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Ultrasonic methods in diagnostics of glass-polyester composites

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Materials

ABSTRACT

Purpose: The aim of the work was to find relationship between the ultrasonic wave velocity and the strenght and Young's module in a glass-polyester composite.
Design/methodology/approach: The experiments have been performed in three distinct phases. During the first phase, typical glass-polyester composite was ageing to get different mechanical properties. In the second phase, strength and ultrasonic properties of composite was testing. In the last of phases we compare changes of properties.
Findings: The experimental results showed relationship between velocity of ultrasonic wave and strength and Young's module.
Research limitations/implications: In those applications, in which polymer structural composites were subjected to a heat and mechanical load, it is essential to test the strength characteristics of the composites in the use of non-destructive methods. That enables contemporaneous status check of the structure and makes it possible to replace the bivalent evaluation scale (good – bad) with an incessantly gradable strength degradation scale for a material.
Practical implications: The results of the investigation have shown possibility of using ultrasonic method to diagnosis of strength changes in composites. This method allowed to test working parts of machines or buildings, without destruction.
Originality/value: The results of the investigations allow to confirm, that ultrasonics can be used to non-destructive testing of the strength and Young's modulus changes.
Keywords: Composites; Engineering polymers; Properties; Non-destructive testing

1. Introduction

Fiber-reinforced composites are being increasingly used as alternatives for conventional materials primarily because of their high specific strength, specific stiffness and tailorable properties. In addition the viscoelastic character of composites render them suitable for high performance structural applications like aerospace, marine, automobile, etc. However, these materials are quite distinct from metals because the former exhibit several peculiar modes of failure (matrix crazing, delamination, fiber failure and interfacial bond failure due to debonding) and interaction at micromechanical [1,2].

Nondestructive testing methods are one of the most dynamically developing branches of diagnosis and science in general.

In those applications, in which polymer structural composites are subject to a heat and mechanical load, it is essential to test the strength characteristics of the composites in use with non-destructive methods. That enables contemporaneous status check of the structure and makes it possible to replace the bivalent evaluation scale (good – bad) with an incessantly gradable strength degradation scale for a material [3].

Based on the measurement of velocity and absorption coefficient of ultrasonic waves propagated in the sample volume, volumetric wave acoustics methods allow to acquire a variety of data concerning the structure of the substance. Velocity and absorption coefficient of ultrasonic waves in a solid body depend on mutual interactions of atoms, molecules or groups of molecules. Virtually every change in the structure of matter causes a change in the interaction amongst vibrating oscillators, which is followed by a change in ultrasonic wave propagation parameters. Apart from microstructural changes, the acoustic characteristics of a material can also be influenced by degradation being a result of accumulated microdamages caused by working conditions put on the structure [3].

Description of the issue of microdamages accumulation process in composite materials creates a basis for efficiency of ultrasonic diagnostics in the load capacity wear evaluation process of a composite material.

This paper is an attempt to determine dependencies between the degree of load capacity degradation and the changes in characteristic of an ultrasonic wave passing through an glass-polyester composite.

1.1. Ultrasonic tests on composites

The procedure of ultrasonic tests on objects comprises passing waves into objects, scanning objects by moving a head over their surface and detecting signals (impulses) caused by waves passed through objects.

The basic rule in such tests is to know dependencies between the value of an ultrasonic parameter being measured (for example, the velocity of an ultrasonic wave) and the tested property of the internal structure of a composite material (for example, the amplifying phase content). Dependencies between acoustic parameters and structural properties of a composite material are usually determined empirically, based on measurements of standard samples with precisely defined and known structural parameters [4]. Characteristic parameters for an ultrasonic wave, which can be its diagnostic features, are [5,6,7,8,9]:

- propagation velocity C
- amplitude damping factor α:
- kinetic damping factor γ

The method to measure velocity of the passing wave, as well as to measure the thickness of the element, are based on the same testing device. Most of flaw detectors allow to measure the time during which the wave passes through the material and, based on the knowledge how fast a wave propagates, also the thickness of the sample.

Most of the time, the measurements are carried out using the echo method and singular or dual heads. Dual heads are used for measurements of objects with curved, defective or corrosion-inflicted surface [10, 11, 12].

Tests on composite materials, as compared with tests on steel, cause problems due to different material properties and, as a result, different image of the passing ultrasound impulse . Figure 1 (Fig. 1.) shows schematics of dynamic echo envelopes for the same fault in steel and composite material with carbon fibre.

In example b) it is difficult to differentiate changes in amplitude of the fault echo from those caused by local differences in reduction coefficient of the material [13].

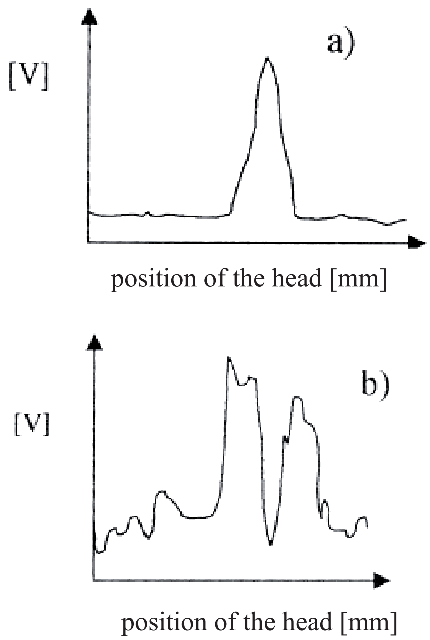

Fig. 1. Shape of echo envelope for the same artificial fault: a) in steel, b) in epoxide resin reinforced with carbon fibre [13]

Experts in ultrasonic testing procedures suggest use of the transition method, especially for less homogeneous materials or for those affected with corrosive processes. However, this method requires use of a set of two opposite-oriented heads. Structure of a subject being tested does not always give access from both sides. These disadvantages are balanced by easier interpretation and repeatability of results given by the flaw detector.

Table 1.
Composite constituents

	Name	Density or substance	Proportions
Resin	Polimal 105	1.3 g/cm^3	Proportion confess in test of gelating time (20 minutes).
Catalysis	Cobalt catalysis	4% solution	
Fabric	STR 010-300-125	300 g/m^2 ,	39 fabric layers in the tested laminate board

2. Experiments

The subject of the test was glass-polyester hand-moulded laminate. Constitution of laminate as shown in the table 1. Dimension of samples was 250x20x8 mm.

2.1. Ageing of composite

Environmental conditions assumed for the tests consisted of water [14]. During the tests, it was assumed that the temperature was a constant. The condition was fulfilled, except for a short period of time (3 hours) when the temperature rose

The ageing process was conducted in the temperature of boiling sea water. That particular temperature was chosen based on correlation formulated in professional literature by Rawe, who proved that a two-hour boiling of composite is equal to three months of immersion in the room temperature [15].

Tests were divided into four series. Each series had different time measuring points, respectively 48, 96, 192 and 288 hours. Time measuring point 0 was set for comparison. Half of samples was deformation. Deflection, in the three point configurations, was 3 mm (Fig. 2.).

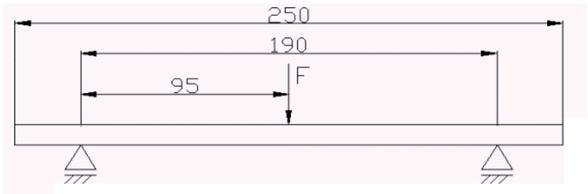

Fig. 2. Sheme of sample deformation

The ageing effect was visible as multiple white spots and delamination occurrences with intensity increasing along with the aging time.

2.2. Strength and density tests

Strength tests of the composite material were carried out according to the PN-EN ISO 141125 standard: "Plastic composites reinforced with fibre. Designation of bending properties."

Changes of density were carried out according to methodology of the PN-EN ISO 62 standard: „Plastics. Designation of absorbing capacity."

The samples were weighted with an analytical balance with accuracy of reading of 0.001 g. The measurements were made before ageing of samples and after a period of time not longer than 30 minutes subsequent to taking out the samples from the corrosive bath.

2.3. Ultrasonic tests

During the tests, an ultrasonic test workstation was used, which comprised: a PC class computer, a UMT 12 ultrasonic card and 1 MHz Unipan 1LN 13 heads. The heads generate longitudinal waves.

The workstation was used to measure the velocity of a passing wave and the sound reduction coefficient. During the reduction measurements a method based on change of amplitude value of the signal passing through the coupling centre was used, after placing a material sample between the ultrasonic heads.

3. Test results

Strength and density tests results present in the table 2 and table 3. Results of measurements were handled statistically .

Strength changes in correlation with acoustic properties of the material describing equation (factor R : 73.3 %, Fig. 3.) :

$$\sigma_f = 261,212 - 0,00064\ C^2 r + 0,00001\ (C^2 r)^2 \qquad (1)$$

Young's modulus changes in correlation with acoustic properties of the material describing equation (factor R: 71.9 %, Fig. 4.):

$$E = 23417,24 - 0,0031\ C^2 r + 0,00001\ (C^2 r)^2 \qquad (2)$$

where: C – velocity of ultrasound wave passing through the sample, r – laminate density, σ_f - strenght, E –Young's module

Table 2.
Test results of samples with deformation.

time measuring point	Change of mass density Δr [%]	Change of strenght ↓ σ_f [%]	Change of Young's modulus↓ E [%]
48 hours	0,506	35,247	15,395
96 hours	1,293	55,462	26,933
192 hours	2,085	68,027	35,787
288 hours	2,466	76,448	44,716

Table 3.
Test results of samples without deformation.

time measuring point	Change of mass density Δr [%]	Change of strenght ↓ σ_f [%]	Change of Young's modulus ↓ E [%]
48 hours	0,369	19,136	4,299
96 hours	1,229	46,114	19,066
192 hours	1,930	65,388	26,263
288 hours	2,218	70,954	32,145

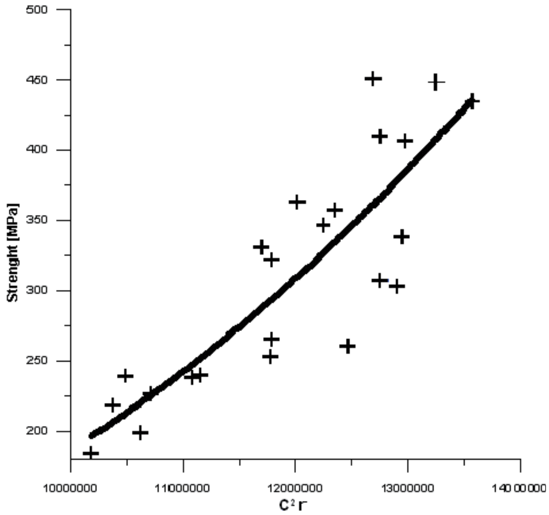

Fig. 3. Strength changes in correlation with acoustic properties and density

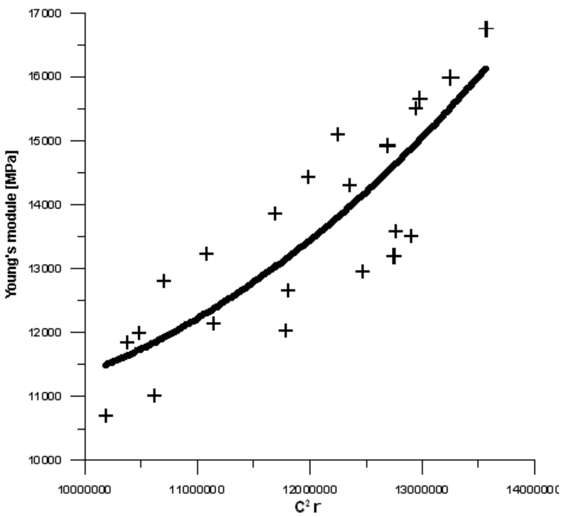

Fig. 4. Young's module changes in correlation with acoustic properties and density

4. Conclusions

Successful definition of clear dependence of the strength of tested composite and its acoustic properties on the degradation conditions gives a starting point for description of the diagnostic relationship between changes of the acoustic properties of a material and the level of degradation of its strength or Young's modulus.

The values of acoustic properties of a material remaining in conditions of constant degradation enable a statistical estimation of the period of actual degradation and remaining, terminal strength value of a material.

Acquired data of tests conducted on glass-polyester composite allow to assume that usefulness of this methodology in tests will be confirmed in the wide class of polymer composite materials, especially machine-made laminates with higher homogeneity and more frequent repeatability of material properties.

References

[1] R. Chandra, S.P. Singh, K. Gupta, Damping studies in fiber-reinforced composites - a review. Composite Structures 46 (1999) 41-51.

[2] L.A. Dobrzański, Engineering materials and meterial design. Principles of materials sciance and physical metallurgy, WNT. Warszawa, 2006 (in Polish).

[3] G. Wróbel, Ł. Wierzbicki, Ultrasounds in the diagnosis of strength changes in laminates put in ageing conditions. 4.784, Sciencefic Confererence on Materials Mechnical and Manufacturing Engineering, Gliwice 2005.

[4] S. Mackiewicz, Ultrasounds testings of the composites materials. Sciencefic Confererence on Ultrasounds materials testing, Zakopane 1995. (in Polish).

[5] M. Rojek, J. Stabik, G. Wróbel, Ultrasonic methods in diagnostics of composites, 5th Sciencefic Confererence on Polimers and constructions composites, Gliwice, 2002. (in Polish).

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

[7] J. Obraz, Ultrasonic Testing of Materials, WNT,Warsaw, 1983. (in Polish)

[8] M. Rojek, J. Stabik, G. Wrobel, Ultrasonic methods in diagnostic of epoxy – glass composites, 11th International Scientific Conference on Contemporary Achievements in Mechanical and Materiale Engineering. Gliwice – Wisła 2005.

[9] G. Wróbel, Ł. Wierzbicki, S. Pawlak, Ultrasonic quality evaluation method for polyester glass laminated materials. 11th International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science. Gliwice – Zakopane, 2005, 1040-1044.

[10] G. Wróbel, S. Pawlak, Ultrasonic evaluation of the fiber content in glass/epoxy composites, 14th International Scientific Conference on Achievements in Mechanical and Materials Engineering. Gliwice – Wisła, 2006, 187-190.

[11] G. Wróbel, Ł. Wierzbicki, S. Pawlak, Ultrasonic quality evaluation method for polyester glass laminated materials, 11th International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science. Gliwice – Zakopane, 2005, 1040-1044.

[12] C. Potel, T. Chotard, J.F Belleval, M. Benzeggagh, Characterization of composite material by ultrasonic methods, Composites Part B (1998) 159-169.

[13] J. Deputat, Nondestructive testing of new materials. Scientific Conference on Nondestructive Testing of Materials, Zakopane, 2004. (in Polish).

[14] J. Stabik, Ageing of laminates in boiling NaCl water solution, Polymer Testing 2004.

[15] L. Holliday, Composite Materials, Elsevier Science Limited 1966.