# Defects detection on a composite structure by an optical measurement of ultrasonic surface waves

Morvan Bruno ; Izbicki Jean-Louis
Laboratoire d'Acoustique Ultrasonore et d'Electronique
Place Robert Schuman
Le Havre
France
Tel:  02 32 74 47 38
Fax: 02 32 74 47 19
E-mail: morvan@univ-lehavre.fr

## ABSTRACT

Acoustic surface waves are excited by a contact transducer on plane structure composed by multilayered bonded composite plates. A laser vibrometer is used to measure the Lamb waves surface displacements. Spectral analysis in the time domain and in the space domain are processed from experimental data. Then the modes identification is performed from the experimental dispersion curves. Many types of bonding defects are investigated. The physical interpretation of the results involves conversion modes, reflection and transmission through the defect.

## 1- INTRODUCTION

Adhesive bonding have emerged as an effective technology to join structural composite. Indeed, adhesive bond is lower weight, better stress distribution and lower fabrication cost compared to riveting or bolting. Assessment of bonded structures leads to the development of specific damage evaluation techniques. Among these methods, ultrasonic inspection is efficiently and particularly studied since many years [1]. We can separate two main ultrasonic methods of evaluation: the measurement of the amplitude of reflection (transmission) coefficient at the adhesive/substrate interface [2,3] or the study of guided waves propagating in the multilayered plate [4,5,6]. Lamb waves are very sensitive to any geometrical or physical properties inhomogeneity in a plate that is why we study Lamb waves propagating on  bonding plates in order to evaluate a defect in the adhesive layer. Several bonding defects are investigated whose induce some complete disbonding  or a weak interface cohesion. This study involves non contact measurement (laser vibrometer)  of the Lamb wave surface displacement along the direction of propagation and a spectral analysis in the space domain. According to this analysis, an interpretation of the Lamb wave interaction with the defect is made and the results for each particular defect is discussed.

## 2- EXPERIMENTAL STUDY

2.1- Specimen description and experimental set-up

Specimens are realised by bonding together two composite plates with a film supported epoxy adhesive. Composite plates are made in epoxy resin reinforced with carbon fibres. The 2.2mm thick plates are layered with eight plies of carbon. In order to simulate a weak bonding or an adhesion failure, some defects are insert between the adhesive and the substrate. Four different types of defect with an approximated 12 mm diameter are investigated:

- a piece of Teflon film
- a piece of separating film for the adhesive layer (this separating film is normally removed from the adhesive before bonding).
- a hole in adhesive film
- some grease mixed to the adhesive.

The experimental set-up is described in figure 1. A pulse generator delivers a pulse voltage (about - 300V) to a Krautkramer broadband piezo-composite transducer whose central frequency is 2.25 MHz. Lamb waves are generated by the wedge method. A BMI laser vibrometer is used to measure the plate normal surface displacements along a line parallel to the incident Lamb wave propagation direction Ox [7]. The displacement amplitudes are collected from x=0mm to x=40mm by 0.2mm steps. At each position, a 200µs long signal is acquired on 10000 points given a time-space signal s(x,t). In figure 2, a transient signal measured at x=10mm on a good joint composite plates is given. In order to improve the signal to noise ratio we perform averaging on 1000 successive shots.
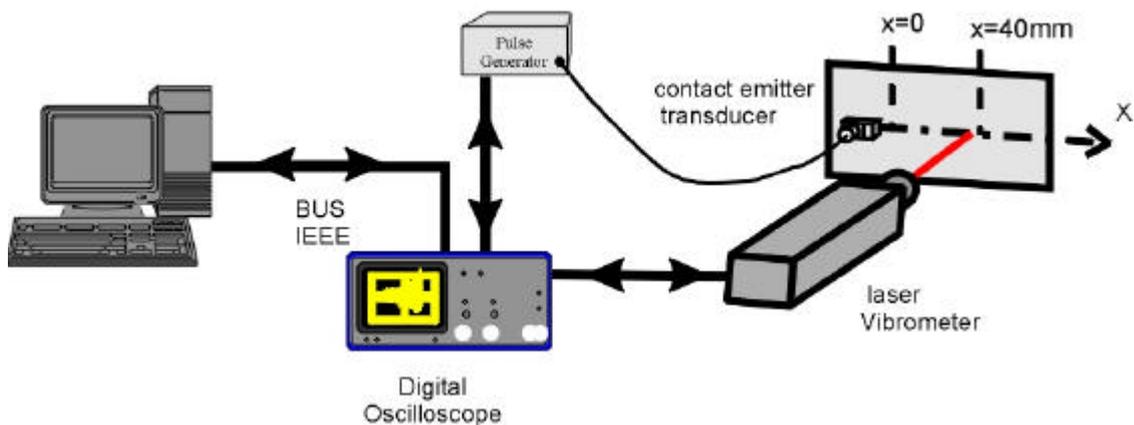


Figure 1 Experimental Setup
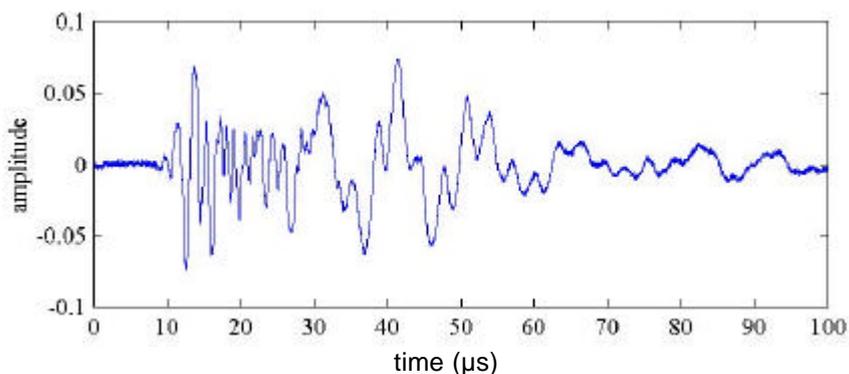


Figure 2  Transient signal at x=10 mm

## 2.2- Signal analysis

Let's now consider the time-space signal s(x,t). We performed successively a time and a space Fourier Transform (FFT) of the signal, in that way, the experimental dispersion curves are obtained on which each propagating incident and reflected waves is separated (figure 3) [8]. Even if the emitter transducer has a frequency bandwidth centred around 2.25 MHz, experimentally there is no signal observed above F=1 MHz. This is due to the strong wave attenuation in composite material especially in high frequencies. Only, the two first Lamb modes A0, S0 and a higher mode A1 or S1 are detectable in this study.
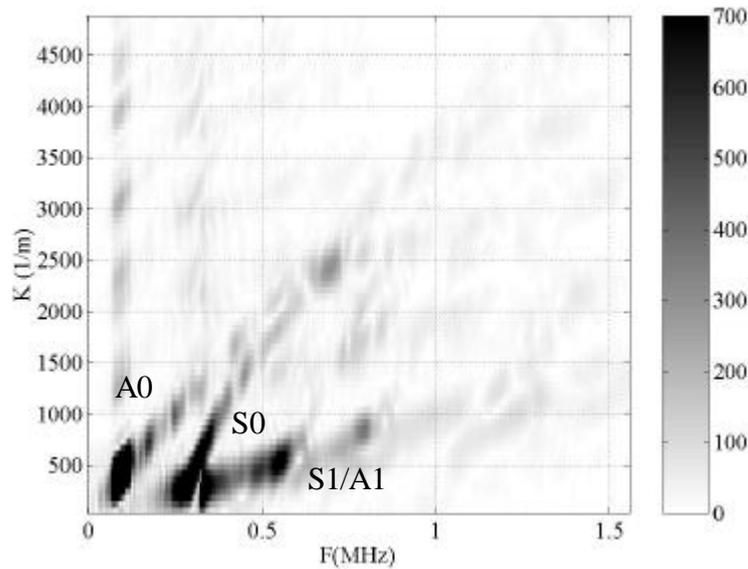


Figure 3  Representation of the signal in the dual space (k,F)

Eventually, we want to locate a bonding defect.  In order to observe the interaction of a wave with a defect, we study the evolution of the wavevector k with the position x. At a given frequency F corresponding to a Lamb wave obtained previously, a Short Time Fourier Transform is performed on the signal. A  50 points window is translated along the x axis and at each position x a spatial FFT is performed on the windowed signal. Hanning window is used to improve the spatial location and avoid a step truncation of the signal. In figure 4, the amplitude evolution of the S0 incident wave at F=0.3MHz propagating in the non-defected sample is shown.
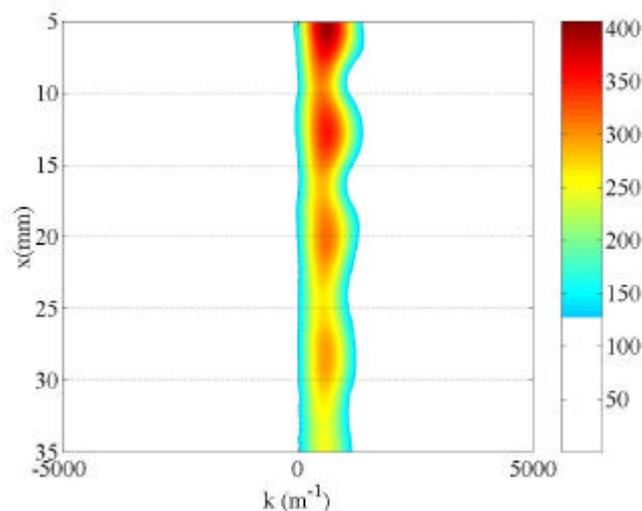


Figure 4  (k,x) representation,  non-defected bonding

We note an amplitude decay of the signal and in the same time regular oscillations. The amplitude decay is due to the wave attenuation during the propagation whereas oscillations are caused by the weak laser reflection onto the carbon fibres which compose the surface plate.

## 3- RESULTS
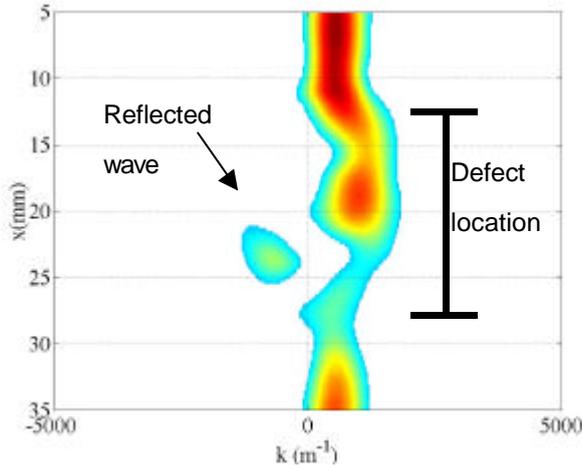


Figure 5 (k,x) representation, adhesive
separating film. Hanning window.
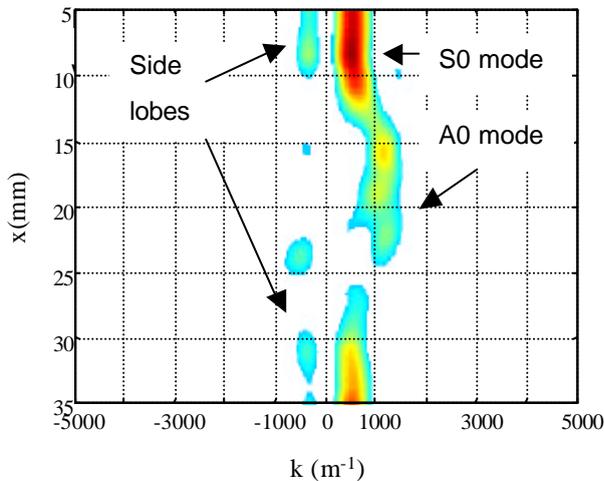


Figure 6 (k,x) representation, adhesive
separating film. Rectangular window.

Several defects are evaluated according to the signal analysis procedure previously presented. 40mm long measurement is performed started at 15mm from the emitter transducer. Defects are located at around x=20 mm. At F=0.3MHz, the (k,x) representation of the signal propagated on sample with a defect induced by a adhesive separating film is shown in figure 5, for a translated hanning window, and in figure 6, for a rectangular window.

At x=12mm in figure 5, a wavevector shift indicates a mode conversion phenomena. At this frequency, there are only the two first modes A0 and S0 (figure 3). Therefore the converted mode is the A0 mode. Unfortunately, the frequency resolution is not sufficient to accurately obtain the wavevector values. At x=25mm there is a second mode conversion, the A0 mode disappears and the S0 mode propagates again. We note a weak A0 reflected mode (negative wavevector) at the last extremity of the defect.

In figure 6, the peak resolution is accurate but the (k,x) representation is polluted by side lobes (Gibbs phenomena). Indeed, it is difficult to discriminate between true reflected waves and side lobes. Nevertheless, incident mode S0 (k=450 $m^1$) and A0 (k=1150$m^{-1}$) converted mode are identified with a good accuracy .

In figure 7, an adhesive defect induced with a teflon film is studied. We note the presence of a reflected mode at the position x=15mm, this position corresponds closely to the first extremity of the defect. Contrary to the case of the defect created by the adhesive separator, the incident S0 wave amplitude is maximum on the defect. Then the amplitude of transmitted S0 mode through the defect is strongly attenuated (after x=25mm).

The interaction of the incident S0 mode with a hole in the adhesif layer is observed in figure 8. This mode disappears at x=16mm and reappears at x=24mm. Between these positions a reflected S0 mode is present. Obviously, the defect size seems to be narrower than the initial

hole (12mm diameter) in the adhesive film. We can explain this narrowing by the spreading of the adhesive during bonding.
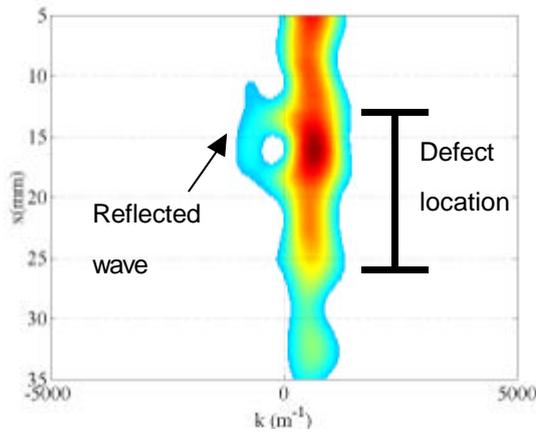


Figure 7 (k,x) representation, teflon film.
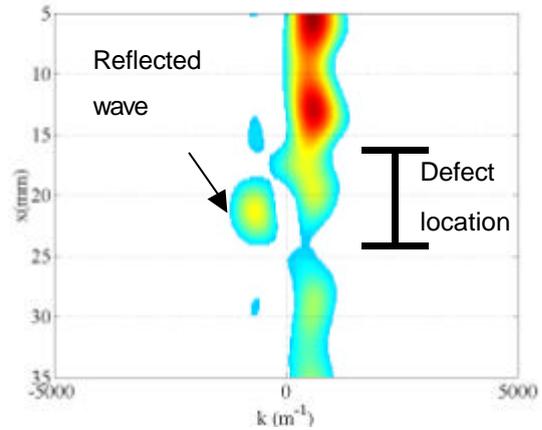


Figure 8 (k,x) representation, hole in the adhesif layer.
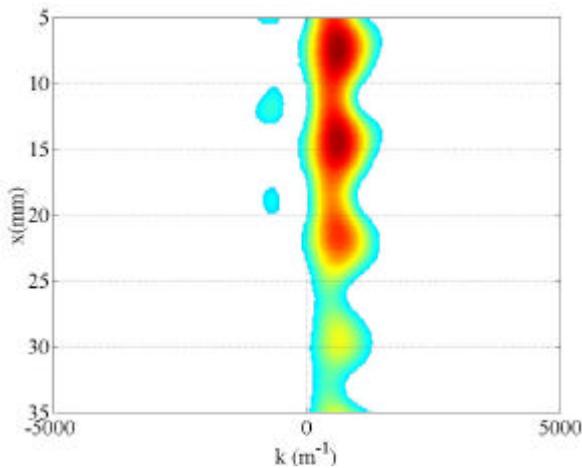


Figure 9 (k,x) representation, grease mixed to the adhesive.

The defect obtained by grease addition to the adhesive layer is studied at last. The determination of exact defect dimensions is difficult because during the bonding of the plates in pressure-sealed, the grease diffuses and spreads in the adhesive layer. The grease induces a weak cohesion at the plates/adhesive interface. The Figure 9 reveals an abrupt variation of incident S0 mode amplitude at x=25mm. In comparison to S0 mode propagating in the satisfactory sample (good adhesion) the decrease of the amplitude is higher.

## 4- CONCLUSION

This study shows the ability of Lamb waves in the detection of very thin defect embedded in a multilayered plate. The identification of the defect is performed in the (k,x) space and allows an estimation of the defect size. In the case of defect which induced only a change in the physical properties of the adhesive, it may be possible, according to the study of the defect induce by the grease, to estimate the strength of the bonding by the evaluation of the Lamb waves attenuation.

**REFERENCES**

[1]     P. Cawley, T. Pialucha and M. Lowe. « A comparison of different methods for the detection of a weak adhesif/adherend interface in bonded joints ». Review of Progress in Quantitative Non-destructive Evaluation, Vol 12, pp1531-1538, 1993.

[2]     A. Pilarski and J. L. Rose. "A transverse-wave ultrasonic oblique-incidence technique for interfacial weakness detection in adhesive bonds". J. Appl. Phys. 63(2), January 1988.

[3]     A. I. Lavrentyev and S.I. Rokhlin. "Ultrasonic spectroscopy of imperfect    contact interfaces between a layer and two solids". J. Acoust. Soc. Am. 103 (2), February  1998.

[4]     K. Heller, L.J. Jacobs, J. Qu. "Characterization of adhesive bond properties using Lamb waves". NDT&E International, Vol. 33, 2000, pp555-563.

[5]     H. Franklin, M. Rousseau, Ph Gatignol. « Influence des conditions de collage sur l'existence d'ondes d'interface entre deux solides élastiques. » Acustica, Vol. 80 (1994), pp 147-155.

[6]     J. Reberol. «Modèles d'adhésion pour le contrôle non destructif ultrasonore de certains assemblages collés. », Thesis, University of Paris 6 (1997).

[7]     Royer D. "Génération et détection optiques d'ondes élastiques". Technique de l'ingénieur, traité d'électronique. Edition périodique E 4415.

[8]     L. Martinez, "Nouvelles méthodes d'identification d'ondes de surface. Etude de l'onde A sur une cible courbe."Thesis, University of Le Havre (1998).