relation gives a basis for non-destructive evaluation of the degree of exhaustion of load-bearing capacity of the material.
Originality/value: Original value of the paper are the experimental results proving the effectiveness of non-destructive thermographic methods for polymeric materials diagnosis.
Keywords: Polymeric materials; Thermographic method; Fatigue assessment; Non-destructive evaluation

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1. Introduction

The aim of this study was to develop a methodology for the use of thermal imaging techniques to assess the extent of the fatigue degradation of polymeric materials, particularly epoxy-glass composite.

Thermal diagnostic method is aimed to using of spatial-temporal characteristics of temperature distribution on the surface of the material in a thermal process stimulated by a heating element. The basic idea is to use the methods of thermal infrared - heat radiation in the band of the electromagnetic radiation emitted by the test object to obtain information regarding its condition, selected physical properties or processes with its participation.
The first applications of thermography may be encountered at the beginning of this century. Parker, in 1914, infrared detector has patented. In 1934, Barker the system for infrared detection of forest fires has proposed. In subsequent years, the first industrial applications have appeared. The immediate object of thermal infrared radiation study is its distribution on the surface of the body. In the studies, whereas the emission characteristics of the surface, a basic knowledge of rights binding characteristics of radiation with the surface temperature of the observed body has been used. Temperature, depending on the scenario of the

experiments, can be a source of information on other properties of the object. In theory of the phenomenon of radiation the concept the model of a black body as an object that absorbs all radiation falling on him, regardless of wavelength, is a key.

The basic rules describing the radiation of bodies, as [1,2]:

- the Kirchoff's rule, stating stability of the ratio of emission to the absorption capacity for any area,
- the Planck's rule, describing spectral distribution of blackbody radiation,
- the Wien's rule, determining the dependence of the wavelength related to the maximum emittance on surface temperature,
- Stefan-Boltzmann's rule, describing the total radiant emittance value depending on temperature,

provided the basis for the experimental method of measuring of surface temperature on the basis of termovision body image.

The samples made of epoxy-glass laminate TSE-6 was tested. Samples were cuted from panels made by pressing in the IZO-ERG in Gliwice. For the tests, the sample in the shape of rectangular plates with dimensions 250x20x4mm was adopted.

2. Thermographic researches

2.1. Research methodology

Test methods using thermographic technique are characterized by great variety, depending on the class of objects studied, the factors highlighted in the plan of the experiment, taken into account as relevant to the thermal phenomena, which final result is a thermal picture, or even what is the heat activation method of the test subject. In particular, this last criterion is the basis for the classification on the passive thermography, based on a passive registration states and processes in the monitored objects and actively, associated with the deliberate heat stimulation of the objects. The characteristic is a large variety of systems, which effectively lend themselves to passive testing from such diverse areas as aerospace, aviation, navy, police, fire brigade, environmental protection, medicine, science and other [3-15].

More interesting possibilities creates active thermography, even through the diversity of ways to activate the object. The nature of activation may be static or dynamic. Among the most popular methods of activation may be mentioned the pulsed method (Pulsed termography), modulation method (Lock-in termography with modulated heating), pulse-phase method (Pulsed-phase termography). Its are used mainly as a radiation methods using the radiation directed at the observation area, providing information on the status of this area and reduced surface material layer.

Another class of methods is dynamic thermography consisting in excitation of structure response in the form of heat emissions by providing for the construction the energy in the form of mechanical vibration - vibrothermography. This technique is implemented through the structure vibration forcing with help of the alternating harmonic forcing and synchronous measurement of structure surface temperature. Measurement of surface temperature is carried out using a very sensitive (with a resolution of 20mK) and rapid (25 000 images per second) thermographic camera. Excited mechanical vibration of the test system, in this case, play only role of a diagnostic tool.

The method that was used in the studies presented, may be classified as active methods of static thermal stimulation. The aim of studies was to develop a methodology for the use of thermographic techniques to assess the extent of fatigue degradation of the constructional polymeric materials, particularly epoxy-glass composite. Since the degradation process is distributed throughout the volume of samples taken, characteristics of the process of temperature changing of the sample surface opposite to the heat-treated activated one as thermomonitored diagnostic values were assumed. Fatigue tests were carried out at room temperature 20 ° C ± 2 ° C. Fatigue machine had four arms with handles, performing cyclic deformation of samples. Samples were charged in conditions of sinusoidal deformations, with a constant value of maximum deflection. Number of cycles was counted by the measuring system. The observed decrease in force (stress) was considered a measure of fatigue degradation of the composite. Bending was performed with a frequency of 70 machine cycles per minute (1.167) Hz. Fatigue tests were carried out to more than 14 million cycles. Samples were subjected to cyclic thermographic testing.

In order to achieve the homogeneity of the load state in cross-section of the samples the special brackets, connects a pair of test samples and separating them polyethylene spacer was applied (Fig.1).

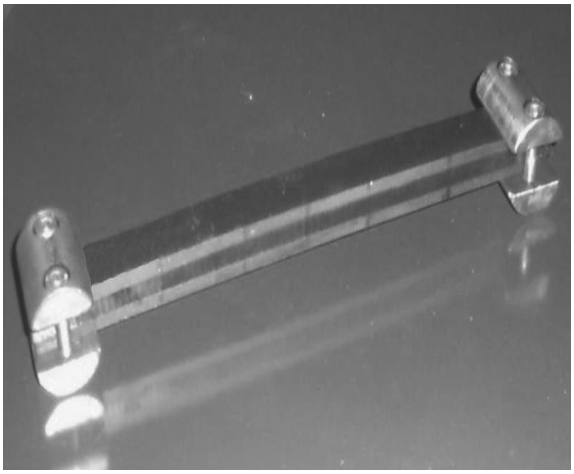

Fig. 1. A set of samples from the polyethylene spacer for fatigue tests

Value of the force necessary to achieve the assumed deflection of the sample was recorded and the level of stress for four measurement points on the length of the sample was calculated. Paper diagram of the distribution of active forces and reactions on the tired sample shows Fig. 2. Posted in the drawing dimensions were used to calculate bending moments and stresses in the individual measuring points. The results of measurements at pairs of points 1 and 4 as well as 2 and 3 are averaged, because the values of bending moments were the same.

Thermographic investigations were carried out in the neighborhood of the points 2 and 3 Results obtained were used to determine the fatigue life curves and diagnostic relations. Thermographic investigations were carried out using ThermaCAM SC640 thermographic camera (FLIR Systems AB, a manufacturer). Diagram of the bench of temperature measurement using a thermographic camera is shown in Fig, 3.

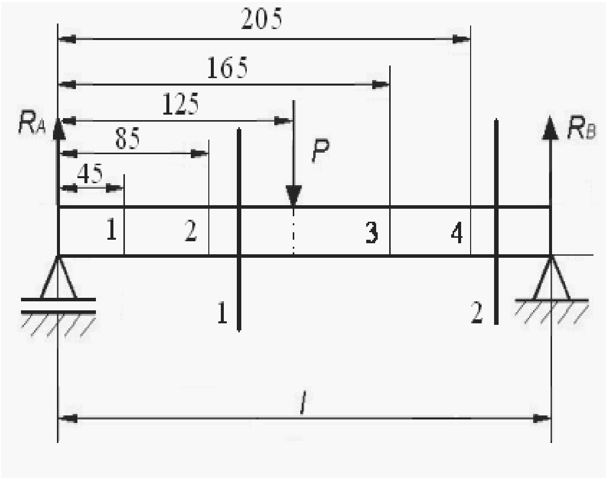

Fig. 2. Diagram of the distribution of forces and reactions acting during deformation of the sample in the fatigue machine and the distribution of measurement points: 1,2,3 and 4

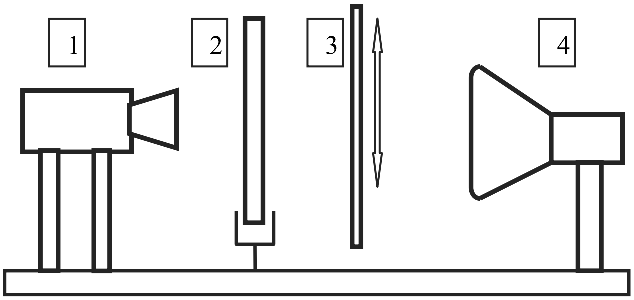

Fig. 3. Schematic draw of thermovision research stand. 1 - thermovision camera, 2 - sample, 3 - removable shield, 4 - infrared radiator

Warm-up time of the samples was the same for each measurement and was 4.0 seconds. Thermographic images were recorded from the start of the process of heating of the sample with the frequency of 3.75 Hz. Analyzed such Figs. of according characteristics as (demonstrated at Fig. 4):

- maximum temperature of the sample surface,
- the rise time of the sample temperature,
- he rise speed of sample temperature,
- temperaturze stabilization time.

As example, the series of images of successive phases of the thermal process, taking place on the sample surface, recorded by using a thermal imaging camera, activated for diagnostic purposes on Fig.6. are showed.

2.2. Results and analysis

The main thesis of the developed research program has postulated the existence of an unique relationship between state-dependent thermal properties of the laminate material and the fatigue load history.

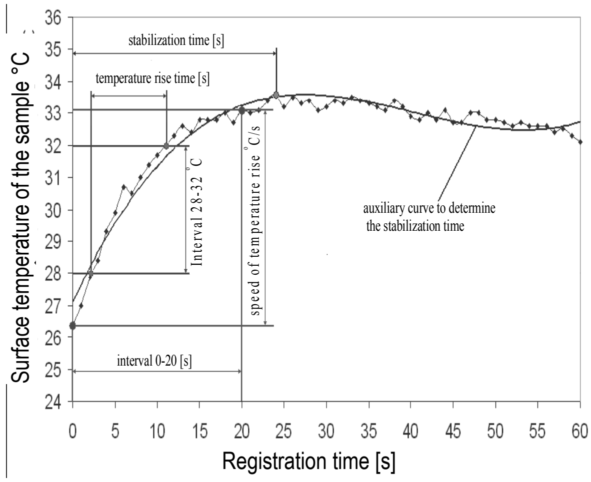

Fig. 4. The course of temperature changes during thermographic measurement

Examples of thermographic image are shown in Fig. 5.

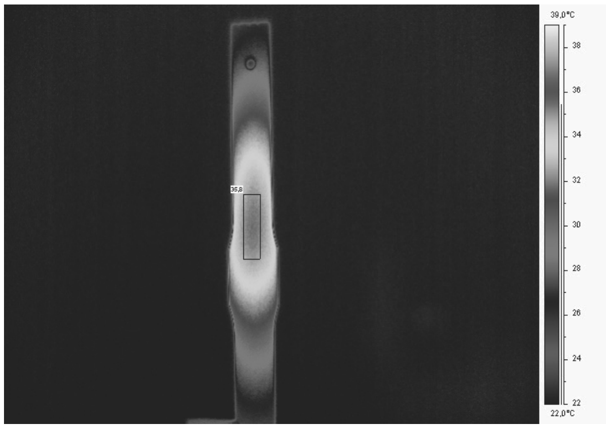

Fig. 5. Example thermogram for the samples subjected to fatigue tests at 10 million cycles (the temperature was read from inside the selected rectangular area)

Finding such a relationship would create a. base of looking for diagnostic relationships allowing a non-destructive diagnostic assessment of the degree of load-bearing capacity exhaustion of the test class of material in conditions of fatigue load.

Fatigue tests have been conducted have not led to the destruction of the test samples. As a measure of the strength properties exhaustion, bending stress reduction needed to maintain a constant deflection in fatigue cycle was adopted.

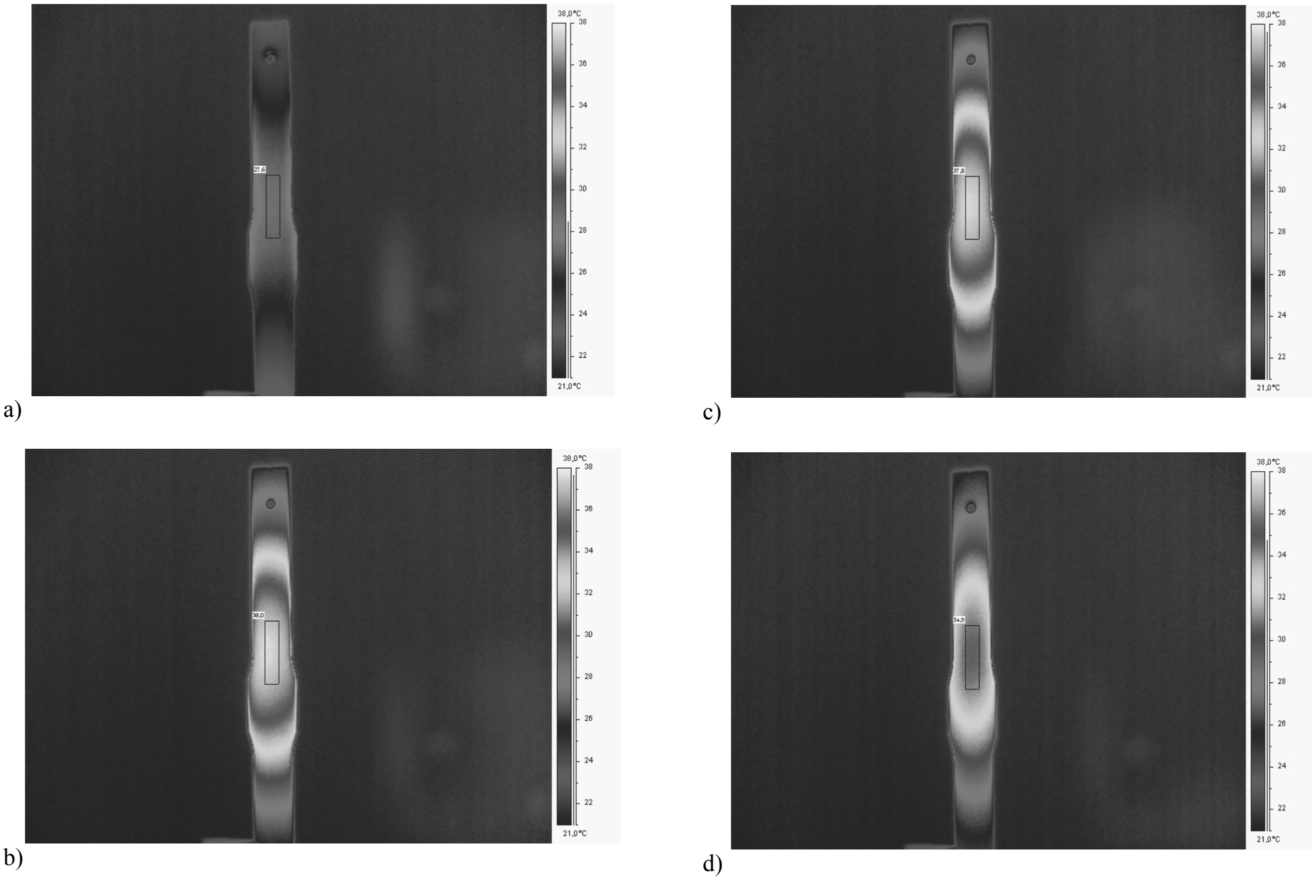

Fig. 6. The series of images of successive phases of the thermal process, taking place on the sample surface: measurement start (a), maximum temperature (b), the initial phase of descent (c), the end of measurement (d)

Diagrams of bending stress on the number of fatigue cycles is shown in Fig. 7. Due to the similar state of stress at points 2 and 3 as well as at 1 and 4 (Fig. 2) to determine the level of stress in the test sample points average values of the measuring points 2, 3 and 1, 4 were taken.

Analysis of the dependence presented in Fig. 7 shows, that in the course of fatigue degradation process the level of stress necessary to obtain constant bending amplitude, as was assumed, decreases. Fig. 8 shows the relationship between the temperature stabilization time, set in the thermographic surveys and the number of fatigue cycles.

A clear correlation between the investigated quantities was obtained. From the graphs shows clear correlation - with an increasing of number of fatigue cycles increases the temperature stabilization time. It is associated with changes in the structure of polymer matrix and the formation of micro-discontinuities in the composite which makes the heat flow in thermographic investigations more difficult and demonstrate by temperature stabilization time increasing. In thermographic searches temperature rise time was determined and in investigations of fatigue degradation stresses decrease in fatigue bending samples at a condition of constant arrow deflection was determined. Fig. 9 shows the dependences of stress drop on the temperature stabilization time, determined on the basis of thermographic tests for measuring points 2, 3 and 1, 4

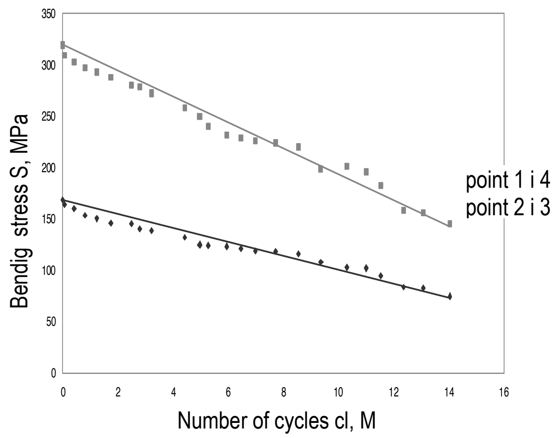

Fig. 7. Dependence of bending stress at the measuring points 2, 3 and 1, 4 on the number of fatigue cycles

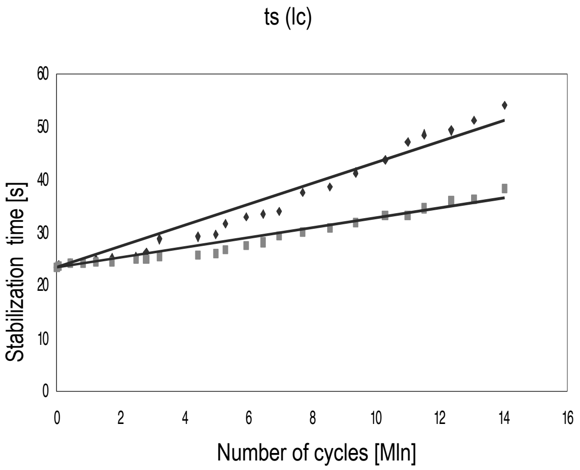

Fig. 8. Dependence of temperature time stabilization versus the number of fatigue cycles for measuring points 2, 3 and 1, 4

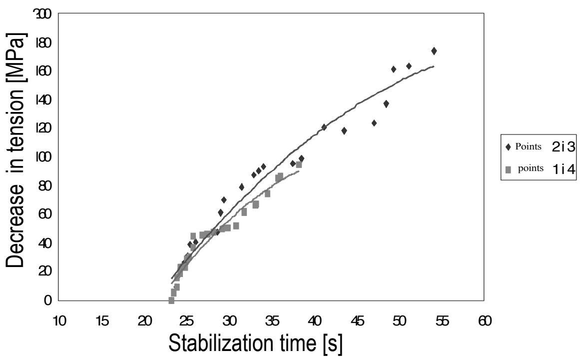

Fig. 9. The dependence of stress drop on the temperature stabilization time for measuring points 2, 3 and 1,4

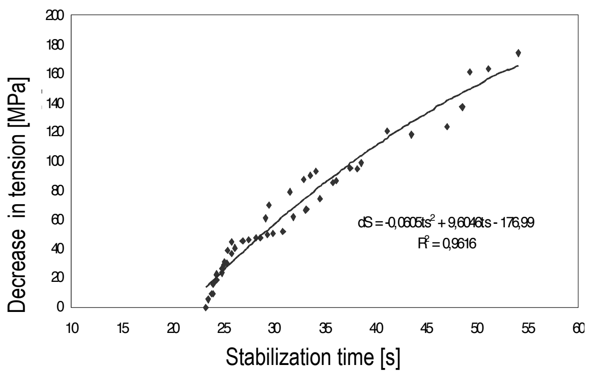

Fig. 10. The relationship between the drop in the bending tension found out in fatigue procedure and the temperature stabilization time specified in thermographic investigations

As in the previous case, common diagnostic relationship binding a stress drop determined in fatigue tests with the temperature stabilization time change, as set out in thermographic non-destructive tests, was set. Fig. 8 shows the diagnostic relationship, fixed in the composite TSE-2, binding the destructive tests results with the results of thermographic investigations.

Shown in Fig. 10 diagnostic relation allows the unequivocal changes in bending stress description, which are a measure of the degree of strength degradation, based on the results of thermographic investigations, in this case based on the temperature stability time on the surface of a tested composite on the side opposite to heat.

3. Conclusions

1. Nondestructive method of thermography can be used to diagnose the extent of strength degradation of polymer composites.
2. Developed relationships clearly involve diagnostic characteristics of thermal processes, designated with use of thermographic method, with the degree of loss of mechanical properties due to the polymer material fatigue degradation.
3. Diagnostic relations designated for different composite materials are similar in nature but their final form should be set separately for each type of polymer composite.

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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