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Fatigue and ultrasonic testing of epoxy-glass composites

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Materials

ABSTRACT

Purpose: The purpose of this paper was to find relationship between the degree of strength degradation caused by fatigue and the changes of ultrasonic wave characteristics such as wave velocity and damping coefficient.

Design/methodology/approach: Epoxy-glass composites were subjected to oscillatory bending loadings with constant deflection. During fatigue procedure the force needed to achieve constant deflection was measured. During fatigue tests samples were subjected to ultrasonic tests. Additionally before fatigue test and after 300 000, 850 000 and 1 900 000 cycles parts of samples were subjected to destructive bending test.

Findings: A good correlation between velocity of ultrasonic wave propagation and the degree of strength degradation of epoxy-glass composites caused by fatigue was found. Ultrasounds can be applied as effective tool to assessment of fatigue degradation of polymer composites.

Research limitations/implications: Achieved results showed that research have to be continued. Fatigue with other loading conditions and for other composite materials is planned.

Practical implications: The results of present research can be applied to elaboration of non-destructive method of measurement of the degree of fatigue degradation of polymer composites.

Originality/value: Presented correlation between ultrasound wave characteristics and the degree of strength degradation caused by fatigue is original value of this paper.

Keywords: Composites; Non-destructive testing; Fatigue; Ultrasounds

1. Introduction

Epoxy-glass composites are applied more and more frequently as high performance engineering materials. They find applications in such demanding fields as civil engineering, car industry, electronic industry, aerospace technology and many others. This leads to the increase in demand for knowledge related to strength of materials understood as the ability to withstand different loading conditions resulting from the purposefulness of their application. During composites exploitation many degrading processes take place. Main degrading influences are thermal ageing, radiation and chemical attack, creep and fatigue. In the case of polymer composites changes of surface appearance can not be used as a measure of state of material degradation. Usually visible surface changes occur in very thin outer layer and precede any inner degradation processes. When degradation occurs in a dispersive way within the element's volume, without any visible external changes of physical and geometrical properties or when surface changes do not correspond to internal degradation processes, a classical inspection of a structure's condition may not reveal any dangerous states. It is the case for example in thermal ageing and fatigue. Results of these processes accumulate in element's volume and lead to sudden damage. Therefore, there is a need of searching non-destructive methods of investigation of the degradation degree. Authors made such an attempt using ultrasonic technique. In our previous research ultrasonic technique was used to investigate the degree of thermal degradation of glass-epoxy composites [1-4]. It was shown that ultrasound velocity changes can be used as a measure of thermal degradation. One of less known properties of epoxy-glass composites are their fatigue characteristics. Oscillating loadings also cause material's changes that are not visible and very hard to evaluate before catastrophic failure. In the present research we investigate the possibility of application of ultrasonic technique to evaluate the degree of fatigue degradation of the same composites.

2. Ultrasonic testing applied to polzmer composites

Ultrasonic methods of materials testing and among them polymer composites has a long-lasting tradition. In this field, ultrasound's physical nature as a mechanical wave is used [5]. Knowledge of sound wave propagation principles in a tested medium allows for its application as a research tool. Taking into account effects of wave reflection, refraction, absorption, dispersion or defraction ultrasonic methods allow measurements of thickness, hydrolocation of ship wrecks and fish shoals or localization of heterogeneities and discontinuities – flaw detection [5-12].

Less information is available on application of ultrasonic testing of fatigue degradation processes especially of fatigue degradation of polymeric composites.

On the basis of wave parameters on boundary of an area, conclusions are drawn concerning geometric properties and distribution of physical properties of a medium. This task only in exceptional cases leads to an unambiguous solution, however, for experienced researchers, it is an effective implement aiding diagnostics.

Parameters that are distinctive for an ultrasound wave and that may constitute diagnostic characteristics include [5]:

- V: propagation velocity
- α: amplitude damping coefficient

$$\frac{dA}{A} = -\alpha \ dx \tag{1}$$

where A – wave amplitude,
dx – path corresponding to amplitude decline (dA)

- γ: energetic damping coefficient

$$\frac{dI}{I} = -\gamma \ dx \tag{2}$$

where I – wave intensity,
dx – path corresponding to wave intensity decline (dI).

In the presented research wave velocity and amplitude damping coefficient were measured as ultrasound wave parameters.

3. Experimental

3.1. The aim and the scope of the research programme

A hypothesis being the basis of the developed and described here research programme is very similar to that accepted in our previous research [1]: For polymeric fibre reinforced composites, there is correlation between strength degradation degree being the effect of fatigue ageing process and a change in a value of selected diagnostics characteristics of an ultrasound wave coming through tested composite material. The main deference between previous and present research is that fatigue ageing is investigated instead of thermal ageing. In order to confirm the formulated hypothesis, selected epoxy-glass fibre reinforced composite was exposed to oscillating loadings and then tested using ultrasonic method and destructive bending test.

3.2. Material

Epoxy-glass composite TSE-5 produced by IZO-ERG S.A. (Poland) was used for samples preparation. It was produced in continuous technology by impregnation of glass woven fabric in epoxy resin solution followed by drying and pressing in elevated temperatures. Laminates produced with this technology have significantly lower properties scatter than that produced with manual methods. Glass fabric's layers are parallel and glass fibres in individual layers are perpendicular. Defects such as air bubbles, voids and resin excess are withdrawn during pressing.

3.3. Testing procedure

At the beginning of the experiment, before fatigue test a set of samples was subjected to non-destructive tests on the ultrasonic test station, thus identifying the initial values of ultrasound diagnostic characteristics and to destructive tests of static bending, thus identifying the initial values of flexural strength and flexural modulus. Results of preliminary tests are given in Table 1.

Table 1.
Results of preliminary tests of TSE-5

Flexural strength	MPa	443,7
Flexural modulus of elasticity	GPa	20,63
Velocity of ultrasound wave propagation	m/s	2898
Damping coefficient	dB/mm	1,947

Fatigue procedure was performed using apparatus designed specially for this purpose. It was possible to change amplitude between 0–12mm and frequency between 0,5 to 2 Hz. To avoid heating of samples during testing amplitude was set to 3mm and frequency to 0,8 Hz. Samples with the following dimensions were tested: length-250mm, width – 20mm thickness – 4mm. Between two samples additional piece of high density polyethylene was assembled. The thickness of this interlayer was 8mm. The set of two samples and interlayer was bended. This allowed to achieve minor stress differences at the cross section of the samples. During bending tensile or compression stresses occurred at the hole cross-section of sample. The loading method of sample and the stress distribution in the cross-section of sample is shown in Fig. 1.

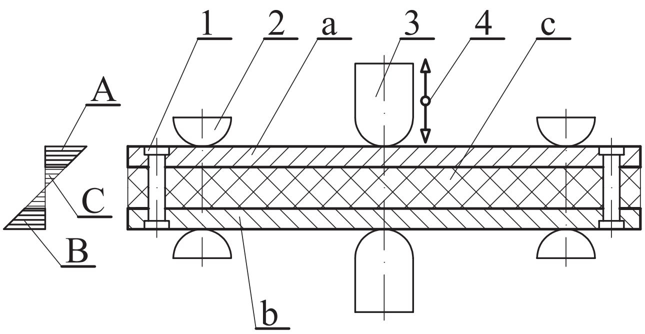

Fig. 1. The loading method of two samples and stress distribution in samples and polyethylene interlayer: a – composite test sample 1, b – composite test sample 2, c – polyethylene interlayer, 1 – bolt joining samples and interlayer, 2 – sample support, 3 – loading pins, 4 – loading directions, A- stress distribution in first sample, B – stress distribution in second sample, C – stress distribution in polyethylene interlayer

Loading pins were assembled to continuous force measurement system. It allowed to calculate stress distribution in samples cross section.

Destructive bending tests were performed using tensile stress machine FPZ-100/1 (Haeckert – Germany). Bending tests were carried out in accordance with the EN ISO 178 standard under the following conditions:

- temperature: 23°C ± 2°C
- bending speed: 5 mm/min
- spacing of supports: 64 mm.

Ultrasonic tests were carried out with the ultrasonic defectoscope UMT-17 (ULTRAMET S.c., Poland). Single 2 MHz ultrasonic head was used.

A time of a sound wave transition through tested samples (τ) expressed in μs was measured. A sound wave velocity (V) through a sample was calculated:

$$V = h/\tau \qquad (3)$$

where h is the sample thickness.

Additionally damping coefficient was calculating using the equation (1). Test pieces were tested perpendicularly to reinforcement layers.

Ultrasonic measurements were performed in five points distributed on sample length (Fig. 2).

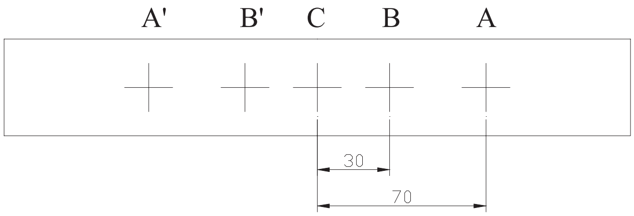

Fig. 2. Distribution of ultrasonic measurement points

4. Results and discussion

Dependences of flexural strength and flexural modulus on number of loading cycles are presented in Fig.3 and 4.

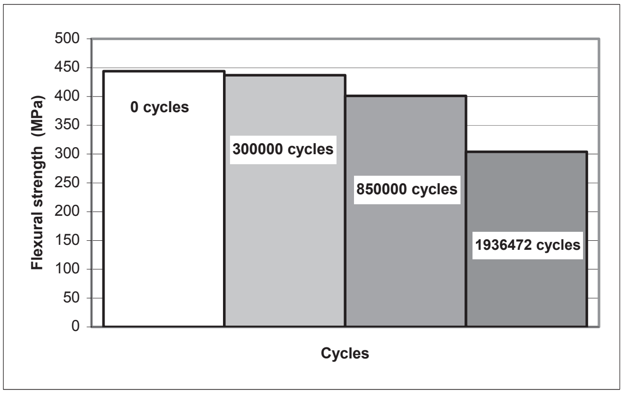

Fig. 3. Changes of flexural strength during fatigue test

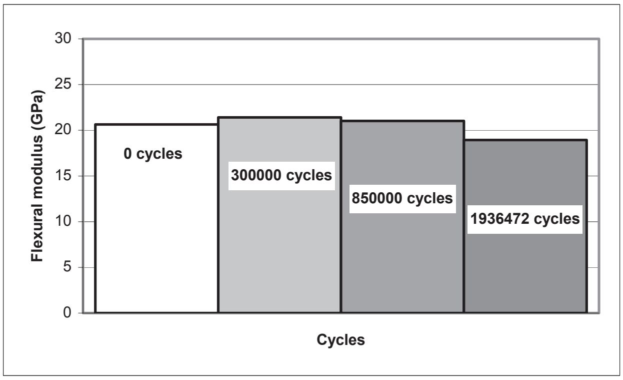

Fig. 4. Changes of flexural modulus during fatigue test

As can be seen flexural strength and flexural modulus decrease with number of loading cycles. It shows that composites undergo fatigue degradation.

Dependences of ultrasound propagation velocity and damping coefficient on number of loading cycles are shown in Fig. 5 and 6.

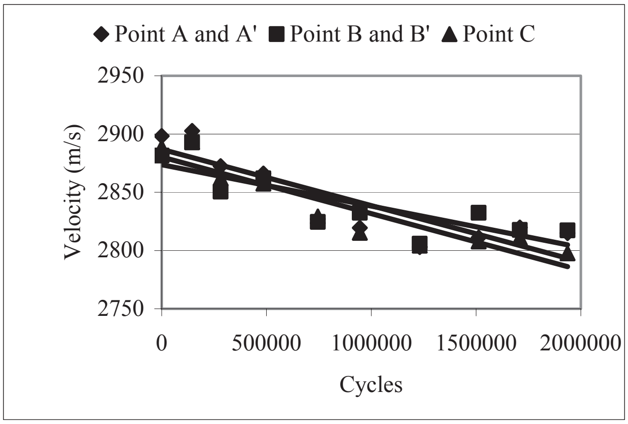

Fig. 5. Dependence of ultrasound propagation velocity on number of loading cycles for different measuring points

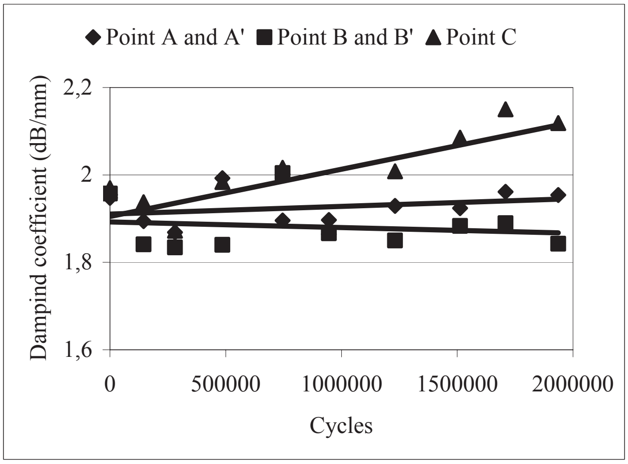

Fig. 6. Dependence of damping coefficient on number of loading cycles for different measuring points

Results presented in Fig. 5 show that velocity of ultrasound propagation decreases with fatigue time. Results are very similar for all measuring points. Correlation coefficient in the range 0,83 – 0,92 was achieved.

Results presented in Fig. 6 are different for different measuring points. In point C, where the maximum stresses occurred, damping coefficient essentially increased with fatigue time. For the rest of measuring points results are ambiguous.

5. Conclusions

Mechanical properties such as flexural strength and flexural modulus decrease as a result of cyclic loadings.

Strong dependence between velocity of ultrasound wave propagation and number of loading cycles was observed.

Ultrasonic tests results together with fatigue tests results form the basis of the non-destructive diagnostics method of fibre reinforced polymeric composites load capacity.

The method may be directly employed in the testing of construction elements made of polymeric composites. For quantitative interpretation of results, it is necessary to elaborate diagnostic dependences individually identified for each tested material.

References

[1] M. Rojek, J. Stabik, G. Wróbel, Ultrasonic methods in diagnostics of epoxy-glass composites, Journal of Materials Processing Technology, 162-163 (2005) 121-126.

[2] M.Rojek, J. Stabik, Thermall resistance of TSE-6 epoxy-glass composite, Proc. V Conf. "High performance polymers and composites", Ustron 2002 178-182 (in Polish).

[3] M. Rojek, J. Stabik, M. Makselon, Nondestructive investigation of properties of glass-epoxy laminatem (in Polish), Agricular Academy of Bydgoszcz, Chemistry and CHemical Technology 91-95. (in Polish)

[4] M. Rojek, J. Stabik, G. Wróbel, Ultrasounds in diagnostics of epoxy-glass laminates, Conf. Proc. Nondestructive testing of materials Zakopane (2003) 203-211 (in Polish)

[5] A. Śliwiński, Ultrasounds and their application, WNT, Warszawa, 1993. (in Polish),

[6] M. Arone, D. Cernigilia, V. Nigrelli, Defect characterization in Al welded joints by non-contact Lamb wave technique, Journal of Materials Processing Technology, 176 (2006) 95-101.

[7] A.H. Nayfeh, Wave Propagation in Layered Anisotropic Media with Applications to Composites, Elsevier, Amsterdam, 1995.

[8] K. Imielińska, M. Castaings, R. Wojtyra, J. Haras, E. le Clezio, B. Hosten, Air-coupled ultrasonic C-scan technique in impact response testing of carbon fibre and hybrid: glass, carbon and Kevlar/epoxy composites, Journal of Materials Processing Technology,157-158 (2004) 513-522.

[9] I.G. Scott, C.M. Scala, A review of Non-destructive Testing of Cmposite materials, Non-Destructive Testing International, 15 (1982) 75-86.

[10] H.C.Y Cartledge, C.A. Baillie, Studies of microstructural and mechanical properties of Nylon/Glass composite, Journal of .Materials .Science, 34 (1999) 5113-5126.

[11] H.W. Ma, X.H. Zhang, J. Wei, Research on an ultrasonic NDT system for complex surfaces, Journal of Materials Processing Technology, 129 (2002) 667-670.

[12] D.N. Collins, W. Alcheikh, Ultrasonic non-destructive evaluation of the matrix structure and the graphite shape in cast iron, Journal of Materials Processing Technology, 56 (1995) 85-90.