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Test Method

Impulse response method for defect detection in polymers: Description of the method and preliminary results

Marco Caniato [a,*], Federica Bettarello [b], Lucia Marsich [a], Alessio Ferluga [a], Orfeo Sbaizero [a], Chiara Schmid [a]

[a] Engineering and Architecture Department, University of Trieste, via Valerio 6/a, 34127, Trieste, Italy
[b] AcusticaMente Designers Team, via Garibaldi 13/b, 31015, Conegliano, TV, Italy

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ABSTRACT

The major problem encountered in the application of polymer industrial products is the difficulty of effectively modelling and predicting material performance and service life according to applied loads and operating environmental conditions. Furthermore, the presence of defects such as voids or inclusions created during manufacturing may affect the final performance.

The aim of this study is to present and investigate the development of an innovative acoustic non-destructive technique (patent pending), able to verify defects into composite laminates.

The analysis was carried out in two steps: the first aims to verify if distinct phases can be recognized within a material, while the second has the purpose of testing the proposed method on defective materials *ad hoc* prepared.

1. Introduction

The increasing use of polymer matrix composites (PMCs) in various industrial fields is justified by their excellent mechanical properties and high stiffness/weight and resistance/weight ratio: they combine low density and good impact resistance typical of polymers with the high mechanical strength of the reinforcing fibres [1].

A significant part of composite materials market is occupied by thermoplastics, which are characterized by low manufacturing cost, high fracture toughness and good impact resistance. In a context where sustainability acquires more and more importance, recyclability is one of the most desirable feature offered by those materials.

A significant class of PMCs is the so-called self-reinforced polymers (SRPs) [2], where polymeric matrix is reinforced by highly oriented fibres of the same polymer, or of a polymer having the same chemical nature. This class of materials presents good recyclability, thanks to the greater homogeneity, and a lower weight than the traditional composites, such as glass fibre composites [3]. Polypropylene (PP) is one of the most widely used polymer for the realization of this type of composite because it provides a good compromise between mechanical performance and cost [4–13].

The major issue in the application of polymer matrix composites is the difficulty of effectively modelling and predicting performance and service life according to applied loads and operating environmental conditions. This drawback is related to the plurality of failure mechanisms. The most important and frequent one is delamination, which can be induced both by the presence of voids created during manufacturing and by the incompatibility between reinforcement and matrix. The approximation in defect determination increases failure risk and limits PMC applications, therefore it is fundamental to explore techniques for defects detection and control in polymer composites. Non-destructive techniques (NDTs) [14–16] are often very expensive and not always capable of providing univocal information by itself; many studies highlighted that each technique is recommended for the detection of a specific class of defect, while other damage can be characterized with lower effectiveness. For this reason, in order to obtain a good result and estimate with greater precision the service life of a component, it is necessary to embed the results obtained using different techniques.

In this paper, the interest is focused on the study and development of an innovative acoustic non-destructive technique (patent

* Corresponding author.
E-mail addresses: mcaniato@units.it (M. Caniato), fbettarello@acusticamente.eu (F. Bettarello), lmarsich@units.it (L. Marsich), aferluga@units.it (A. Ferluga), sbaizero@units.it (O. Sbaizero), schmid@units.it (C. Schmid).

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pending EP16177665.3), in order to verify its effectiveness in the defect identification of polymer products.

This technique is classified as an acoustic method because it is based on the application of an impulsive load producing a pressure wave in the system, composed of a heavy plate positioned over the material.

On the contrary, traditional NDTs classified as 'acoustic techniques' [17–19], are based on the measurement of the sound response produced by a crack during its propagation. Similar non-destructive tests are used for the study of other classes of materials such as, for example, those employed in buildings floor insulation [20–26].

Starting from the determination of the dynamic stiffness of resilient materials for floating floors [27,28], the aim is to extend the application range of this technique and provide information on PMCs internal structure.

The dynamic stiffness s' is based on the mass-spring effect. An impact source excites a resonant system investigating its resonance frequency f_r. Using equation (1) the s' value is provided:

$$s' = 4\,\pi^2\, m'\, f_0^2 \tag{1}$$

where s′ is the dynamic stiffness of the resilient layer [MN/m^3], m′ is the mass per unit area [kg/m^2] and f_0 is the resonance frequency of the resonant system.

The dynamic stiffness parameter explains the spring behaviour of a single layer. However, the material could be modelled as a series of equal springs where every single element is characterized by identical stiffness (elastic constant).

By means of those tests, it could be possible to check the presence of defects within materials without using destructive tests. The aim of this study is to demonstrate that different phases could show diverse spring stiffness, and then that the described method could be used to verify those properties.

The first step of the analysis aims to verify if two distinct phases can be recognized within a material, while the second has the purpose of testing the method on defective materials *ad hoc* prepared.

2. Materials and method

The adopted equipment is the same as used for dynamic stiffness testing [29]: it is configured as a mass-spring system for the determination of resonance frequency pulse signal, as described in ISO 7626-5 [30]. The measurement set-up is composed of: impact hammer PCB Piezoeletronics® Mod. 086C03, N. 26753; accelerometer Dytran® Mod. 3023M2 Triaxial; hardware National Instruments® mod. NI 9234; software LabVIEW® Sound and Vibration Toolkit for signal acquisition. The sampling frequency is 51200 Hz and the frequency resolution is 0.5 Hz.

The method uses the same equipment as the ISO 7626-5 standard specifies (mass-spring effect – see Fig. 1), but how it is used, the typologies of tested materials and the final aim are very different.

In the standard, the specification identifies the measured maximum value (peak) of the resonance frequency; this procedure is to be performed having both single and multiple peaks. Then, this value is used to determine the dynamic stiffness according to equation (1), neglecting the other minor values (minor peaks). On the other hand, the new method aims to identify if there are more than one single resonance peak, both exciting the system according to the traditional method and moving the source and the receiver(s) along the surface area of the upper massive plate.

The standard highlights that the application fields are located on the materials used under floating floors. In the new method composite materials were tested.

The investigated material (20 × 20 cm) is inserted between two plates (the first of ideally infinite dimensions compared to the sample, the second of similar size, 2.5 cm thickness and 8 kg weight); a mechanical impulse is then applied on the top plate, while the accelerometer (placed also on the top plate) records the resonance frequencies of the mass-spring system.

The influence of the top plate preload and the possible modification of the mechanical properties on viscoelastic materials has already been studied [21–23]. Nevertheless, the composite tested materials are not significantly affected by preload since their Young's modulus ($Y_{ort} = 1.8$ MPa, $Y_{paral} = 3.7$ MPA) and though their mechanical properties allow them to bear the top plate weight. A creep test was performed on composite materials providing no significant thickness change in 6 months; both resonance and Young's modulus tests were executed before and after the creep test providing the same results, as expected.

With this method, it is possible to move source and receiver over the whole specimen surface in order to explore many

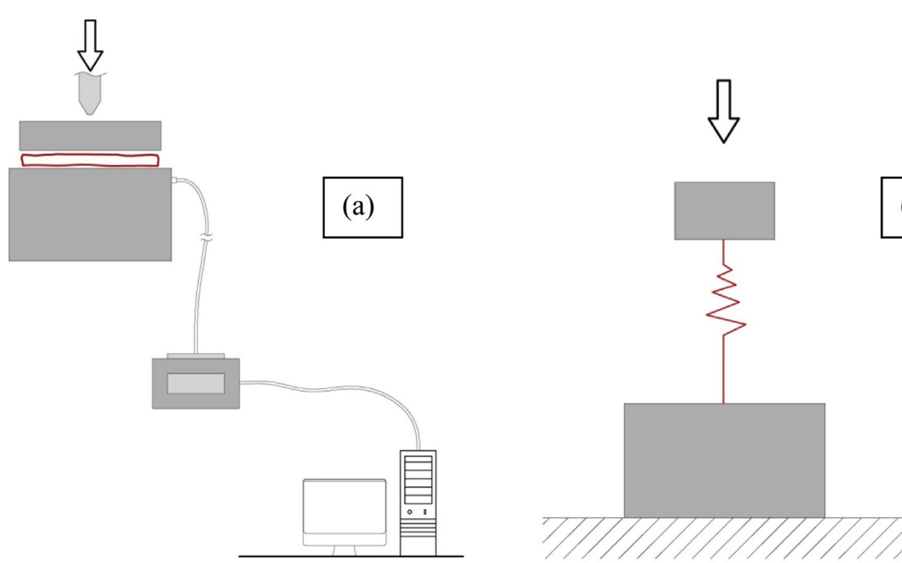

Fig. 1. (a) Test apparatus and (b) mass – spring effect.