PROPAGATION OF LAMB WAVES ON ROUGH PLATES : ANALYSIS OF THE BEAM SECTION

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ABSTRACT. This work is a study of Lamb waves propagating on one-side rough plates : it deals with the analysis of the energy repartition in the perpendicular direction of propagation. An experimental work is performed involving an optical interferometer (YAG laser). The energy repartition is the result of the transducer diffraction and the roughness diffusion. The roughness diffusion manifests itself first as an increase of the beam spreading and in a second time, depending to the distance of propagation, as an apparent focusing.

INTRODUCTION

This work deals with the propagation of Lamb waves on one-side rough plates. The goal of this work is the nondestructive study of the bonding between plates. The bonded surface has to be prepared : in many cases, the surface is roughed in order to increase the quality of bonding. Previous studies [1] have shown that the phase velocity of Lamb waves is not significantly modified. On the contrary, their attenuation increases strongly with the root mean square value (RMS) of height deviations usually called R_q. This fact was shown by D.E. Chimenti and O.I. Lobkis [2-4] and C. Potel *et al* [5,6]. Our first experimental results are in the same order as the theoretical ones. However significant differences are observed for some Lamb modes. Hypotheses are put forward to explain the differences between theoretical and experimental results. The theoretical computation does not take into account the coupling between the air and the plate but this is negligeable and does not justify the differences between theory and experimence.

The limited size of the emitter transducer is not theoretically considered nevertheless in the experiments the ultrasonic beam is spreading during the propagation. This well known diffraction phenomenon leads to apparent attenuation of the wave amplitudes as $1/\sqrt{x}$ along the x propagation direction. The aim of this study is an experimental analysis of the wave spreading and the influence of the roughness of the plate.

Description of the Samples

The studied samples are glass plates with 200 mm sides and a thickness d = 5 mm. The measured parameters are the glass density : 2490 kg m⁻³, the shear and longitudinal velocities : $c_T = 3485$ m s⁻¹ and $c_L = 5825$ m s⁻¹. These plates are treated just on one side in order to obtain a rough surface except one meant as a reference plate. Two quite different techniques are used to create surface roughness: sanding and shot blasting. We can observe the studied surface topography using an optical surface profiler. The roughness is characterized by the usual statistic parameter R_q [7] which is the root mean square (RMS) value of the height deviations. For the non treated sample, R_q is inferior to 0.01 µm. For the sanded sample, R_q is equal to 6.0 µm, for the shot blasted 29.8 µm and for the strong shot blasted 67.4 µm.

Evaluation of the Beam Section : Experimental Set-Up

The experimental set-up is reported in figure 1. A generator delivers a burst of 50 cycles (amplitude : 10 V and central frequency : 1.7 MHz) to an emitting piezo-composite transducer. Lamb waves are generated by the wedge method. The receiver is a YAG laser which detects the normal displacements of the plate. This optical detection avoids problem of coupling between the receiver transducer and the plate. The emitting transducer and the laser are set on the non-rough side. The emitter transducer remains unmoved whereas the laser allows scanning in the two directions x (propagation direction) and y (perpendicular to the direction of the propagation).

The amplitude displacements are acquired at a given x position. Origin x = 0 corresponds to the wedge position. The laser scans from y = 0 mm to 80 mm by 0.1 mm step, y = 40 mm corresponds to the principal axis of propagation. For each position of the laser, a 100 µs long signal is acquired on 5000 points. An average of 350 successive shots is performed in order to improve the signal to noise ratio. An example of signals acquired on a non-treated plate at x = 20 mm is given in figure 2. This figure gives us an image of the repartition of the amplitude displacements at a given x position. When the front wave can be considered as quasi plane, it is convenient to define a characteristic width of the beam in order to make a quantitative evaluation of the spreading of the wave.



FIGURE 1. Experimental set-up.



FIGURE 2. a) Temporal signal for non treated sample – perpendicular scan at x = 20 mm,b) Temporal signal at y = 40 mm.

Energy Distribution in the Front Wave

Signal Processing

For a given y position, amplitudes of the temporal signal (figure 2.b) are squared and summed over all times. A low pass filter is used to eliminate the high-frequencies measurement noise. For the four different samples, we report on the same graph the results for x = 20, 40, 60 and 70 mm (figure 3a, 3b, 3c and 3d). These curves also represent the evolution of the mean energy along the y axis. All the curves are normalized to have a maximum energy equal to unity.

Interpretation

We note, for the non treated and sanded samples, a widening of the beam with increasing distance of propagation. The side lobes of diffraction are more and more visible when the distance to the emitter increases. In the following the side lobes are not taken into account for the width beam evaluation. We only consider the part of main lobe when energy is higher than 0.5. For the non-treated, the sanded and the shot blasted samples, the energy distribution of the main lobe approximately follows a gaussian distribution. Moreover, for the shot blasted samples, the roughness is such important that the wave front is splitted and transverse energy repartition loses the Gaussian envelope.

Evaluation of the Beam Width

Definition

In order to quantify the energetic spreading, it is convenient to introduce a variable called L_y which is the width of a Gaussian distribution. It is define as :



FIGURE 3a. Energy distribution in the perpendicular direction of propagation for non treated sample.



FIGURE 3b. Energy distribution in the perpendicular direction of propagation for sanded sample.





FIGURE 3d. Energy distribution in the perpendicular direction of propagation for strong shot blasted sample.

$$L_{y} = \sqrt{\frac{\sum_{i=1}^{N} (y_{i} - \overline{y})^{2} \cdot E(y_{i})}{\sum_{i=1}^{N} E(y_{i})}}$$

with $E(y_{i}) = |A(y_{i})|^{2}$ and $\overline{y} = \frac{\sum_{i=1}^{N} y_{i} \cdot E(y_{i})}{\sum_{i=1}^{N} E(y_{i})}$

 $E(y_i)$ is, for a position $y = y_i$, the modulus of the amplitude square (proportionnal to an energy). \overline{y} is the position of the energetic centre of gravity. The width L_y is calculated from the energy distribution of the three samples of smalest R_q (<30µm). Indeed in these cases the energy distribution (3.a to 3.c) can be well fitted by a Gaussian envelope. For the strong shot blasted, the roughness is such important that wave are scattered in all directions. There is a considerable spreading of the beam. The coefficient of correlation between the energy distribution and a gaussian envelope is less than 0.80 so the L_y width has no physical meaning in this case.

Results

For each sample the width Ly is plotted versus x (figure 4 and 5). In figure 4, the width L_y of the beam is plotted versus the distance of propagation x of the Lamb waves. The width of the beam in the case of the non-treated sample is in constant increase because of the transducer diffraction effect. On the contrary, for the sanded sample, after a monotone growth until x=5cm the width L_y decreases. Referring to the figure 3a and 3b, the energy transverse distribution of the wave has a gaussian envelope (correlation coefficient higher than 0.96 between the gaussian envelope and the experimental energy distribution). We can give an interpretation of this phenomenon: in a first time the width of the beam increases because of the roughness diffusion. In the second time, only the part of the wave propagating along the x axis is coherent (in the main direction of propagation) and the localisation of the energy seems to be "focused" along this direction. For the sanded plate, in the case of small values of x, the width L_y are greater than those of non-treated plate because two additive effects occur : transducer diffraction effect and roughness diffusion.



FIGURE 4. Beamwidth of a Lamb wave versus the distance of propagation : (-) non-treated plate and (o) sanded plate.



FIGURE 5. Beamwidth of a Lamb wave versus the distance of propagation : (-) non-treated plate and (Δ) shot blasted plate.

In figure 5, the beamwidth of the wave propagating on the shot blasted plate follows the evolution of the non-treated one. The apparent "focusing" observed at x = 5 cm for the sanded plate is present from x = 2 cm in the case of the shot blasted plate. For this sample the spreading induced by the roughness diffusion is counterbalanced by the "focus" effect due to the roughness diffusion.

CONCLUSION

Previous papers have shown that Lamb waves can propagates on rough plates. The effect of the roughness acts mainly on the attenuation of the Lamb waves. Here we are interested in the energy distribution of the guided waves on the plate. For the non-treated plate the beam width of the Lamb waves can be fitted by a Gaussian distribution ; its width continuously increases during the propagation. For samples with small values of R_q the beam section can be also fitted by a Gaussian profile. In these cases, for a short distance of propagation, the width increases fastly than in the case of non-treated plates, because of the roughness diffusion. Nevertheless the beamwidth decreases for a larger distance of propagation : a apparent focalisation effect occurs. For larger values of R_q the effect of the diffusion is dominant and the structure of the beam section is very altered.

Future works will take into account the 2D character of the propagation of Lamb waves on rough plates.

ACKNOWLEDGEMENTS

This work is supported by the research group of ultrasonics (GDR CNRS $n^{\circ} 2501$) : we thank the director M. Deschamps. And many thanks to the secretary B. Desoudin for the travel organization.

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