DISPERSIVE ULTRASONIC WAVES IN ADHESIVE BONDS

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INTRODUCTION

The verification of the adhesive bonds is one of the major problems in many fields. Different methods were suggested to check the quality of the bonds between a layer and a layer or a substrate. Most of these techniques are based on a spectral analysis of the acoustical signal reflected at normal incidence [1-5]. In this paper we focalize our attention on the analysis of the phase velocity dispersion curves characterizing the different samples and we suggest the use of these curves for checking the quality of the bonds.

EXPERIMENTAL METHOD

According to the investigated samples, various methods can be used to measure the phase velocity dispersion curves of the generalized leaky guided waves. The classical critical angle and spectral analysis techniques were used for measurements on bi-metallic samples showing interrogating plane interfaces. The critical angle technique consists on pointing out the angles of incidence (θ_c) for which a minimum exists in the amplitude distribution of the specularly reflected signal at a given frequency. The transmitter and the receiver are then immersed in a fluid (water) in which the sample is also located. The phase velocity V_p is then related to θ_c by the well known relationship sin $\sin\theta_c = V_{water}/V_p$ where V_{water} is the velocity of the acoustic wave in water. For a given angle, the spectral analysis of the reflected signal gives also information: the maxima recorded in the frequency spectra indicate the resonance frequencies for which an interface wave is generated. Both these techniques are applied whatever is the type of samples. In case of thin samples, transmission measurements are also possible and the previous experimental methods (angular and frequential analysis) can be used. Typical records are given in Fig. 1.

Two kinds of bi-metallic samples were investigated depending on the nature of the contact of the layer with the support: perfect contact or bonded contact with another layer or a substrate. We shall distinguish the welded samples (ES) formed with a tin layer (or a plate) and a brass support which is either a plate (ES_{pp}) or a substrate (ES_{ps}). The lower indexes "p" and "s" mean respectively "plate" and "substrate". In case of bonded layered samples (EC) the same conventions are used giving arise to the EC_{pp} and EC_{ps} samples (See Fig. 2).

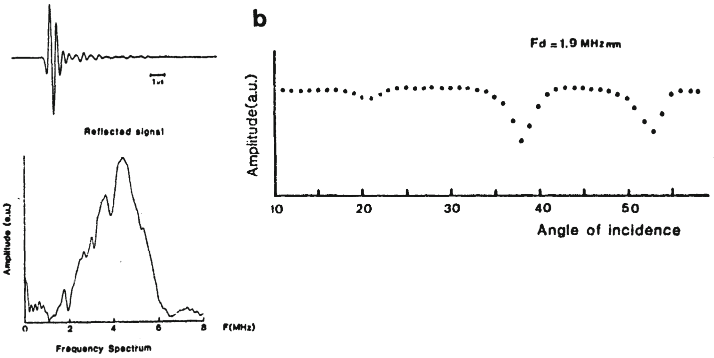

Fig. 1. Typical results observed for a EC^{bd}_{ps} sample: a) Spectral analysis, b) Critical angle method.

EXPERIMENTAL RESULTS

The experimental phase velocity dispersion curves which are reported in this section deal with various samples whose geometrical characteristics are given in Table 1. In the following we study successively the adhesive bonded and the welded samples and we represent the variations of the angle of incidence versus the product Fd (F is the frequency and d is the thickness of the layer submitted to the acoustical insonification).

Adhesive Bonded Samples (EC_{ps} and EC_{pp})

In this subsection, we analyze the influence of the adhesive layer on the phase velocity dispersion curves. The results are concerned with samples including two bonded media where one of the two is a brass plate and the other is either a duraluminum EC^{bd}_{pp} or a brass plate EC^{bb}_{pp} or a duraluminum semi-infinite half-space EC^{bd}_{ps}.

Case of the EC_{ps} Sample

Three kinds of adhesive were used for bonding the two metallic pieces. The dispersion curves represented in Fig. 3 are obtained by

Table 1. Geometrical characteristics of the investigated samples.

Sample	Characteristics of the layer.	Characteristics of the layer or of the substrate.	Nature of the contact between the two media.
EC^{bd}_{ps}	Brass(d=1.7mm)	Dural.(d'=25mm)	Bonded with : Salol(e=50 and 200μm) Epoxy(e=50μm) Glue(e=50,100,200μm) Tin(e=140μm)
$EC^{bd}_{pp}=EC^{db}_{pp}$	Brass(d_1=.81mm)	Dural.(d_2=1mm)	Bonded with glue (e=160μm).
EC^{bb}_{pp}	Brass(d_1=.81mm)	Brass(d_2=.5mm)	Bonded with araldite epoxy(e=140μm).
ES^{tb}_{ps}	Tin(d_1=1,.38, and .22mm)	Brass(d_2=25mm)	Welded
$ES^{tb}_{pp}=ES^{bt}_{pp}$	Tin(d=1.02mm)	Brass(d'=.99mm)	Welded

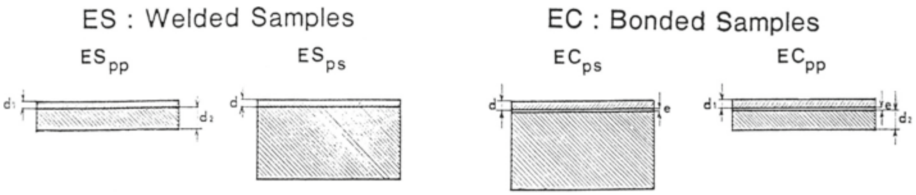

Fig. 2. Schematic diagrams of the investigated samples.

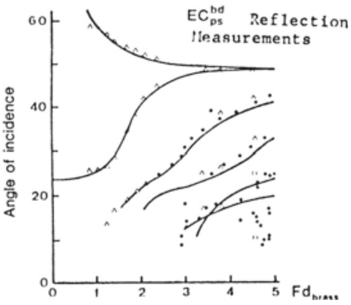

Fig. 3. Dispersion curves obtained by reflection measurements for EC^{bd}_{ps} sample (d=1.7 mm and e=.22 mm, glue).

reflection measurements; the adhesion is insured by a thin layer of glue (e=.22 mm) which is usually used for coupling of shear contact transducer. We note that with this adhesive, the experimental data (Δ,●) agree very well with the theoretical calculations achieved for a free brass plate whose the thickness (d=1.7 mm) is the same that the one of the bonded plate. In Fig. 4 we compare the results obtained in the same experimental conditions but with different adhesive (*, epoxy; Δ, glue; ● salol); we observe exactly the same behavior for the two first modes A_0 and S_0. A similar agreement is observed for the higher modes. The influence of the thickness of the adhesive was checked on one of these; the glue Sofranel. The results are given in Fig. 5. We do not observe any significant variation as the thickness varies.

Case of the EC_{pp} Samples

In this configuration, either reflection or transmission measurements are possible and the first medium encountered by the incident acoustic beam can be removed from one side to the other. The experimental data obtained by reflection measurements are plotted in Figs. 6 which represent different dispersion curves following the nature of the first insonified plate: brass (Fig. 6a), duraluminum (Fig. 6b). The bonding layer of .16 mm thickness is in araldite epoxy. We observe again that these plots are identical to those calculated for a free plate of the same material.

The transmission measurements (Fig. 7) reveal curves which represent the dispersion curves associated with the two metallic media independently. Recall that, in this case only, the variations of the angle of incidence versus the frequency are plotted. Mention also that these results are the same if we reverse the positions of the transmitter and of the receiver.

Similar observations are done with bi-metallic samples with two bonded plates of the same material. The result is illustrated in Fig. 8 in which are plotted the experimental variations of the critical angles of incidence obtained as Fd_i varies (d_i is the thickness of the first brass plate which is insonified).

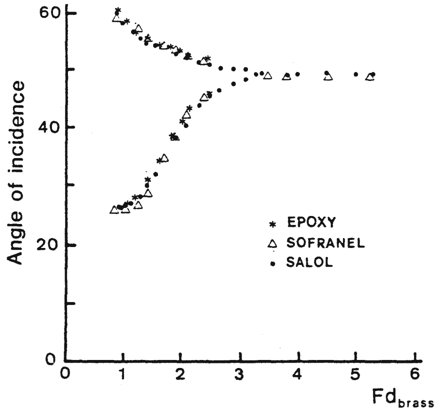

Fig. 4. A_0 and S_0 modes of EC_{ps}^{bd} sample for different adhesive layers (Reflection measurement, e=.22 mm and d=1.7 mm).

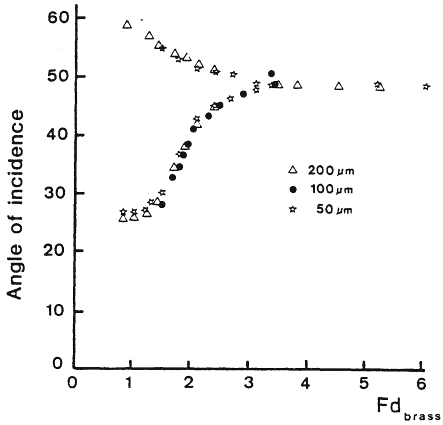

Fig. 5. A_0 and S_0 modes of EC_{ps}^{bd} sample for different thickness of the glued layer (Reflection measurements, and d=1.7 mm).

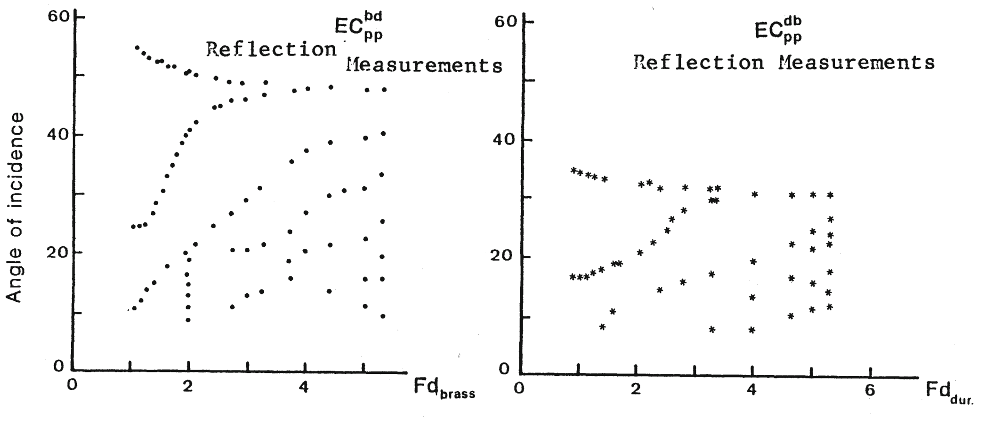

Fig. 6. Dispersion curves obtained by reflection measurements. The first insonified medium changes: a) brass, b) duraluminum.

Table 2. Acoustical properties of the materials.

	C_l	C_t	ρ
Brass	4480	2156	8.1
Duraluminum	6286	3278	2.8
Glue(Sofranel)	2110	--	1.9
Araldite-Epoxy	2560	1070	1.2
Tin	2930	1300	8.5
Salol	2120	?	1.28

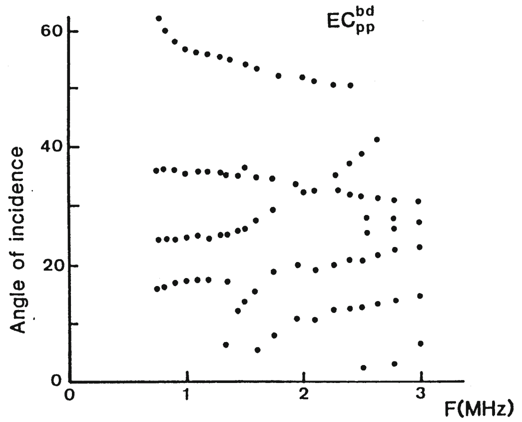

Fig. 7. Phase velocity dispersion curves obtained by transmission measurements.

From this first part we conclude that, for the adhesive bondings which we used, the reflection measurements achieved on bi-metallic samples point out phase velocity dispersion curves corresponding to the first encountered plate as if it was free (or isolated). No influence of the back media is discernible. The transmission data when they are possible, show two series of dispersion curves corresponding to the two initial plates considered as free and no bonded.

One possible explanation of this result has to be found in the acoustical properties of the adhesive which present a low acoustic impedance in comparison with those of the metallic media (See Table 2). From this observation, it is possible to conclude that the transmission coefficient at the plate-bonding interface is low and the transmitted energy is insufficient to generate a detectable perturbation of the eigen-modes of the plate which behaves as a "free" plate. This qualitative interpretation appears to be coherent with the results plotted in Fig. 9. The investigated sample includes two brass plates bonded with a tin layer. With this geometrical arrangement, it is shown that the phase velocity dispersion curves agree with the theoretical plots calculated for a bi-metallic sample considered as a unique free plate whose the equivalent thickness is the sum of the thickness of the two plates. Note that for this particular adhesive medium (tin) the acoustic impedance is very close to the bonded plates and the transmission coefficient at the interface between brass and tin is high. We mention also that the transmission measurements agree with the data obtained by reflection technique and so confirm the hypothesis previously suggested.

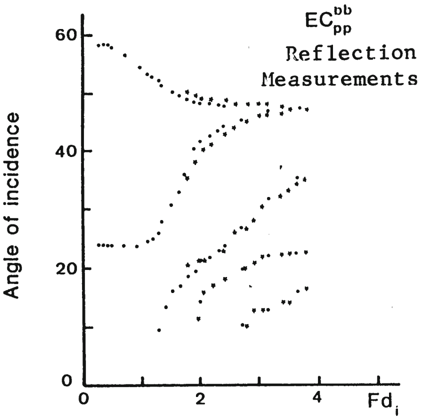

Fig. 8. Phase velocity dispersion curves obtained by reflection measurement in case of two glued brass plates (e=.14 mm, ● incidence on .5 mm plate, * incidence on .8 mm plate).

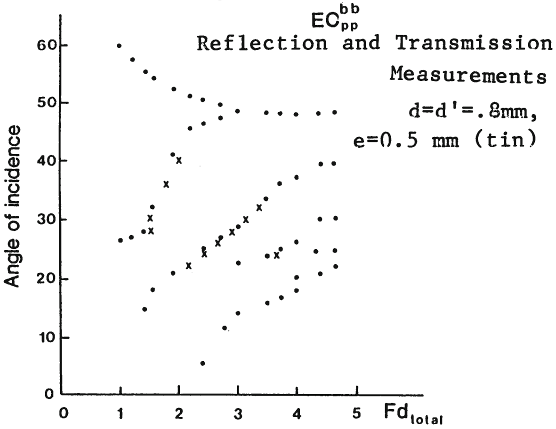

Fig. 9. Phase velocity dispersion curves obtained with a sample formed with two brass plate (● angular reflection measurements and x spectral transmission measurements).

Welded Samples (ES)

Two welded samples were investigated: one consists of two welded plates (ES_{pp}) and the other is made by a plate welded to a substrate (ES_{ps}). Tin and brass were chosen for these samples. The choice of these substrates was suggested by the fact that tin liquifies at low temperatures and adheres relatively well to the materials of copper (the geometrical description of these samples is given in Table 1). The same experimental techniques were used for measuring the dispersion curves versus the product Fd_{tin} (where d_{tin} is the thickness of the tin layer).

Study of the ES^{tb}_{ps} Sample

In Fig. 10 are plotted the angular dispersion curves of the investigated sample. These plots are similar to those previously published [6-8] and agree with the theoretical predictions in case of two materials whose shear velocities are different and verify the inequality $\hat{V}_t < V_t$ where $\hat{V}_t$ is the shear velocity in the layer and V_t the shear velocity in the substrate [9]. The experimental curves point out different modes: the pseudo-Rayleigh mode which leaks back into the liquid and the pseudo-Sezawa mode whose one of its properties is to leak back into the substrate; the additional modes are designated by M_3 and M_4.

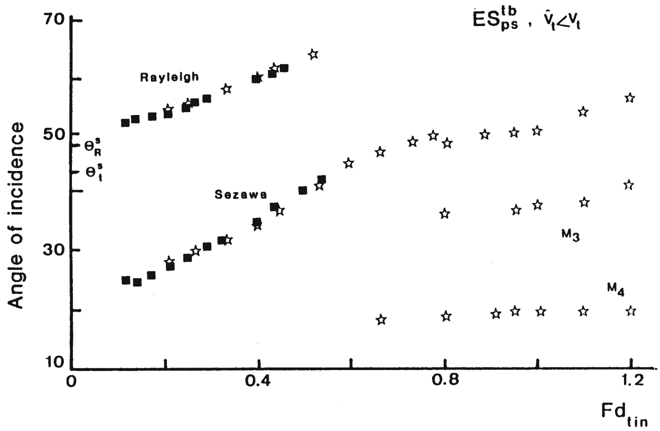

Fig. 10. Angular dispersion curves obtained for a tin layer-brass substrate welded altogether.

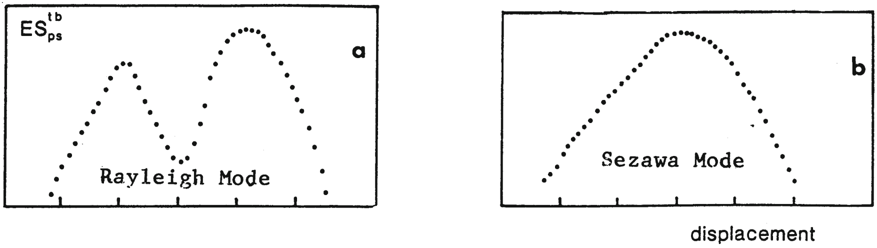

Fig. 11. Linear profiles observed in case of a pseudo-Rayleigh mode a) and in case of a pseudo-Sezawa mode b).

The leaking character of the two first modes is illustrated in Fig. 11 where are plotted the linear profiles recorded for different angles of incidence corresponding to different modes at a given frequency. The nonspecular effect is visible on the profile obtained at $\theta_i = 58°$ which corresponds to the Rayleigh mode. In case of the pseudo-Sezawa mode (Fig. 11b) the reflected beam profile is very similar to the one obtained out of mode, justifying the fact that no energy leaks back into the surrounding fluid medium but into the substrate.

Study of the ES^{tb}_{pp} Sample

The measurements observed with a tin layer welded on a brass infinite substrate are reported in Fig. 12. Both reflection and transmission data agree and the results do not depend on the medium of incidence. In this case, the dispersion curves themselves are not comparable with those obtained for a tin or a brass free plate alone. The bi-metallic system is equivalent to a new plate whose eigen-modes are different from those characterizing the media which form the sample.

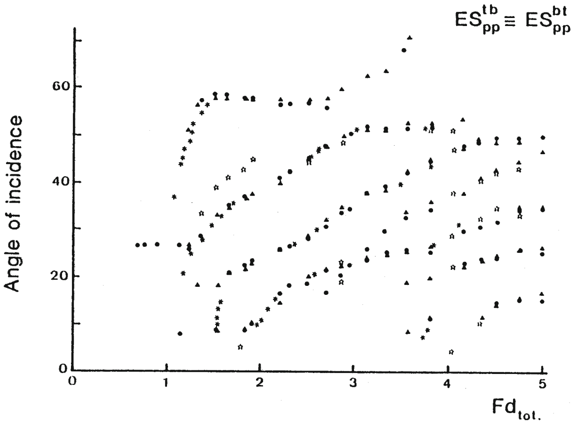

Fig. 12. Phase velocity dispersion curves observed for a tin layer welded on a brass plate. ●, * reflection measurements, incidence on brass plate, △ reflection measurements, incidence on tin plate, * transmission measurements.

CONCLUSIONS

The experimental investigation reveals the complexity of the response of a bonded layer to its interaction with a bounded acoustic beam and each sample has to be considered as unique. The acoustical properties (velocity, density) of each medium are very important for the interpretation of the results. These qualitative results show mostly that we have to be careful in the conclusive information that we can deduce from the curves. Most of the experimental plots are not predicted by the available theory which should take into account the absorption and the attenuation in the different media to obtain a better agreement between theoretical and experimental data.

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REFERENCES

1. G. A. Alers, P. Y. Flynn and M. J. Buckley, Mat. Eval. 77-84 (April 77).
2. J. C. Couchman, F. H. Chang, B. G. W. Yee and J. R. Bell, IEEE Trans. on Sonics and Ultra. SU-25, 5-293-300 (1978).
3. C. C. H. Guyott, P. Cauley and R. D. Adams, Journal of Adhesion, Vol. 20, 129-159 (1986).
4. G. Biggiero, G. Canella and A. Moschini, NDT Inter. April 83 (pp. 67-73).
5. A. Pilarski, Mat. Eval., 43, pp. 765-770 (1985).
6. A. H. Nayfeh and D. E. Chimenti, J. Acoust. Soc. Am., 75, 1360-1368 (1984).
7. M. Hattunen and M. Luukkala, Appl. Phys. 2, 257-263 (1973).
8. M. Luukkala and M. Hattunen, Appl. Phys. Letters 19, 56-57 (1971).
9. G. W. Farnell and E. L. Adler, Physical Acoustics Vol. IX, Academic Press, New York (1972), Chap. 2.