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## Relation between the ultrasonic attenuation and the porosity of a RTM composite plate

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### Abstract

We propose a comparative study of X-ray tomography and ultrasonic reflection methods, for determining the porosity of a composite plate realized in LOMC with an industrial process. We measure the attenuation of ultrasound propagating in the thickness by using 10 MHz plane transducer in pulse-echo mode. Comparing these results to the 2D porosity tomographic map allows establishing a relation between attenuation and porosity. A C-scan picture of the plate given by the echoes reflected by the rear surface also provides a local information on the attenuation. Furthermore, we propose a method for the mapping of the reflecting sources as the included bubbles and the interfaces resin/fibers.

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*Keywords:* RTM composite, porosity, attenuation, X-ray tomography, X-ray radiography.

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### 1. Introduction

The determination of the porosity in a composite RTM (Resin Transfer Molding) material is of great interest. Among the methods used to measure the porosity, the X-ray tomography can be used but only for small samples and its cost expensive. The reference 3D and 2D representations of the porosity in and on the plate have been obtained from X-ray tomography by another laboratory. We measure the attenuation of ultrasound propagating in the thickness of the plate by using 10 MHz plane transducer. A comparison of these results to the 2D porosity map helps to establish a linear relation between attenuation and porosity. These average values are estimated on surfaces of about one cm<sup>2</sup>. We then realize a C-scan of the plate with a focusing 10 MHz transducer. The picture given by the

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ultrasonic echoes reflected by the upper surface is comparable to the photography of that surface. The picture given by those coming from the rear surface provides a local information on the attenuation. Furthermore, we propose a method for the mapping of the reflecting sources such as the included bubbles and the interfaces resin/fibers.

## 2. Relation between the ultrasonic attenuation and the porosity

The used sample has been elaborated by the RTM process (injection of hot resin (RTM6) under pressure into a mold containing carbon fibers (AS7 satin 5)). Our sample contains 6 plies of superimposed fibers and its fibers volume ratio is 53 %. The porosity of plates strongly depends on parameters of injection (temperature, pressure, flow). The sample is 3.17 mm thick and the dimensions of the studied sample area are 37 x 38 mm<sup>2</sup>.

### 2.1. Comparison between X-ray radiography and ultrasonic attenuation cartography

We have defined 9 identical zones on the sample numbered one through nine. On each of them, we successively realize the X-ray tomography (by Safran Composites) and the measurement of the ultrasonic attenuation (by LOMC). The Fig. 1. (a) shows the 3D tomographic images obtained by transmission of the X-rays through the 9 zones of the sample. The analysis of the tomographic images involves determining, in 3 dimensions, the contour of each bubble and to assign to it a volume. From the sum of these volumes is deduced the porosity expressed in percent of the volume. Moreover, on the same sample, we realize an ultrasonic attenuation measurement by reflection. The immersed focused transducer (10 MHz, focal 2" and diameter 0.25") used in pulse-echo technique is normally set at 43 mm from the plate. This transducer has a beam of small diameter (about 1.2 mm) which remains constant inside the plate. It behaves as a plane transducer as demonstrated by Duong et al. [1]. The cartography of a variable of the plate is obtained from a C-Scan by moving the transducer with a fine step (0.2 mm) on the plate's surface. For each (x, y) position, the signal reflected by the plate is then windowed. In each window, the values of a physical quantity as the maximum of the signal are recorded. The attenuation is calculated from the ratio R of the back-wall echo amplitude and the surface echo amplitude. The attenuation  $\alpha$  is given by the following relation where z is the ratio of plate and water impedances.

$$\alpha = \frac{1}{2E} \log \left( \frac{4z}{(1+z)^2 R} \right) \quad (1)$$

This approach constitutes a simplification in the calculation of the attenuation which, as a matter of fact depends on the frequency. In this case, the attenuation is considered constant and called "simplified attenuation" (Fig. 1. (b)). This value is substantially equal to those we could measure at the optimal frequency of the transducer.

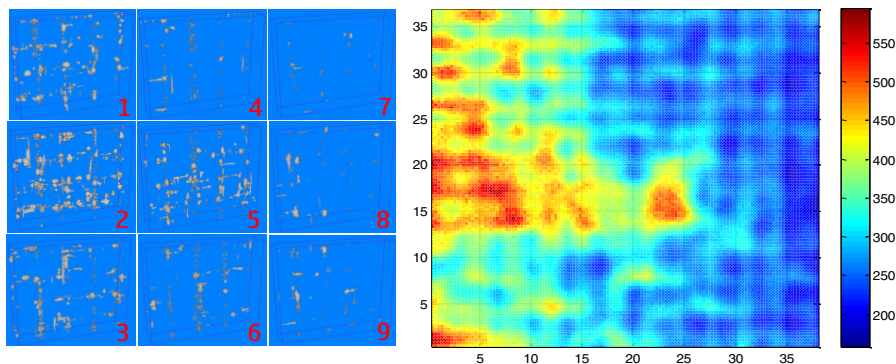


Fig. 1. (a) Tomographic image of a RTM composite plate in 9 square areas; (b) Attenuation (Np/m) cartography of the same plate.

## 2.2. Relation between ultrasonic attenuation and porosity

Table 1 summarizes the values of porosity and attenuation obtained in each area. The porosity is expressed in % and the attenuation in Neper/m.

Table 1: Porosity and ultrasonic attenuation evaluated in 9 areas

Area	1	2	3	4	5	6	7	8	9
Porosity (%)	0.781	1.34	0.687	0.115	0.77	0.251	0.034	0.166	0.119
Attenuation (Np/m)	446	508	409	340	426	357	302	328	312

The average value of the porosity on all the samples is 0.47 %, and a linear relation between the ultrasonic attenuation  $\alpha$  and the porosity  $p$ :  $\alpha=156p+307$  is obtained (Fig. 2.) like Lin et al. [2] for weak porosities. The intrinsic attenuation (without porosity) of the studied material is then 307 Np/m.

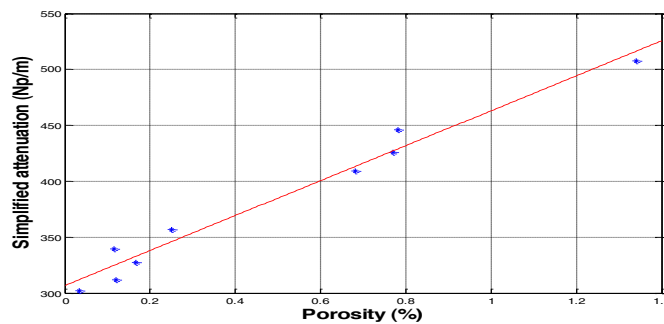


Fig. 2. Link between porosity and ultrasonic attenuation.

## 3. Cartographies

Kastner et al. [3] showed that the X-ray tomography provides the exact location of the defects which cause the porosity. The information about the porosity included in any depth slice of the plate can then be extracted. On combining the tomographic data of the multiple planes, bubbles included in the thickness of the composite plate can be visualized. A 2D representation can then be obtained as well as a planar representation called radio. The radio gives the porosity in every (x, y) point of the plate.

### 3.1. B-scan of RTM composite plate

In the field of ultrasound, we can try to represent the reflecting sources inside the plate. It is thus necessary to use a focused transducer whose the length of the focal spot (depth of field) is at least equal to the thickness of the plate. Its lateral resolution should also be as minimal as possible. The 10 MHz central frequency transducer used has a 1" focal length and a diameter of 0.5". Its beam is very narrow (diameter 0.3 mm) and its depth of field in the water is about 4 mm (values at - 6dB) for the nominal frequency.

The experimental set up is not modified. The scanning of the plate is realized by step of 0.2 mm. A 100 MHz sampling rate is performed and the signals contain between 500 and 700 points. The observation of the signals shows the existence of a strong surface echo, many internal reflections and a back-wall echo. Temporal echoes do not allow a precise location of the internal reflections (from fiber/resin interfaces or bubbles) because the signals are

quite oscillating. Moreover, no information can be obtained below the surface of the composite because the intensity of the surface echo is too high and its duration is too large.

To solve these problems, we replace each signal by its equivalent impulse response i.e. the calculated reflected signal which corresponds to a  $\delta(t)$  pulse emitted by the transducer. In our case, the bandwidth of the transducer is rather narrow so the width of each pulse echo is over 50 ns. We obtain a good location of reflected pulses whose values exceed a fixed threshold. The method also presents the advantage to easily eliminate the impulse corresponding to the surface echo. The B-scan of Fig. 3. shows the presence of several internal reflections between the two faces of the plate without the presence of a dead zone under the surface.

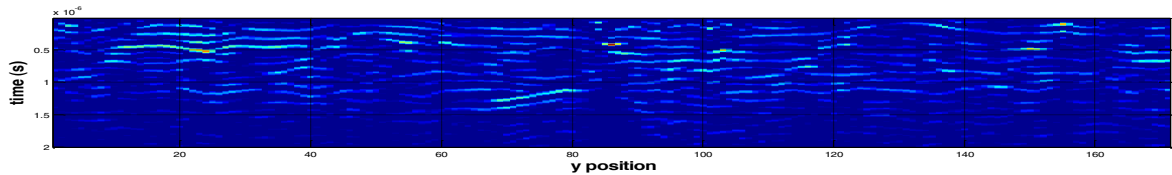


Fig. 3. B-scan of RTM composite plate.

### 3.2. X-ray radiography and internal ultrasonic reflections

It is possible to collect all the impulse responses and thus to obtain an image similar to the radio issued from the tomography. In order to obtain an ultrasonic radio, the pulse amplitudes in the thickness are summed at each point of the plate (internal reflections). The ultrasonic radio is presented Fig. 4. (b), and can be compared to the X-ray radio Fig. 4. (a). Both images contain some identical information, however some differences exist because the interactions of X-rays and ultrasonic waves with the reflecting sources have very different nature.

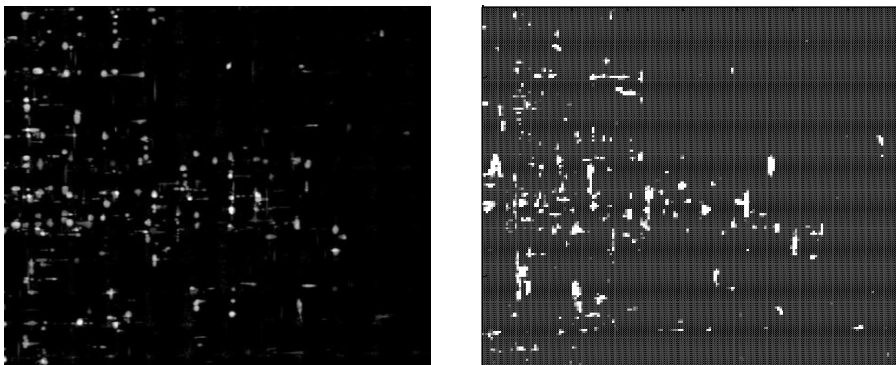


Fig. 4. (a) Radiographic image of a RTM composite plate; (b) Internal reflections of the same plate.

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