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A comparison study of the pulse-echo and through-transmission ultrasonics in glass/epoxy composites

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Properties

ABSTRACT

Purpose: The aim of the present study was to assess the limits and compare abilities of the pulse-echo and through-transmission ultrasonics to evaluate a chosen property of composite materials.
Design/methodology/approach: Two different ultrasonic non-destructive techniques were employed to measure the mechanical wave velocity in glass/epoxy composites. The study was performed on various specimens with different glass content at the range from 30 to 65%. The exact glass content in examined materials was determined using the standard destructive analysis.
Findings: A comparison showed that the results obtained for the wave velocity from pulse-echo and through-transmission are in good agreement, indicating that both techniques can be considered as a quantitative non-destructives tools of local fiber content evaluation. The results are presented in the form of linear relationships of wave velocity versus fiber content in the composite materials.
Research limitations/implications: In order to obtain lower dispersion of data, there are many factors to be considered such as void content in composite materials and/or transducer frequency of ultrasonic device, which were out of the scope of the present study.
Practical implications: The considered ultrasonic techniques can be applied to the industrial quality control of composite products, but for any different composite structures, distinct relationships should be determined.
Originality/value: The results presented would be of interest to the industrial quality procedures, especially in the case of products with high failure-free requirements.
Keywords: Non-destructive testing; Pulse-echo ultrasonics; Through-transmission ultrasonics; Glass/epoxy composites

1. Introduction

During the last few years, the industrial interest has been oriented towards the development of new materials in order to achieve high strength performance with low weight [1]. At the same time, there has been an increasing demand for quality caused by an increasing demand for safety, especially in the aerospace, aircraft and automotive industry. At the present the fiber reinforced composites are one of the most attractive materials for high performance applications due to their high strength-to-weight and stiffness-to-weight ratios as well as their fatigue and corrosion resistance [1, 2]. It is known that the mechanical properties of fiber reinforced composites, among others, highly depends on fiber content variations. The influence of fiber content on the chosen characteristics of composites can be found in Ref. [3÷5]. Local reinforcement variations arising during production process decide about out-of-control variations of strength and stiffness in a given component, which is of a great importance for the products with high failure-free requirements. To improve manufacturing quality it is necessary to develop suitable methods, which can be used to reinforcement content evaluation.

In a wide range of different non-destructive methods, ultrasonic techniques occupy one of the leading places [6] and are widely used in characterization of composite materials [7-16]. Ultrasonic testing is a non-destructive method in which beams of high-frequency sound waves are introduced into material for the detection of both surface and internal flaws in the material. The mechanical waves travel through the material with some loss of energy, and are deflected at interfaces and/or defects. The deflected beam can be displayed and analyzed to assess the presence and location of flaws or discontinuities. Ultrasounds also seem to be the most promising method for the purpose of fiber content evaluation, because the mechanical wave propagation highly depends on elastic properties and density of the medium [13].

Generally, two different approaches to the ultrasonic testing are the most popular in the non-destructive evaluation of materials. Where access allows, two transducers can be placed at each side of the material, so that a through-transmission test can be carried out. But in the cases where only one side is accessible, both transducers or one transmitter-receiver transducer is located on that side and a pulse-echo technique is used [7]. The choice of the most appropriate technique mainly depends on specific application with particular regard to the materials specifications and requirements of the quality control process.

An attempt to explain some problems of the ultrasonic characterization of glass/epoxy composites using pulse-echo and through-transmission techniques is made in this work.

2. Experimental

The present investigation has been performed in two distinct phases. During the first phase, glass/epoxy specimens were ultrasonic tested using pulse-echo and through-transmission techniques. In the second phase, the standard destructive method was applied to determine the exact glass content in the investigated specimens. Finally, the three methods based on experimental data were analyzed and compared.

2.1. Materials

The composite specimens were made of E-glass [0/90] woven fabric (Saint Gobain Vetrotex Europe) with areal weight of 800 g/m^2, epoxy resin L 1000 (Bakelite, Germany) and hardener VE 5195 (Bakelite, Germany). The details about constituent materials are summarized in Table 1.

Table 1.
The properties of constituent materials

Parameter	Unit	E-glass	Epoxy resin
Density	g/cm^3	2.58	1.13
Tensile strength	MPa	3500	65.4
Elastic modulus	GPa	75	3.1

Glass fiber reinforced composites were fabricated by hand lay-up, and the matrix was cold-cured under ambient conditions. The variation of glass content was achieved using different number of layers with the same total thickness (~10 mm) of the specimens.

2.2. Pulse-echo ultrasonic testing

The time-of-flight between the transmitted and back-reflected waves was measured using a PC UMT-12 flaw detector (Ultramet S.c., Poland) and one single transmitter-receiver “1LN” 1MHz transducer with a diameter of 13 mm (Unipan, Poland). The ultrasonic instrumentation was operated in the time-of-flight mode using the pulse-echo technique (Fig. 1.).

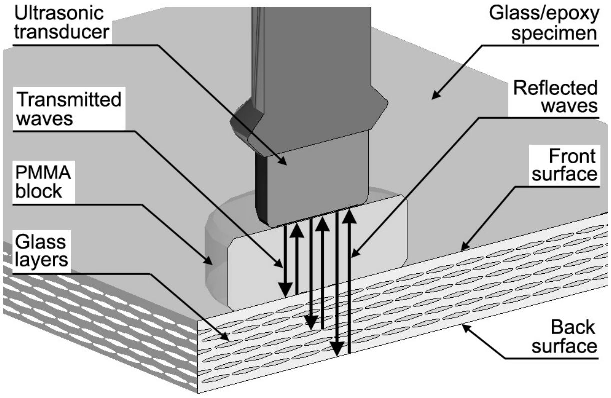

Fig. 1. Scheme of the ultrasonic testing (pulse-echo technique)

The longitudinal velocity (c_L) of the propagating wave was determined on the basis of the formula:

$$c_L = 2 \cdot h / \tau \qquad (1)$$

where:
$2 \cdot h$ – doubled thickness of the specimen in the place where the transducer was put against it [mm],
τ – time-of-flight of an ultrasonic wave in [μs].

During the ultrasonic tests, it was observed that first echo from the front surface of the specimen was masked by an initial transducer signal. That inconvenient situation caused an application of the 10 mm thick PMMA block which was put between specimen and ultrasonic transducer (Fig. 1.) to provide better wave matching and to provide a time delay to ensure the pulse-echo signal was not masked by the initial pulse signal. The PMMA block was chosen because of its well-known acoustic properties and it is also the material used in angle-transducers manufacturing. As a coupling medium “Zelpol USG” (Centrum Medicum Poland) was used.

A-scans observed on the screen were characterised by a cluster of free peaks, and these signify the reflection of ultrasound waves from the rough back-surface of the specimen. There were also observed many echoes reflected from glass layers of the composite specimen as well as echoes from PMMA surfaces. In the case of specimens with higher glass content (above 50%), the signals from back surface were only detectable, due to their size, which was similar to size of the signals from glass layers.

The results obtained from this testing were averaged to give the velocity values presented in Table 2.

2.3. Through-transmission ultrasonic testing

The time-of-flight of an ultrasonic wave in the specimens was measured using a MG 2000S ultrasonic thickness meter (AZ Industry Supplier, Warsaw, Poland). The schematic view of the ultrasonic investigation is shown in Fig. 2.

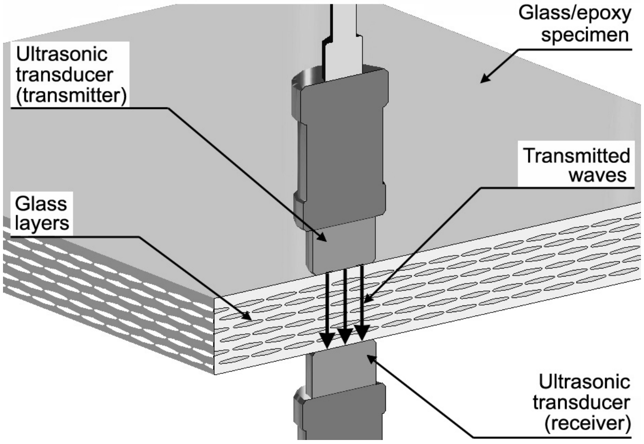

Fig. 2. Scheme of the ultrasonic testing (through-transmission technique)

The ultrasonic device was operated in the time-of-flight mode using through-transmission technique. For longitudinal velocity measurements, two standard transducers of 2 MHz frequency were used. The accuracy of velocity measurements was within ±1 ms^{-1}. The ultrasonic velocity (c_L) was calculated dividing the specimen thickness (h) by the time-of-flight (τ) of an ultrasonic wave on the basis of well-known formula:

$$c_L = h / \tau \qquad (2)$$

For longitudinal wave velocity, eight measurements were made and the average values have been reported (Tab. 2.).

2.4. Destructive analysis

To obtain information about exact glass content in the specimens, the standard destructive analysis was used. The analysis was performed in accordance with the procedure described in the ISO 1172:2002 [17].

Two test specimens were cut from the composite volume to be representative of the material and had weight within the range of 2÷10 g. These pieces of the specimen were dried to evaporate moisture and weighted with the use of a precision balance. Then, each specimen was burned-off in a melting pot at the temperature of 600 ºC for approximately 1 hour. That time was determined experimentally as weight of the specimens did not change after subsequent burnings. The glass content from each specimen was determined in accordance with the standard as a fraction of the initial weight.

The results of destructive examination for each specimen are shown in Table 2.

3. Results and discussion

It was observed from Table 2, that there were some differences in the values of wave velocity obtained using pulse-echo and through-transmission techniques. The variation was caused by the application of two different ultrasonic devices and transducers with different frequency. But due to the purpose of the study, these factors were not considered any further.

Table 2.
Determined properties of investigated glass/epoxy specimens

No.	Glass content [wt.%]	Average wave velocity [m/s]	
		Pulse-echo [15]	Through-transmission
1.	31.0	2461	2656
2.	37.2	2580	2676
3.	56.8	2949	2808
4.	57.3	2963	2866
5.	65.2	3045	2920

Table 3 gives a comparison of the three techniques used in the present work to determine the fiber content in glass/epoxy composites. The standard destructive analysis gave the lowest deviation of results, but for time-saving considerations, both ultrasonic techniques were definitely less time-consuming. Of the two non-destructive techniques, through-transmission was faster giving direct information about the time-of-flight of the wave.

Considerable dispersion of data in the wave velocity (Fig. 3.) can be attributed to the local void content in the specimens indicating that the accuracy of presented methods could be influenced by this factor. However, the extent to which void content affects the wave velocity is yet to established. Further work is needed in this area.

Table 3.
Comparison of the techniques used in the present study

Testing method	Advantages	Disadvantages
Burn-off (ISO 1172:2002)	Low standard deviation, reliable	Destructive, time consuming
Pulse-echo	Non-destructive, one-side accessible, convenient	Trained operators only, susceptible to voids
Through-transmission	Non-destructive, fast, convenient when two sides are accessible	Required accessibility of two sides

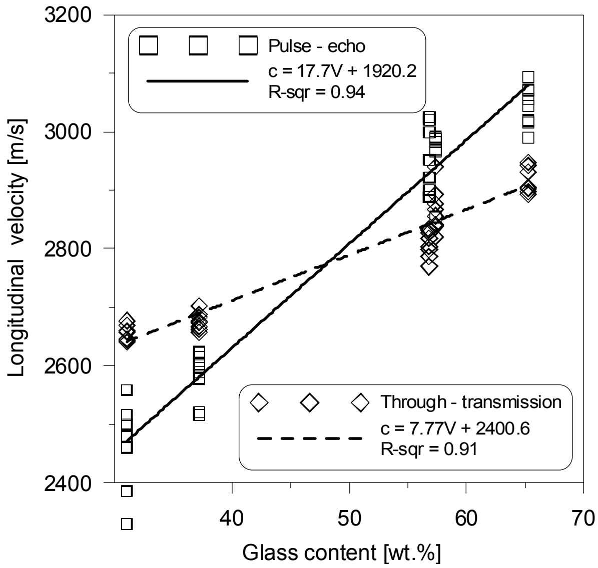

Fig. 3. Ultrasonic wave velocity vs. fiber content

4. Conclusions

The main objective of this work was to study efficiency and ability of the pulse-echo ultrasonics in comparison with through-transmission technique to evaluate the local fiber content in glass/epoxy composites. The variation of fiber content was clearly identified by the use of both considered techniques. Furthermore, pulse-echo proved to be a suitable method for the investigation of such materials, but it was also more time-consuming than the second considered ultrasonic technique. The described difficulties that can be expected using pulse-echo technique suggest that in the cases where two sides of the composite are accessible, through-transmission technique is recommended.

A good agreement between the results presented in this study, indicates that both ultrasonic techniques can be considered as a quantitative non-destructive assessment tools. It is therefore concluded that these methods can be used in the evaluation of local fiber content in polymer composites, producing interpretable results.

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