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ULTRASONIC INSPECTION OF IMPACT INDUCED DAMAGE IN POLYMERIC COMPOSITE MATERIALS

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1. INTRODUCTION

Despite the well known advantages in weight reduction and corrosion strength, the use of polymeric composite materials in structural and dynamic aeronautical parts introduces some new problems. One of the most important is their impact susceptibility mainly for thin solid laminates and sandwich structures.
In fact, in these configurations, an impact can generate an internal damage that reduces both static and dynamic mechanical characteristics even if the damage is not visible from the surface.

In order to obtain predictions for mechanical strength reduction, the first step is the knowledge of the extent of material damage after impact, which must be evaluated in a nondestructive way.

At the same time, selection of composites must take into account their impact behaviour and qualification must show, by adequate complementary mechanical testing, that their impact resistance is acceptable.

The subject of this paper is the presentation of nondestructive ultrasonic methods of inspection which have been developed by AGUSTA in collaboration with the NDE laboratory of the JRC Ispra. These methods were applied on graphite-epoxy composites in laminate and sandwiches.

This work was performed within the framework of BRITE EURAM research program (contract n.BREU 0085C(A) - DeSiR).Three helicopter manufacturers (AGUSTA Italy, EUROCOPTER Germany and WESTLAND England) and two Research Institutes (CIRA Italy and RISØ Denmark) are involved.

Aim of this research program is the evaluation of the effects that damage and defects have on the mechanical behaviour of composite aeronautical parts and the possibility to repair damaged structures; of course the Non Destructive Evaluation activities play a determining role in this context.

The experimental results presented in this paper were obtained on the following materials:

- Solid laminates: obtained from 17 plies of prepreg (985-GT6-135/Cyanamid) with a quasi-isotopic lay up.

- Sandwich: two plies of prepreg (985-GF3-5H-1000/ Cyanamid) for each skin and 15 mm of Nomex Honeycomb with a cell of 3 mm.

The damage induced ranges from a barely visible impact up to the scrap of the structure.

2. TECHNIQUES OF INSPECTION

The main problem to be solved was to get, for each specimen previously damaged by impact, an image defining the real boundaries of the damaged area with the highest possible resolution.

An inspection based upon the immersion ultrasonic technique was judged to be the most suitable for this purpose; an image of the damage is obtained by scanning automatically the specimen with an ultrasonic beam while acquiring either the variation of attenuation through the thickness or the time of flight of the pulse reflected by defective areas.

Figure 1 shows the ultrasonic system used for the study. The computer drives the step motors for a scanning of 64x64 points or for a multiple of this matrix.

During the scanning a C-SCAN image is built in which the colours indicate the variations of the attenuation for both of the two materials or the variations of the time of flight for the specific case of the solid laminate.

For the industrial application, an automatic equipment based upon a conputerized system for data acquisition and processing, with a full dynamic range of 60 dB and with a scanning system which assures an accuracy of 0.1 mm was used.

When an impact causes visible damage on the sample (on a single side or on both), with a consequent breakage of the surface it is necessary to make the specimen water tight by using a thin adhesive film before the ultrasonic inspection in order to prevent water penetration into the damaged area, which reduces the sensitivity.

First we have to determine the resolution with which the real boundaries of the damaged area should be defined.

For sandwich specimens this limit must be lower than 3 mm because the honeycomb cell is just 3 mm large; in fact the ultrasonic wave can pass through the specimens via the honeycomb walls which act as wave guides while it is completely reflected at the center of every cell.

For solid laminates a resolution of 1 mm was judged to be sufficient for our purposes.

When only the surface of the impact side is lightly marked (low impact energy), the attenuation is relatively strong in the annular part around a small undamaged area at the center of the impact. In this case, the C-SCAN image can be obtained by acquiring the amplitude of the signal transmitted through the thickness.

The resolution depends on the diameter of the ultrasonic beam. By using high frequency focusing transducers, we cannot increase the resolution because the composite material filters the high frequencies.

Therefore it is necessary to take into account the centered frequency of the filtered signal for an evaluation of the actual beam diameter.

Some preliminary measurements were performed to guide the choice of transducers to be used and the ultrasonic parameters to be acquired.

2.1 CASE OF THE SANDWICH STRUCTURE

The transmitted signal through a sandwich structure results strongly filtered and its spectrum is centered at about 1 MHz for an incident pulse generated by a broadband transducer with a nominal frequency of 5 MHz (see fig.2).

The solution consists in using a small hydrophone having a 0.6 mm piezoelectric element as receiver.

The resolution is improved to about 1 mm provided that the distance from the surface of the specimen is below 1 mm.

When the adhesive film is used to prevent water penetration, care must be kept to avoid air entrapping between the adhesive film and the surface of the specimen which can obstruct the ultrasonic beam path.

2.2 CASE OF THE SOLID LAMINATE

The diameter of the beam can be reduced to about 0.5 mm when using focusing transducers having a nominal frequency of 10 MHz, but, as reported in figure 3, the spectrum of the transmitted signal is centered at about 5 MHz and the focal diameter cannot be smaller than 1 mm (this is in compliance with the resolution requested).

As in the case of sandwich structure inspection, it is similarly possible for thin laminates to obtain an image of the variations of the attenuation in the ultrasonic signal transmitted through the specimen. However, the best results are obtained by measuring the time of flight of the signal reflected. This time correspond obviously to the depth at which the delaminations have occurred.

In this case, the inspection from the front wall of the spcimen will be carried out in pulse-echo mode and it is not important to have a perfect adhesion between the film and the back surface of the specimen where the impact creates the largest delaminations with breakage of the surface.

3. *RESULTS*

The high resolution level of the method used for the through transmission is shown in figure 4 which represents a zoomed area of an undamaged specimen; the correspondence between the grey scale and the signal intensity is also reported.

In this picture the fine discrete structure of the honeycomb is even revealed: double layer wall, single layer wall and center of the cell (as partially indicated in the C-SCAN image). In fact this structure allows the ultrasonic signal to reach the hydrophone receiver with three different intensity levels that on a C-SCAN correspond to three different grey levels.

With this inspection technique it is immediate to distinguish the border between an impact damaged area and the surrounding undamaged area. An example is shown in figure 5.

The corresponding results obtained from the pulse echo inspection of solid laminates are illustrated in figure 6 which represents a damaged area. In this picture the correspondence between the grey scale and the depth at which the delamination occurs is also given (the depth of a delamination is obtained by multiplying the time of flight of the echo from the delamination itself by the sound velocity in the material).

The advantage of this method is that the time of flight of the echo having the largest amplitude within the gate can be recorded. During the inspection of an undamaged area the time of flight of the back wall echo is acquired (thickness of the specimens); when the center of the ultrasonic beam is crossing the border of a delamination, the echo from the delamination itself will exceed the back wall echo.

Using a 5 MHz focusing probe and a scanning indexing of 1 mm, it is possible to give a position of the damage border with a precision equal to the resolution required.

4. CONCLUSIONS

The results obtained have shown that the inspection methods (both for sandwich and for solid laminates) allow to evaluate the impact damage with the requested definition and resolution.

These methods have been used to inspect all the planned specimens of the research program BRITE EURAM BRE-0085-C.

Moreover, these methods have been applied on real composite parts during the certification tests of the civil version of the AGUSTA-WESTLAND helicopter EH 101.

More in particular, time of flight measurement as described in this article has been used frequently for both immersion and contact inspections before, during and after static and dynamic tests.

In its actual configuration, the hydrophone technique can only be employed for laboratory activities.

However, its adadption for an industrial use should not create major difficulties.

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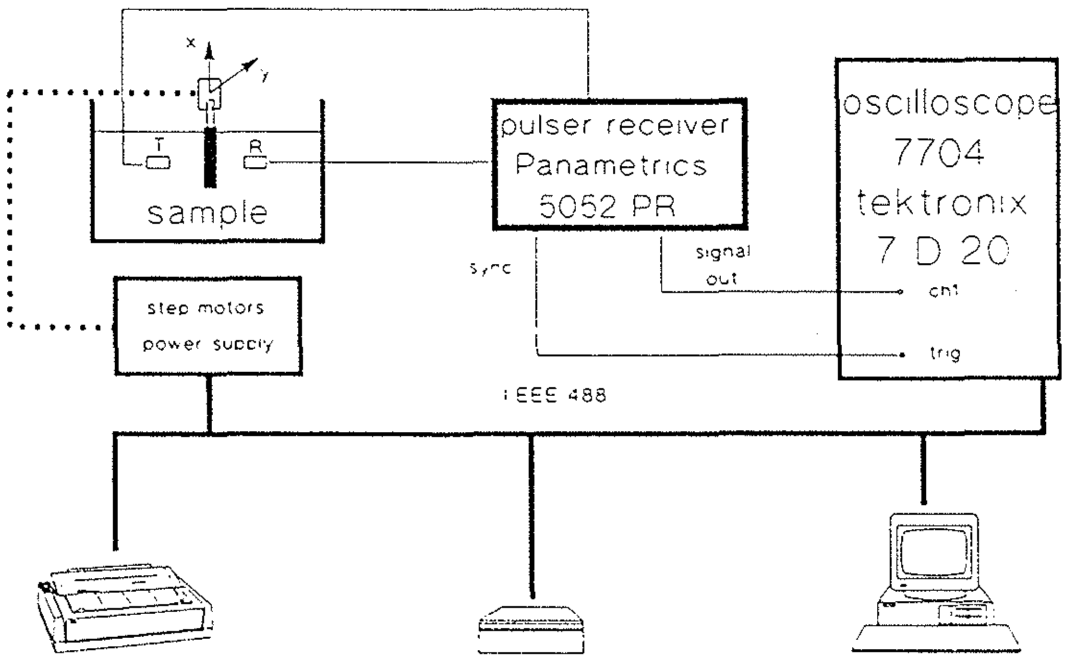


Figure 1: Scheme of the ultrasonic system for measurement

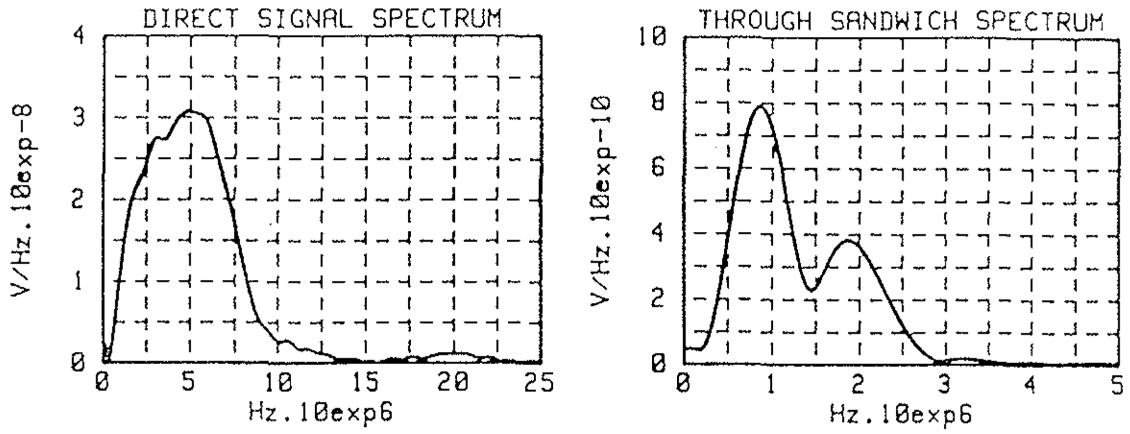


Figure 2: Attenuation measurements in the frequency domain with two transducers PANAMETRICS, 5 MHz.
A: Spectrum of the transmitted signal in water without specimen.
B: Spectrum of the transmitted signal in water through a sandwich specimen.

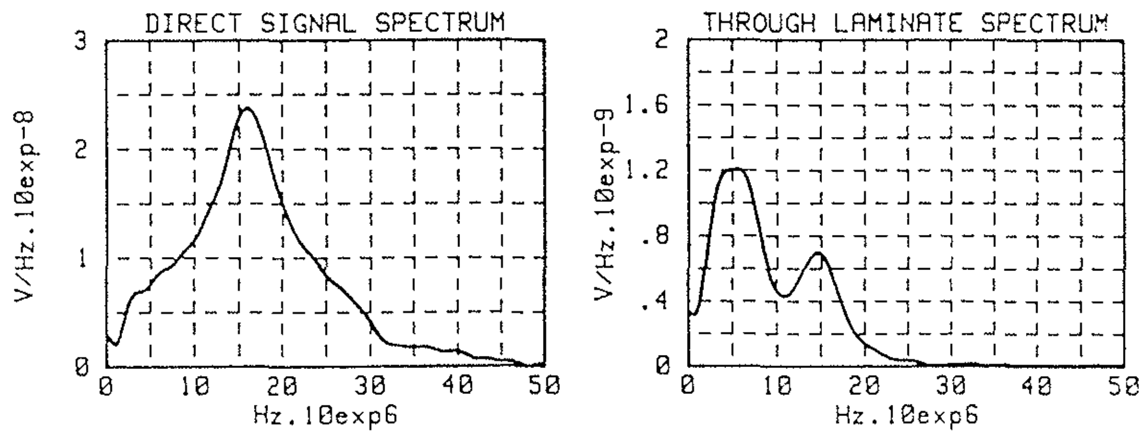


Figure 3: Attenuation measurements in the frequency domain with two transducers COGENT PVDF, 22 MHz.
A: Spectrum of the transmitted signal in water without specimen.
B: Spectrum of the transmitted signal in water through a solid laminate specimen.

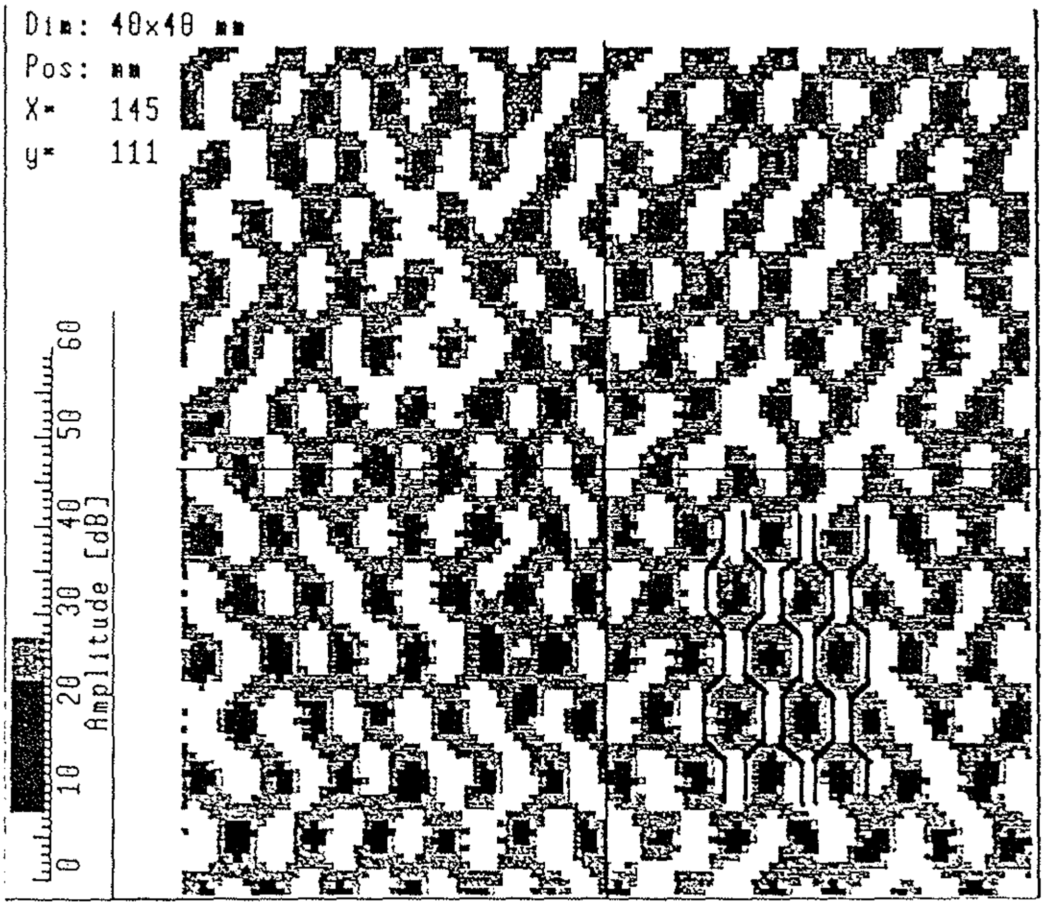


Figure 4

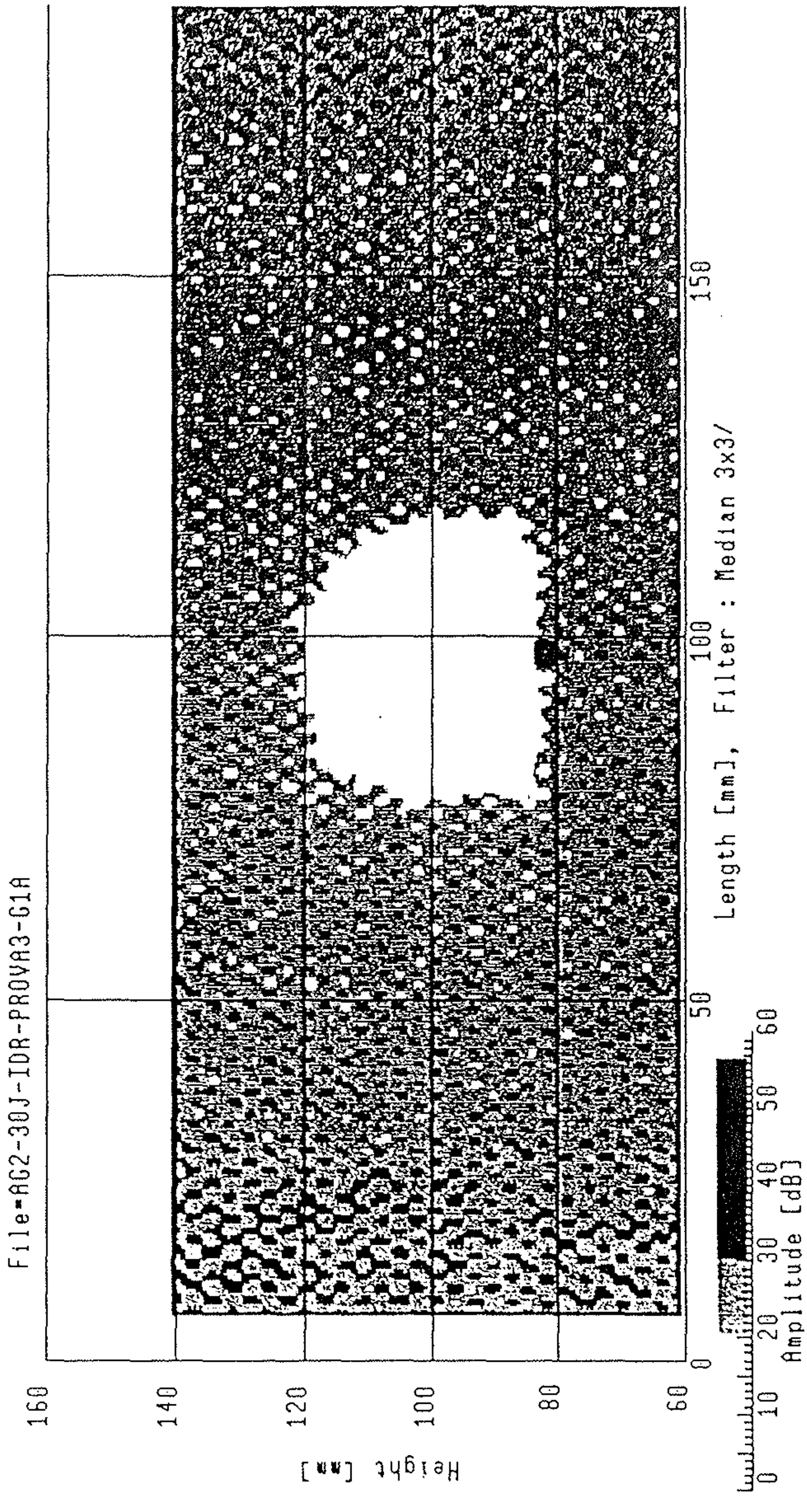
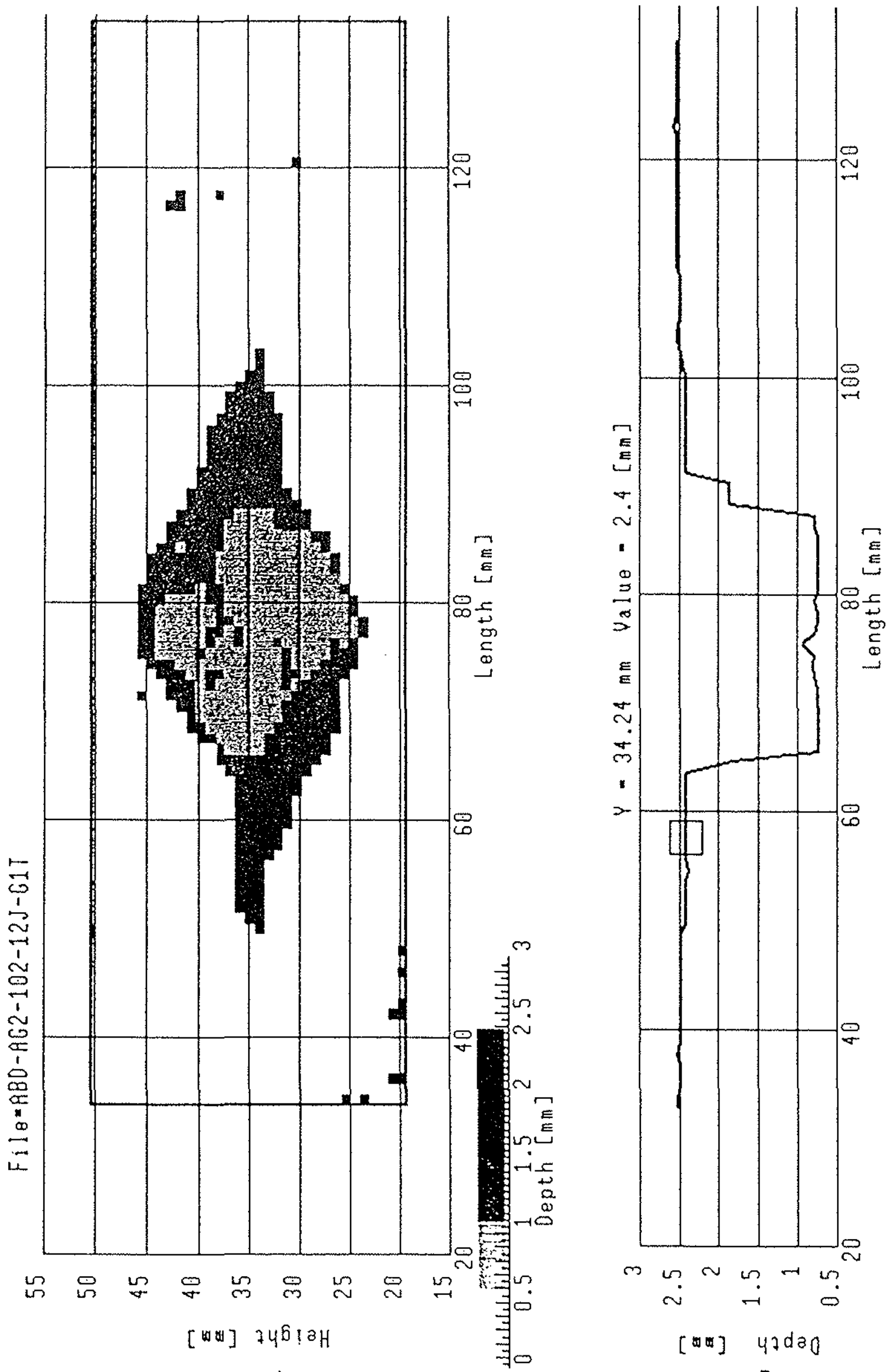


Figure 5: Amplitude C-scan of a sandwich specimen damaged by an impact of 30 Joules. The black little spot at the border of the damage corresponds to a cell filled with water.



A B

Figure 6 A: Depth (Time of flight) C-scan of a laminate specimen damaged by an impact of 12 Joules.
B: B-scan along the line Y = 34.24 of the same specimen. Thickness of undamaged area and delaminations depth are shown.