INTERLIEVED REINFORCED CARBON FIBER EPOXY LAMINATE INSPECTION BY THE LAMB WAVE METHOD

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Abstract

This study proposes the use of lamb waves, in the assessment of laminate carbon fibre-epoxy laminated materials with a PEEK-Graphene interleaved reinforcement, that was added in order to increase the interlaminar fracture toughness (IFT) of the material in Mode I and Mode II fracture. The main aim of this article is to provide insights of the inspection of CFRP laminates with added polymeric veils and their comparison with typical CFRP laminates using Lamb waves, stepping forward the research of inspection of reinforced composite with the ultrasonic technique. The results show the capability of lamb waves to propagate throughout interleaved composite materials and through damage zones inside them.

Keywords | Non-destructive testing; Ultrasound; Composite materials;

INTRODUCTION

Composite materials are as resistant as metals such as steel or aluminium but considerably with less density, hence, lighter. These materials are made out by the combination of two or more constituents that influence the resultant properties of the material. This make possible the acquisition of particular and complex properties that otherwise would be tough to find in a singular material. That tailoring ability has made composite material set their place in the fields of constant development of automotive, aerospace, military, sports and even medicine industries [1–3].

Due to their manufacturing process and the fact that composite material commonly found their service environment to be highly demanding, critical flaws may appear in composite structures. These flaws can appear in the form of delamination, cracks, adhesive joint deboning and fibre splitting, among others. A common factor that increases the risk of these flaws is the fact that in many cases they would show neither significant evidence of being there nor the size of such damage [4].

In order to detect flaws inside the structures with composite materials, before any catastrophic outcome may occur, non-destructive test (NDT) and structural health monitoring (SHM) methods are commonly used [4]. Some non-destructive test methods include visual inspection, CT-Scan, X-Ray and ultrasonic inspection, the latter, is one of the most used techniques due to relatively low cost, small equipment requirements and good flaw detection capacity even in large structures [4–7].

The Ultrasonic Testing (UT) is based on high frequency wave propagation; these waves are propagated throughout the material and are reflected by the rear surface of the specimen. Inside the threshold of UT there is a type of waves called guided waves, these sort of waves can propagate specifically throughout the thickness of a plate, an interface or a surface the former being named Lamb waves. Lamb waves are capable of inspecting large areas of material, which may be difficult with traditional UT methods that employ bulk waves instead of guided waves. Lamb waves offer many advantages such as a large area of inspection capacity, shorter period during inspection and a reduced risk of missed flaws due to human errors, all characteristics that are valuable and useful for composite materials inspection. In contrast, the use Lamb waves may present some difficulties in farfetched part geometries, after test raw data processing and in certain materials or set ups may be really tough to apply [6–8].

In order to address these advantages and difficulties, a broad study upon the state of the art of these waves and how they are capable of inspecting different types of carbon fibre reinforced polymer (CFRP), laminates and metal plates, was carried out by Zhongqing *et al* [9]. In the work of Zhongqing, fundamentals in the field of inspection with the use of Lamb waves are addressed. In addition, both general theoretical bases and specific concepts of Lamb wave inspection are treated.

As an applied study that gathers many of the concepts studied by Zhongqing, the use of guided lamb waves in the inspection of wind turbines made out of glass fibre reinforced polymer (GFRP) laminates and sandwich structures, staying the capability of this test method to detect discontinuities such as delamination, disbonds and impact damage carried out by Yang *et al* [4].

Stepping forward to more detailed analysis of Lamb waves the interaction between lamb waves and the edge of delamination in CFRP laminates, was approached by Feng et al in a recent study [10]. This can be associated with the broad use but yet required study of lamb waves and their possible used in the different fields of science, for example, a test set up based on Lamb waves that is capable of performing blood coagulation test [11].

A topic that requires further research is the effect of interlaminar reinforcements in the inspection of composite laminate materials. A work that preceded this study was conducted by Ramirez *et al*. Whose work spins around the use of polymeric veils added to laminate carbon fibre/epoxy to enhance the interlaminar fracture toughness in mode I and mode II [12].

This study provides insights of the inspection of CFRP laminates with added polymeric veils and their comparison with typical CFRP laminates using lamb waves, stepping forward the research of inspection of reinforced composite with the ultrasonic technique.

MATERIALS AND METHODS

The Composite laminate specimens, with reinforcing PEEK-Graphene non-woven veil interleaved, Figure 1 (A), were manufacture with the vacuum assisted resin transfer molding (VARTM) method. Further explanation of interleaved laminate composite manufacture is provided by Ramirez et al [12]. A typical carbon epoxy laminate, Figure 1 (B), with variable thickness (5-ply 28-ply) was use as a control material for the sound propagation velocity in this work.

CFRP Composite Laminate (0°-90°) 14-ply, 3 PEEK- Graphene veils. (A)

CFRP Composite Laminate (0°-90°) 5-ply edge, 28-ply center. (B)

Figure 1 (A) Veil interleaved specimen; (B) Carbon fibre-epoxy laminate specimen.

For the ultrasonic inspection of the specimens, an Olympus® square wave pulser/receiver model 5077PR in addition to a four channel and 60MHz Keysight® Oscilloscope model DSO1004A was employed at a pulser voltage of 200 volts and +1 Gain as configuration. Also two Olympus® 1 MHz transducers V103-RM served as transmitter and receiver. The test scheme is show in figure 2. For all the testing, in an attempt to achieve some wave mode filtering, 30° angle PLA-carbonfibre (PLA-CF) wedges, figure 3, created by 3D printing. The 3D printer used was an Anycubic® I3 Mega 3D printer.

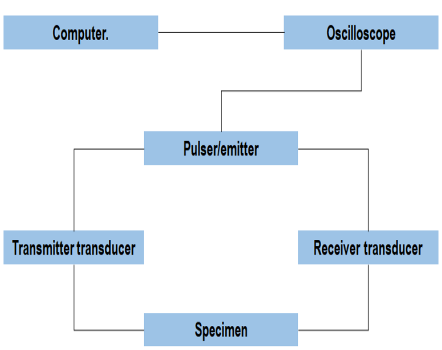

Figure 2. scheme of test connection.

Figure 3 3D printed 30° angle wedges.

RESULTS AND DISCUSSION

For the use of lamb waves, the linear and transvers velocities of sound in the specific medium to analyse are required. To collect this information, the specimen velocities were obtained using simple transmission test. The interleaved laminate composite and the control group plate are composite laminate materials and present two pairs of sound velocities, Vl1 and Vt1, which represent the velocity of sound travelling perpendicular to the plane in which the plies are oriented. Vl2 and Vt2 represent the velocity parallel to the same plane. All the sound velocities collected including the linear velocity of the PLA-CF wedge are show in Table 1.

Table 1 Linear and transvers velocities of sound

Linear and transvers velocities of sound				
Material	Vl1 mm*µm-1	Vt1 mm*µm-1	Vl2 mm*µm-1	Vt2 mm*µm-1
Laminate (0°-90°) veil	1,84	1,27	3,57	1,35
Laminate (0-90°)	2,10	1,28	3,00	2,17
PLA-CF wedge	1,50	-	-	-

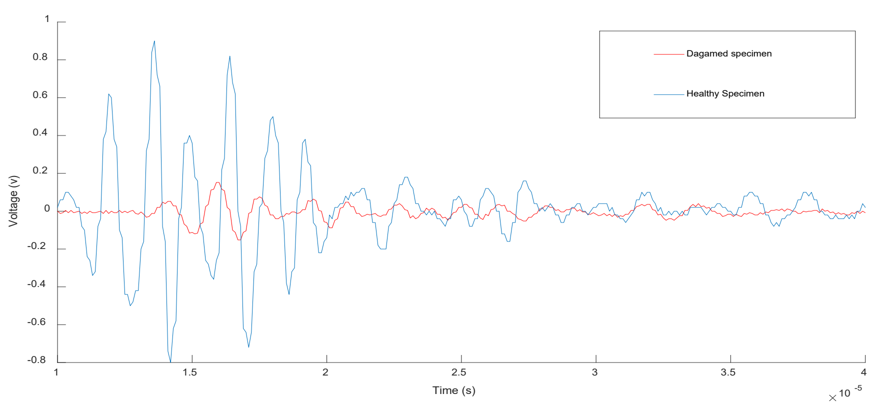

Figure 4 laminate with veils in good condition and with considerable damage.

With the configuration previously described, lamb waves were able to be propagated trough out the interleaved composites and even trough out damaged zones in the same material, showing clear alterations to the time of arrival of the wave package and the amplitude of the waves that had to pass through out these damage areas. A comparative graphic between Lamb waves, in damaged and healthy interleaved reinforced composites of the same geometry is show in Figure 4. It is clear that the differences are quite noticeable once a damaged specimen is compared to a healthy specimen trough this method. Nonetheless, this is yet an unrefined used of the lamb waves. In this set up there is not a specific wave mode being propagated throughout the material to detect a specific type of flaw or a specific size of the defect that is desired to detect.

CONCLUSIONS

The data shows that the propagation of lamb waves is possible through interleaved reinforced carbon epoxy laminates and can transmit throughout damage areas showing an increase in arrival time and a considerable reduction in amplitude.

Based on the Snell law for wave refraction and the propagation velocities found for these materials, the PLA-CF 30° wedge can't filter any particular wave mode at this particular angle, but with the use of a signal generator and a bigger angle for the wedge, at least above 45°, different wave modes may be filter to specific needs and it is suggested to be used in future work.

The use of interlaminar reinforcements in laminate composite materials alters, in a sensitive way, the speed at which ultrasonic waves can propagate through the material. Closer inspection required in the selection of test parameters in order to compensate for the changed cause by the interleaved will be required for the proper application of this NDT method.

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REFERENCIAS

[1] W. J. W. Donald R. Askeland, Pradeep P. Fulay, *What is Materials Science and Engineering ?* .
[2] R. Baptista, A. Mendão, M. Guedes, and R. Marat-Mendes, "An experimental study on mechanical properties of epoxy-matrix composites containing graphite filler," *Procedia Struct. Integr.*, vol. 1, pp. 74–81, 2016.
[3] Federal Aviation Administration, "Aviation Maintenance Technician Handbook - Airframe," *Aviat. Maint. Tech. Handb. - Airframe*, vol. 1, p. 588, 2012.
[4] R. Yang, Y. He, and H. Zhang, "Progress and trends in nondestructive testing and evaluation for wind turbine composite blade," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1225–1250, 2016.
[5] A. Fahr and A. Y. Kandeil, "Ultrasonic C-scan inspection of composite materials," *Eng. J. Qatar Univ.*, vol. 5, no. May, pp. 201–222, 1992.
[6] ASTM, "ASTM E2981 Standard Guide for Nondestructive Testing of the Composite Overwraps in Filament wound pressure vessels used in aerospace applications," *Astm*, pp. 1–36, 2015.
[7] ASTM, "Standard Guide for Resonant Ultrasound Spectroscopy for Defect Detection in Both Metallic and Non-metallic Parts 1," *Astm*, vol. 98, no. Reapproved, pp. 1–7, 2015.
[8] J. L. Rose, *Ultrasonic Guided Waves in Solid Media*. 2014.
[9] Z. Su, L. Ye, and Y. Lu, "Guided Lamb waves for identification of damage in composite structures: A review," *J. Sound Vib.*, vol. 295, no. 3–5, pp. 753–780, 2006.
[10] B. Feng, A. L. Ribeiro, and H. G. Ramos, "Interaction of Lamb waves with the edges of a delamination in CFRP composites and a reference-free localization method for delamination," *Meas. J. Int. Meas. Confed.*, vol. 122, no. October 2017, pp. 424–431, 2018.
[11] J. Nam, H. Choi, J. Young, W. Jang, and C. Seung, "Sensors and Actuators B : Chemical Lamb wave-based blood coagulation test," vol. 263, pp. 190–195, 2018.
[12] V. A. Ramirez, P. J. Hogg, and W. W. Sampson, "The influence of the nonwoven veil architectures on interlaminar fracture toughness of interleaved composites," *Compos. Sci. Technol.*, vol. 110, pp. 103–110, 2015.