PZT SENSORS APPROACHING FOR THE EVALUATION OF MULTIPLE IMPACT EFFECTS IN FIBRE GLASS COMPOSITE PLATES

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RESUMO

Neste trabalho propõe-se uma nova abordagem para analisar os efeitos de impacto em placas de compósitos de fibra de vidro usando sensores PZT. Foram usados quatro conjuntos de amostras fabricadas com diferentes tamanhos e sequências de empilhamento. Os testes de impacto foram realizados usando uma máquina de impacto de queda de peso. Os níveis de energia de impacto utilizados foram proporcionais à espessura das placas. Os sensores PZT foram colados nas placas numa configuração pitch-and-catch. Foi escolhido o modo simétrico fundamental (S_0) das ondas Lamb devido às suas melhores propriedades de propagação. Os resultados demonstraram que a avaliação da severidade dos defeitos, devido a impactos múltiplos, é possível com a técnica proposta.

ABSTRACT

In this work, it is proposed a new approach to analyse multiple impact effects in fibre glass composite plates by means of PZT sensors. Four sets of samples fabricated with different size and stacking sequences were used. Impact tests were carried out using a pressure-assisted drop-weight test machine. The used impact energy levels are proportional to the plate thickness. PZT sensors were bonded to the plates in a pitch-and-catch configuration and the Lamb wave symmetrical mode (S_0) signal was selected due to its better propagation properties. The results have showed that the evaluation of the severity of multiple impact defects is possible with the proposed technique.

1. INTRODUCTION

Fiber – reinforced composite materials are widely used in various engineering applications including automotive, aviation, civil engineering structures, aerospace, and so on, due to the known benefits, such as high specific stiffness and strength, lower weight, damping characteristics and the materials' tailoring facilities for creating high performance structures. Karakuzu et al (Karakuzu, 2010) studies the effect of equal mass, the equal velocity and equal energy on the impact behavior of the glass/epoxy laminated composite plates. Multiple impacts promote multiple delaminations and increased delamination area. Sevkat et al (Sevkat, 2010) studied the effect of repeated impacts on the response of composites and concluded that the lay-up sequence has significant effect on the repeated impact response of the hybrid composites. Also, the repeated impacts can cause very quick damage accumulation and promote a progression of the damage. Single hit may not generate significant damage in composites whereas subjecting the specimen to repeated impacts can cause severe damage and substantial reduction in residual strength. When the load reaches a critical level, the crack will extend and the failure occurs.

Recently, damage detection through ultrasonic guided waves, such as Lamb waves, has been gained increasing importance due to the possibility of inspecting large composite structures. Once excited, the Lamb waves can propagate all over considerable distances. Thus, a receiver positioned on the structure at a remote position can collect the propagation signals observed along with the path between transmitter and receiver, providing information about eventual surface defects or internal cracks. The generation of Lamb waves by conventional transducers has some limitations because they are relatively large and expensive. An emerging technique based on piezoelectric lead zirconate titanate (PZT) sensors has the potential to improve significantly the structural health monitoring (SHM). These sensors are small, lightweight, inexpensive, and can be produced with different geometries. They can be bonded on the structures surface, mounted inside built-in structures and can even be embedded between the structural and non-structural layers of a complete construction [Giurgiutiu, 2008].

2. EXPERIMENTAL PROCEDURE

The composite materials used in this study are manufactured from unidirectional E-glass fibers and epoxy resin. The volume fraction of E-glass fiber is 44.5 %. Several different laminates with stacking sequences, $[0_2,90_2]_s$, $[0]_{16}$, $[0_2,90_2]_{2s}$ and $[0]_{24}$ were considered to manufacture plates with three different thicknesses (t = 1.0, 2.1 and 3.4 mm), relatively to the number of plies, 8, 16 and 24 respectively. The plates were manufactured in a useful size of 300 x 300 x t [mm]. The specimens used in the impact tests were cut from these plates, with dimension of 150x150xt [mm].

The low velocity impact tests were made using a drop weight-testing machine Instron-Ceast 9340. A hemispherical impactor of 10 mm in diameter and a mass of 3.400 kg was used. The specimens were centrally supported and the impactor stroked the centre of the specimens. A range of impact energies between 1 J and 6 J were used, corresponding to impact velocities between 0.77 m/s and 1.88 m/s. Detailed information about the samples utilized in the experiments and the corres-ponding energies used in the multiple impacts are presented in Table 1. Three samples of each type (A, B, C and D) were impacted to analyze the repeatability of the process.

Table 1 Fiber glass composite properties and correspondent energy used in multiple impacts.

Sample	Stacking sequence	Thickness (mm)	Impact energy (J)		
			1º	2º	3º - end
A	$[0]_{24}$	3.4	3	4.5	6
B	$[0]_{16}$	2.1	2	3	5
C	$[0_2,90_2]_S$	1	1	1.5	2
D	$[0_2,90_2]_{2S}$	2.1	2	3	5

For Lamb waves generation the used PZT sensors were cut in square pieces of 7x7 mm from a bar type PZ29 (50x20x0.4 mm). For excitation, an arbitrary waveform generator Tektronix AFG3022 was used to produce a 3-cycle toneburst with a Hanning window that was previous synthesized in Matlab. This windowing technique is used to narrow the signal bandwidth and to focus the maximum amount of energy into the desired frequency with a minimum sprea-ding to neighbor frequencies. The signal has 10 V of amplitude. The PZT sensors were mounted in a pitch and catch confi-guration. The received signal after ampli-fication was collected by a digital oscillos-cope and transferred by USB to further processing. The complete setup using an aluminium plate is presented in Fig. 1.

For experiments in composite plates the PZTs were mounted 100 mm apart on the surface using conductive glue. A frequency swept was done allowing to verify that the maximum signal in the receiver was obtained for 320 kHz. Using time of flight and Rayleigh-Lamb dispersion equations, it has easily been proved that the signal obtained corresponds to the fundamental symmetrical mode S_0. A typical signal observed in the composite plates is presented in Fig. 2.

Fig.1 Experimental setup using an aluminium plate

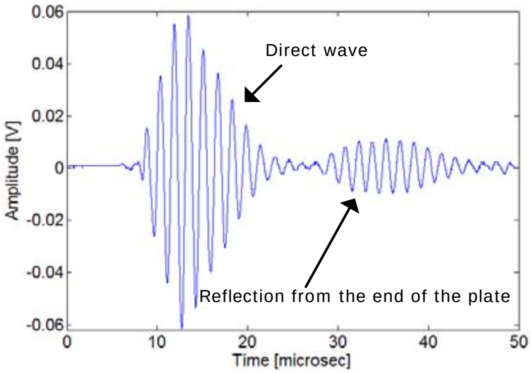
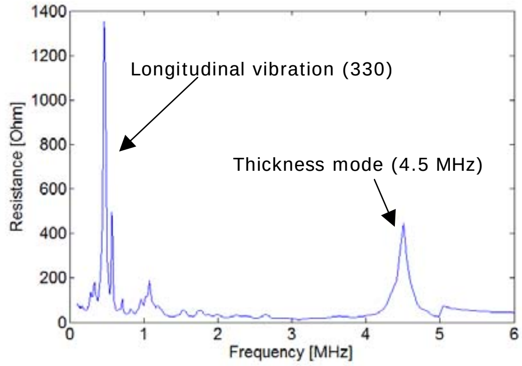


Fig.2 Fundamental symmetrical S_0 mode in the composite plate

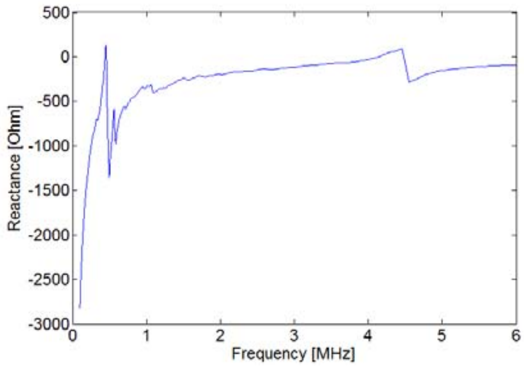
Electromechanical impedance was also analyzed using an HP 4194 impedance phase-gain analyzer (Fig. 3). A sharp peak around 320 kHz in the resistance trace, accompanied by a strong inversion in the reactance value, identifies clearly the resonance, which was already verified in the Lamb wave tuning experiment. The fundamental resonance in thickness mode was also detected near 4 MHz and is according to theory.

3. RESULTS AND CONCLUSIONS

Figure 4 illustrates typical load versus displacement curves for the $[0]_{16}$ laminates. In these force-displacement curves it is possible to observe a slope. These diagrams represent a typical behaviour and are in agreement with those reported on literature [Amaro, 2011; Hosur, 2005; Iqbal, 2009]. The curves contain oscillations that result from the elastic wave and are created by the vibrations of the samples [Schoeppner, 2000].The total damage was observed for the 6th impact in the unidirectional case. Fig. 5 represents typical load versus time



(a)



(b)

Fig.3 PZT electromechanical impedance: (a) Resistance; (b) Reactance

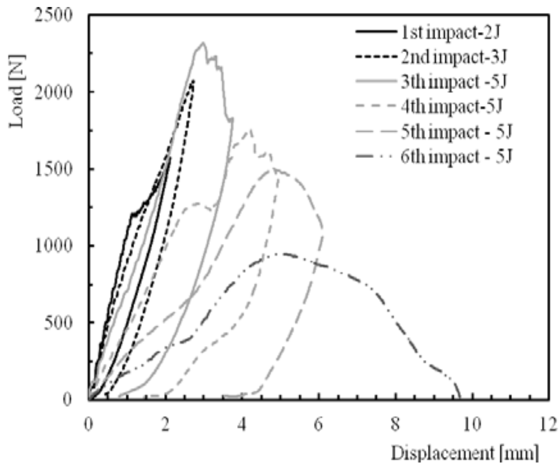


Fig.4 Load-displacement curve for $[0]_{16}$ composite.

curves for the $[0_2,90_2]_{2s}$ laminates. In this case it is possible to observe that the total damage occur for the 8th impact.

A typical set of energy versus time curves is presented in Fig. 6, for the $[0_2,90_2]_s$. The beginning of the plateau of the curve coincides with the loss of contact between the striker and the specimen, so, this energy coincides with that absorbed by the specimen [Río, 2005]. For this laminate

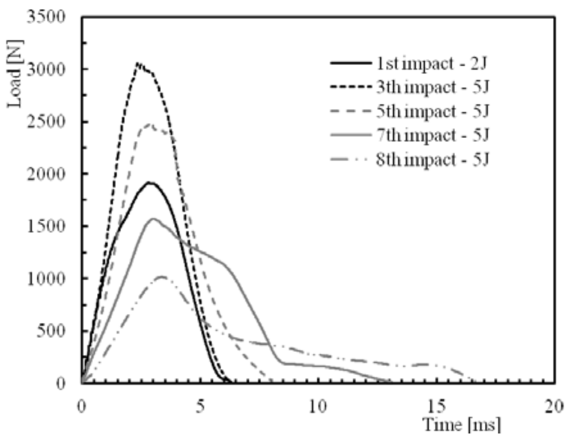


Fig. 5 Load- time curve for $[0_2,90_2]_{2s}$ layup.

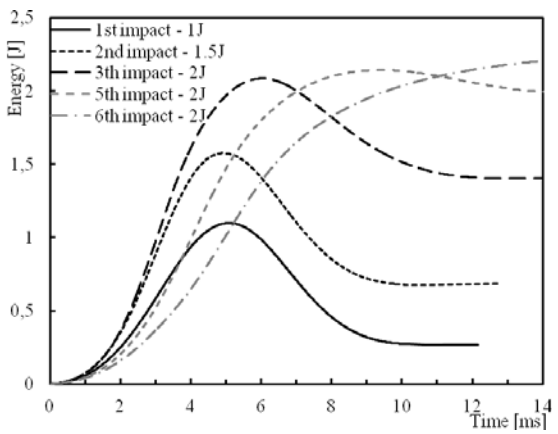


Fig. 6 Energy- time curve for $[0_2,90_2]_s$ layup.

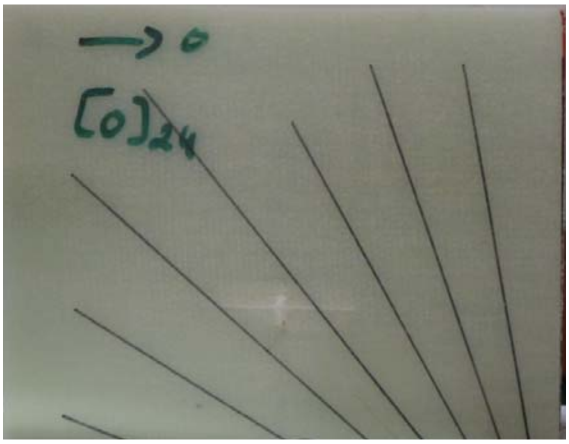
the total damage appear for the 6th impact. The same curves were observed for the other lay-ups studied.

As the glass-laminated plates are translucent it is possible to obtain the image of the damage using photography. To achieve the best possible definition of the damaged area, the plates were photographed in counter-light using a powerful light source. Plates were framed in a window so that all the light could fall upon them. The plates were photographed on the opposite side of the impact (back face) and are showed in Fig. 7. It can be observed that the delamination shape is oriented along with the fibres direction of the adjacent lower ply (0º) and the crack is also aligned with the fibres direction of this lowest ply.

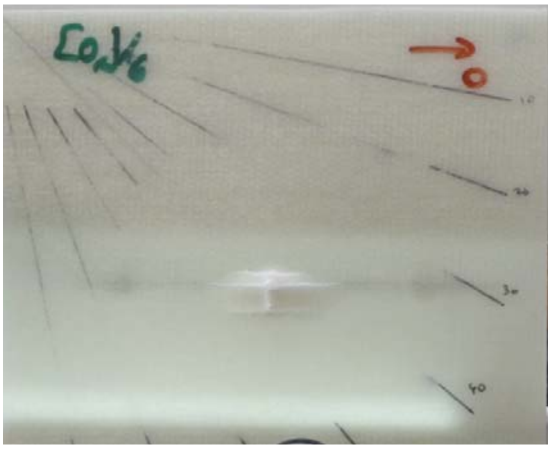
Using the setup in Fig.1, peak to peak voltage amplitudes were measured for each set of samples from the first to the 4th impact. After the last impact, all samples presenting high damages were not considered in the study. Typical amplitude variations of about 20% were observed for the same type of sample, which is related to the non homogeneous structure of the composites. That variation can also be related to the small dimensions of the analyzed plates, which give rise to high reflected signals in the edges that interfere with the direct signals. In future high size plates should be used.

The normalized signal amplitude versus defect dimensions was analyzed. As expected, the amplitude decreases as the defects increase for all samples. Figure 8 depicts this behavior for plates B and C. A linear correlation was established between these two parameters. This tendency with a high R^2 coefficient (0.95) was only observed for the plate B. For the other plates the values of R^2 were around 0.6, indicating a poor linear correlation.

The main reason for this behavior might be related with the structure of plates and with the orientation of the PZTs. Plates A and B have unidirectional fiber orientation and plates C and D crossing fiber orientation. For plate A, the sensors were bonded normal to fibers direction and for plate B, they were parallel to fibers. Looking at the results, it seems that when the propagation is in fiber direction, as for plate B, it is possible to predict the defect extensions by measuring the signal amplitude. For the other cases, due to the cross fibers in the propagation direction, more complicated phenomena arise, conducting to a non linear behavior. We can conclude that using ultrasonic guided wave technique with PZT sensors, the amplitude measurements of the received signals could be related with the severity of the defects in certain circumstances. Further processing techniques are now being studied to get more detailed information, which could be correlated to other defect parameters in order to validate the presented results. Generalization to other types of composite materials is another objective in future works.



(a)



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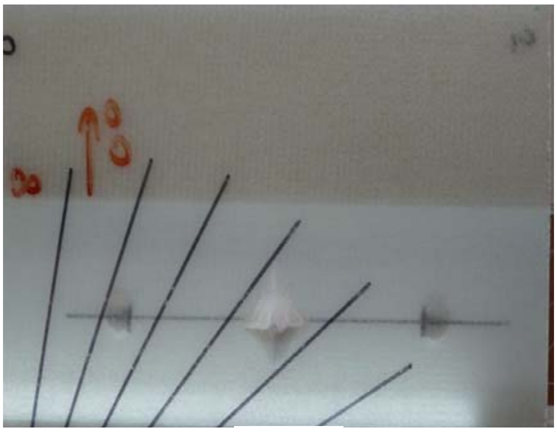

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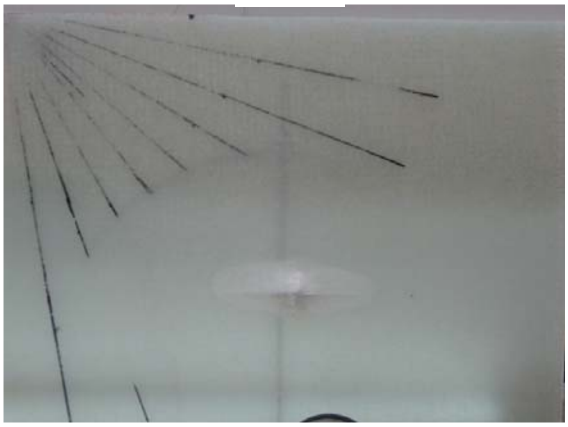
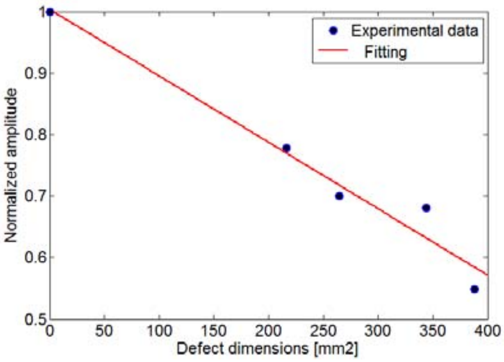


(d)

Fig. 7 Typical damages occurred after the 6th impact for laminates: a) $[0]_{24}$; b) $[0]_{16}$; c) $[0_2,90_2]_s$; d) $[0_2,90_2]_{2s}$.



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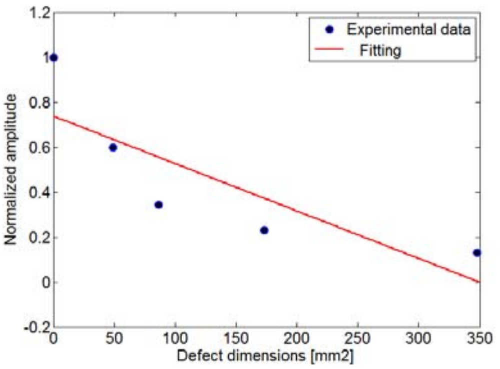

(b)

Fig.8 Normalized signal amplitude versus defect dimensions: (a) Plate B; (b) Plate C

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