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Thermographic diagnosis of fatigue degradation of epoxy-glass composites

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Properties

ABSTRACT

Purpose: The purpose of this paper was to describe results of application of thermography to evaluate the degree of fatigue degradation of epoxy-glass composites.

Design/methodology/approach: Samples of epoxy-glass composite were subjected to fatigue degradation. During fatigue test, after defined number of cycles, samples were heated using infra-red heater and at the opposite side temperature increase was evaluated with thermovision camera.

Findings: Analysis of achieved results allowed to elaborate relation between number of fatigue cycles and the degree of fatigue degradation. Such relation may be applied in diagnostic procedures.

Research limitations/implications: Performed tests were of preliminary character and results will be applied to prepare research programme on thermographic testing of composites.

Practical implications: Results of such tests may be applied in the future in diagnostic procedures to non-destructive evaluation of the degree of fatigue degradation of high performance polymer composites.

Originality/value: Thermographic methods are applied up till now to non-destructive flaws detection. Proposed in the paper method may be applied to evaluate the degree of thermal and fatigue degradation in composites without any macroscopic flaws.

Keywords: Engineering polymers; Non-destructive testing; Thermography; Composites; Fatigue

1. Introduction

In previous research ultrasonic methods were applied to non-destructive evaluation of fatigue and thermal degradation of composites [1, 2]. The aim of the present research is to elaborate the evaluation methodology of the degree of polymer composites fatigue degradation using thermography.

The basic idea of thermography is to apply infrared frequency range of electromagnetic radiation to obtain information concerning selected physical properties or processes taking place within tested objects. Thermography evaluates the distribution of infrared radiation emitted by scanned body surface. Scientific and industrial methods apply basic knowledge concerning relations between infrared radiation and temperature distribution on body surface. Depending on experiment conditions, temperature distribution can also be a source of additional information about other interesting object's properties.

The basic physical laws applying to radiation process are [3, 4]: the Kirchoff law, the Planck law, the Wiena law and the Stefan-Boltzman law. These laws constitute foundations for theory and practice of thermography.

Knowing the surface temperature distribution it is possible to formulate the inverse problem: What is the reason, what caused defined surface temperature state or given temperature changes? In the described research relations between the degree of fatigue degradation of polymer materials especially polymer composites and surface temperature distribution or surface temperature changes were investigated.

There are many different criteria for thermographic methods classifications. Depending on the way of thermal object activation thermography methods are divided into active and passive. Passive thermography lies in recording temperature states and temperature changes on surfaces without any interference. Active thermography evokes thermal processes and then records surface temperature distribution and temperature processes. The activation process can be static or dynamic. Very often applied activation methods are pulse activation, modulated heating, pulse-phase heating. The most frequently used is radiation activation. Information concerning surface or thin surface layer of tested material is gathered in thermography. There are many scientific and industrial fields of application of this type of thermography methods [5-16].

Dynamic thermography is next class of methods in which energy (mainly in the form of mechanical vibrations) is transferred to tested object. This energy is subsequently radiated by tested body and heat emission is observed (vibro-thermography).

Temperature in thermographic methods is measured using sensitive (with resolution up to 20mK) and very quick (up to 60 images per second) thermovision cameras.

2. Experimental

2.1. Materials

Epoxy-glass composite TSE-6 [18] in the form of plate produced by hot pressing technology by IZO-ERG Gliwice, Poland was used. Samples with dimensions 250mmx 20mmx4mm were cut with diamond saw.

2.2. Methodology

The method used belongs to active thermography with static thermal activation [18]. Samples were activated by 40 seconds heating. The main aim of the research was to find relations between fatigue degradation and temperature changes after heating. Fatigue degradation is expected to influence thermal conductivity, and in this way the surface temperature distribution and surface temperature changes. Surface temperature monitored by thermographic methods is expected to be useful as diagnostic tool in evaluation of the degree of degradation.

In the first stage of experiment sets of samples were subjected to fatigue in double-sided three point bending with constant deflection amplitude equal to 3mm. Low frequency (0,8 Hz) was chosen to avoid sample heating due to energy dissipation. Maximum 1 930 000 fatigue cycles were realized.

In the second stage thermographic experiment was performed. Test specimens were heated individually by infrared radiator during 40 seconds. To enhance heat absorption, heated side of specimens was matt black painted. Testing specimens were placed 78 mm before heater. After 40 seconds the heater was removed and temperature increase on the opposite side of testing sample was measured using thermovision camera INFRAMETRICS type 76B, USA. Fig. 1 shows schematic diagram of testing stand.

2.3. Results

It is not possible to present all taken thermographic images and temperature measurement results in this paper. Only the most representative results will be presented. Fig. 2 and 3 present temperature changes at central point of the sample on the side opposite to the heated one. Photographs (Fig. 4, 5, and 6) show termographic images taken 1 second, 10 seconds and 20 seconds after the beginning of temperature measurement for sample subjected to 1 190 000 fatigue cycles.

Curves presented in Fig. 2 and Fig. 3 and all other analogues dependences allowed to distinguish initial stage where temperature increase is almost linear with time. The rate of temperature increase was different for different degree of fatigue degradation. Three dependencies of the rate of temperature increase on time are presented in Fig. 7.

Good correlation between temperature and time was achieved. Correlation coefficient was in the range 0,96 - 0,985. The lines inclination coefficients are equal to the rate of temperature increase. The rate may be taken as a measure of changes of

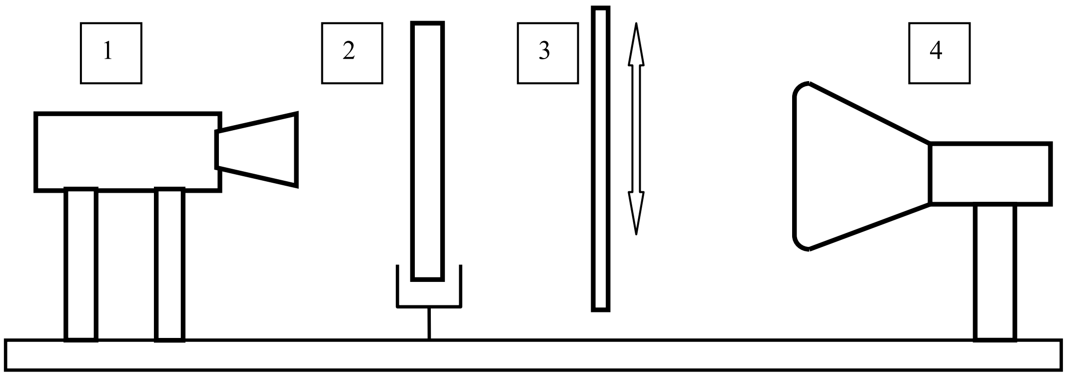

Fig. 1. Schematic draw of thermovision research stand. 1 – thermovision camera, 2 – sample, 3 – removable shield, 5 – infrared radiator

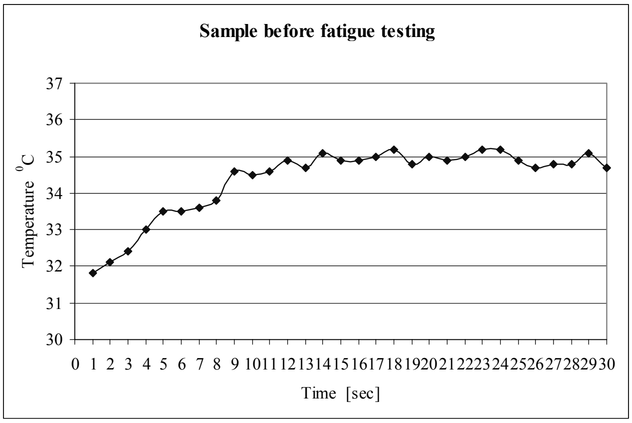

Fig. 2. Temperature increase with time after heating for sample without fatigue testing

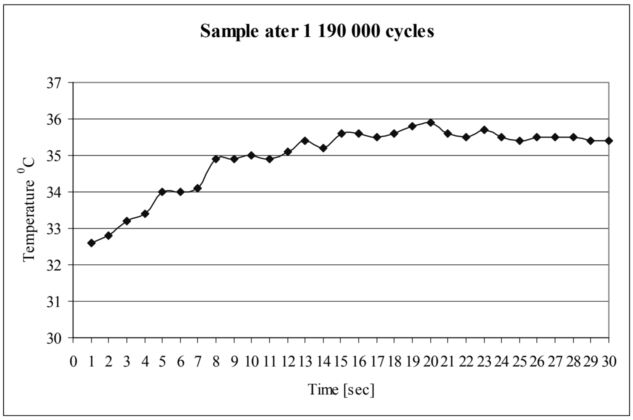

Fig. 3. Temperature increase with time for sample after 1 190 000 fatigue cycles

Fig. 4. Thermographic image of sample after 1 190 000 fatigue cycles of fatigue testing 1 second after heating

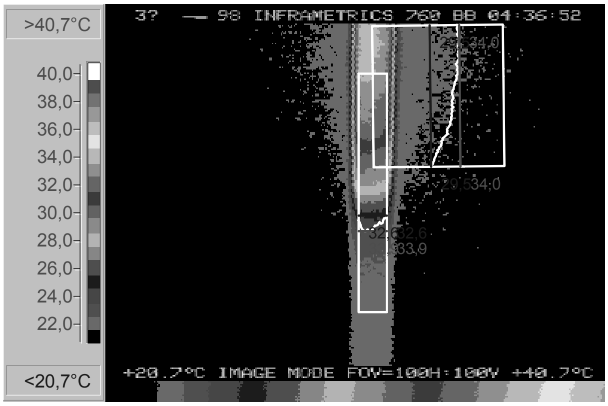

Fig. 5. Thermographic image of sample after 1 190 000 fatigue cycles 10 seconds after the end of the heating

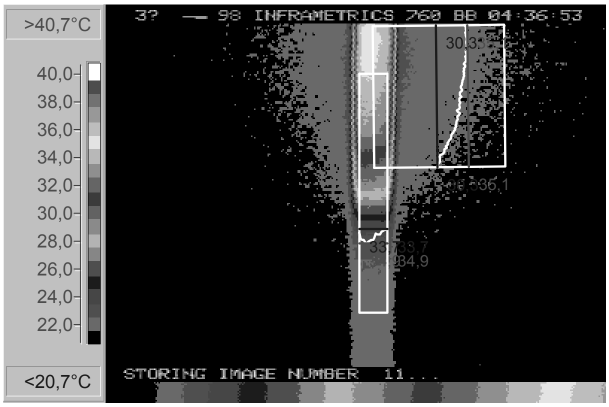

Fig. 6. Thermographic image of sample after 1 190 000 fatigue cycles of fatigue testing 20 seconds after heating

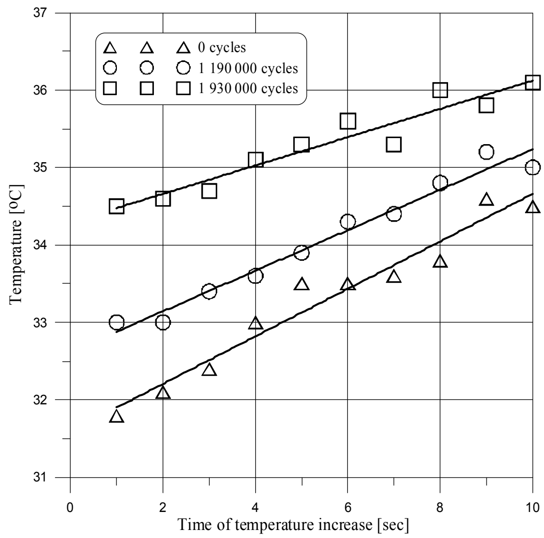

Fig. 7. Temperature increase in the first 10 seconds of temperature measuring procedure together with approximation lines

composite properties due to fatigue. The dependence of rate of temperature increase on number of fatigue cycles is shown in Fig. 8. Least square approximation gave the following relation:

$$rT = -4.399E-008 \times N + 0.303 \quad (1)$$

where: rT – rate of temperature increase, N – number of fatigue cycles.

Coefficient of correlation for this relation was 0,765. It is satisfactory taking into account preliminary character of the research.

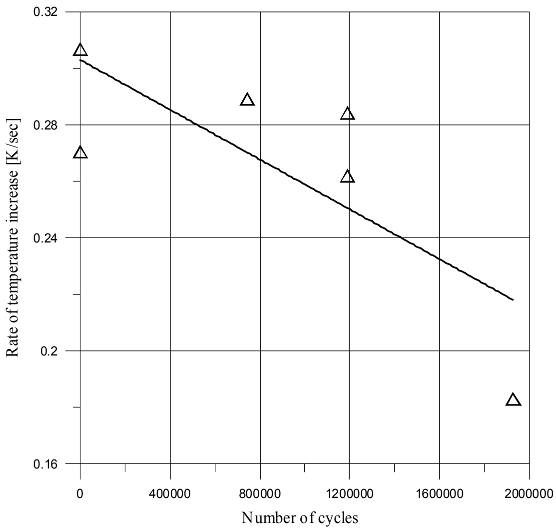

Fig. 8. Dependence of temperature increase rate on number of fatigue cycles

3. Conclusions

1. Fatigue degradation of epoxy-glass composites caused changes of its thermal properties. These changes can be indirectly determined with thermography help.
2. Analysis of the dependence between number of fatigue cycles and the rate of temperature increase allowed to establish correlation satisfactory for diagnosis procedures.
3. Further research is needed to elaborate more precise relations between degradation degree and thermographic results.

References

[1] M. Rojek, J. Stabik, S. Sokół, Fatigue and ultrasonic testing of epoxy-glass composites, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 183-186.

[2] G. Wróbel, Ł. Wierzbicki, Ultrasonic methods in diagnostic of glass-polyester composites, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 203-206.

[3] S. Ochęduszko, Applied thermodynamics, WNT, Warsaw, 1970 (in Polish).

[4] E.H. Wichmann, Quantum Physics, PWN, Warsaw, 1973 (in Polish).

[5] S. Poloszyk, Active thermovision in non-destructive testing, Proceedings of Conference Manufacturing'01, Poznań, Vol. 2, 2001, 221-228, (in Polish).

[6] W. Oliferuk, Active thermovision in non-destructive testing of materials, Proceedings of the XII Conference Non-destructive testing of materials, Zakopane, 2006, 10-25.

[7] D. Bates, G. Smith, D. Lu, J. Hewitt, Rapid thermal non destructive testing of aircraft components, Composites B/31 (2001) 75-185.

[8] N.P. Avdelidis, B.C. Hawtin, D.P. Almond, Transient thermography in the assessment of defects of aircraft composites, NDT & E International, 36 (2003) 433-439.

[9] N.P. Avdelidis, C. Ibarra-Castanedo, X. Maldague, Z.P. Marioli-Riga, D.P. Almond, A thermographic comparison study for the assessment of composite patches, Infrared Physics & Technology 45 (2004) 291-299.

[10] M. Krishnapillai, R. Jones, I.H. Marshall, M. Bannister, N. Rajic, Thermography as a tool for damage assessment, Composite Structures 67 (2005) 149-155.

[11] C. Meola, G.M. Carlomagno, L. Giorleo, Geometrical limitations to detection of defects in comosite by means of infrared thermography, Journal of Nondestructive Evaluation 23 (2004) 4.

[12] N. Rajic, Principal component thermography for flaw contrast enhancement and flaw depth characterization in composites structures, Composite Structures 58 (2002) 521-528.

[13] C. Santulli, IR thermography study of the effect of moulding parameters on impact resistance in E-glass/polypropylene commingled laminates, NDT & E International 35 (2002) 377-383.

[14] D. Bates, G. Smith, D. Lu, J. Hewitt, Rapid thermal non destructive testing of aircraft components, Composites B/31 (2000) 175-185.

[15] C. Meola, G.M. Carlomagno, A. Squillace, A. Vitiello, Non-destructive evaluation of aerospace materials with lock-in thermography, Engineering Failure Analysis 13 (2006) 380-388.

[16] T. Uhl, Dynamic thermography as a construction diagnosis tool, Proceedings of the XLVI Conference Modeling in mechanics, Wisła, 2007 (in press).

[17] TSE-6 Product Data, Izo-Erg Gliwice, Poland (2006) – www.izoerg.com.pl.

[18] G. Muzia, Z. Rdzawski, M. Rojek, J. Stabik, G. Wróbel, Thermovision diagnosis of the degree of fatigue degradation of epoxy-glass composites, Proceedings of the XLVI Conference Modeling in Mechanics, Wisła, 2007 (in press).