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FOCUSSED PROBES ULTRASONIC FOLLOW-UP OF ACTUAL FLAW GROWTH DURING FATIGUE TESTING

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SUIVI PAR TRADUCTEURS A ULTRASONS FOCALISES DE LA CROISSANCE DE DEFAUTS REELS LORS D'ESSAIS DE FATIGUE

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A B S T R A C T

In the framework of a more general study entitled "Probabilistic study of nuclear pressure vessel rupture", a programme was undertaken to follow-up the growth of actual flaws purposely introduced during the welding process of five test specimens.

The aim of this test programme is to measure the actual size of the cracks which develop from the known defects during the fatigue testing.

The sizing method is based on the use of focussed probes developed for several years in France, which allow good accuracy and repeatability, as well as good sensitivity.

Examples are given of the first results :

- sizing before testing, then step by step during the fatigue testing and also under compression.

This last point is very important in view of the ultrasonic testing during periodic in-service inspection.

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R E S U M E

Dans le cadre d'une étude plus générale intitulée "Etude Probabiliste de la rupture de cuves nucléaires", on a entrepris un programme pour le suivi de la croissance de défauts réels volontairement introduits au cours du processus de soudage de cinq éprouvettes.

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Le but de ce programme est de mesurer les dimensions réelles des fissures qui se développent à partir de défauts connus pendant les essais de fatigue.

La méthode de dimensionnement est basée sur l'utilisation de traducteurs focalisés, développés depuis de nombreuses années en France, qui permettent une bonne précision et une bonne reproductibilité, ainsi qu'une bonne sensibilité.

On donne des exemples des premiers résultats :

- dimensionnement avant essai, puis étape par étape au cours de l'essai de fatigue, et également en compression.

Ce dernier point est important dans l'optique du contrôle par ultrasons au cours des inspections en service périodiques.

I. INTRODUCTION

A non destructive testing programme has been undertaken in the frame work of a general probabilistic study of pressure vessel rupture, to determine the behaviour of welded test specimens containing purposely introduced defects. The follow-up of the crack growth initiated from the defects during fatigue testing was made by focussed ultrasonic transducers. This paper will describe the programme as well as the first results of the testing of two test specimens among the five provided for in the programme.

II. DESCRIPTION OF THE TEST SPECIMENS

Two plates 500 mm x 1000 mm x 85 mm, (A 533 class B steel) were welded together and five defects were purposely introduced at regular intervals during the welding process. A first examination of the welded plates was made to position the defect and allow for proper cutting of the test pieces. The five resulting test specimens were then machined to their final size 1020 mm x 96 mm, x 80 mm.

Table I lists the type of intended defect for each test specimen.

Test Specimen	Type of defect
1/5	porosities
2/5	lack of fusion
3/5	slag inclusion
4/5	lack of fusion
5/5	crack

Table I : Types of intended defects.

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III - EVALUATION OF THE INITIAL DEFECT SIZES

This evaluation was made four times :

a) in the shop just after completion of the test specimen, using standard procedure and manual probes.

b) In the shop using immersion testing and focussed probes.

c) In the CEA Laboratory using also immersion testing and focussed probes.

d) Finally in the Laboratory of the "Service Technique des Constructions et Armes Navales" using both contact and immersion focussed probes.

After comparison of all the resulting C-Scans ,only the immersion focussed probes technique was choosen for the final evaluation (contact focussed probes technique suffers from lack of fidelity).

Six directions of testing were used to evaluate the introduced defects :

- 1. Normal incidence, longitudinal waves, on both sides.
- 2. 45° incidence, shear waves, on both sides according to fig.1

The sizing method associated with the use of focussed probes is described in reference (1). It makes it possible to size individually (if necessary) each part of a given defect. Moreover, the area of the defect was defined as the area of the rectangle circumscribed around the image of the defect.

Fig. 2 shows typical C-Scans obtained just before the beginning of the fatigue testing for test specimens 3/5 and 4/5.

Fig. 3 shows the fatigue machine equipped with the immersion tank on one side of the test specimen, and with one transducer.

Table 2 gives the main characteristics of the probes used.

	Longitudinal waves	Shear waves 45°
Frequency	4 MHz	4 MHz
Crystal diameter	30 mm	30 mm
Focal length (in water)	260 mm	260 mm
Length of the focal zone	> 20 mm	> 30 mm
diameter of the focal zone	3 mm	3,5 mm

Table 2 - Transducers characteristics

IV - EVALUATION OF DEFECT GROWTH

C-Scans were made during the fatigue testing according to the same process as that described previously, and at given time intervals. In addition, it was decided to perform on the test specimen 4/5 the same measurements under traction and under compression to evaluate the influence of the stress field under the flaw size determination accuracy.

4.1. Test specimen n° 3/5

The fatigue cycle had the following characteristics :

- Frequency 2 Hz
- Amplitude : either 130 to 1300 kN or 250 to 2500 kN and finally 300 to 3000 kN.

Ultrasonic C-Scans were made at 85 000, 90 000, 95 000, 100 000 and 107 500 cycles (the test specimen broke at 109 514 cycles) using the directions L_1 , T_1 , T_1 bis, according to fig.1.

Fig.4 shows typical results on C-Scans at 107 500 cycles just before rupture. Fig.5 shows one side of the ruptured test specimen 3/5.

As the defect growth was almost perpendicular to the surface of the test specimen, the C-Scans obtained at 45° shear waves give a relatively good representation of the actual crack size.

Taking into account the surface geometry of the developped crack, the correlation appears to be sufficient.

According to the sizing method of the C.E.A., several records were made at different gain settings.

Fig.6 shows the evolution of the crack area versus the number of cycles.

4.2. Test specimen n° 4/5

The same process was used for this second test specimen. The range of the applied load varied between 150 to 1500 kN and 200 to 2000 kN with the same frequency (2 Hz).

C-Scan records were made at 0 kN, + 1000 kN, - 1000 kN using the same testing directions (L_1, T_1, T_1bis).

Fig.7 shows typical C-Scans obtained at 175 530 cycles (i.e.just before rupture).

The rupture of the specimen 4/5 was achieved by cooling the piece at minus 100°C with liquid nitrogen, under a traction load value of 1980 kN. In order to identify the crack boundary at 100 000 cycles, 10 000 cycles were made from the 97 000th cycle by varying the load between 1000 to 1500 kN.

Fig.8 shows the evolution of the crack area versus the number of cycles.

Fig.9 is an example of the C-Scans obtained after 175 530 cycles,the test specimen being stressed by a load value of + 1000 kN and - 1000 kN. The influence of the compressive stress is clearly shown.

Fig.10 shows the surface of the fatigue crack after rupture. In this case it exhibits a quasi circular shape.

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V. ANALYSIS OF THE RESULTS

The consideration of the above results shows that the ultrasonic testing used during this experiment is particularly well suited to the determination of the size of the fatigue crack. Fig. 11.1 shows the superimposed boundaries taken from fig. 4 (T_1 and T_1bis) and from fig. 5 relating to the test specimen 3/5.

This figure shows the rather good correlation between the actual size of the crack and its ultrasonically recorded patterns. It may be pointed out that the reconstruction of the actual shape is incomplete due to :

- 1/ - possible variation of reflectivity of the crack surface

- 2/ - Surface geometry of the crack. It is obvious on fig. 5 that half of the crack exhibits very deep undulations as well as strong deviation from plane.

Fig. 11.2. shows the same results for test specimen 4/5. The correlation in this case is much more better.

The lack of good definition of the lower part of the fatigue crack is due partly to the gate length used on the ultrasonic apparatus, partly to the above reasons.

VI. CONCLUSIONS

Ultrasonic follow-up of fatigue cracks growth during laboratory experiment on two welded test specimens having purposely embedded defects, was carried out using focussed probes. It has been shown that the correlation between the C-Scans and the actual defect was good. The use of immersion testing technique as well as the good resolution of the focussed probes allowed excellent reproducibility of the results. This experiment has also shown that the sizing of such fatigue cracks (having a relatively well defined and known orientation), is only possible when using at least two directions of incidence opposite to each other. For unknown defects having random orientation and shape, several directions of incidence are obviously required.

Moreover Fig. 9.2 shows how the compression stresses modify the ability to detect the front edge of the crack. This very important factor needs further consideration, particularly because the extensive use of ultrasonic testing for in service inspection of pressure boundaries in nuclear plants.

ACKNOWLEDGEMENTS.

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Thanks are also due to Mr. VARCIN from CREUSOT LOIRE who have made all the preliminary work in the shop.

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- LITERATURE -

[1] - SAGLIO R. , TOUFFAIT A.M., PROT A.C,
"Determination of weld defects characteristics using focussed probes" - International Institute of Welding XXXth Annual Assembly - Colloquium of Commission V. 3 - 9 July 1977.

[2] - SAGLIO R., TOUFFAIT A.M., PROT A.C. "Determination of Defects Characteristics using focussed probes" - Materials Evaluation Janv. 78 - Vol 36. N° 1 P. 62 - 66.

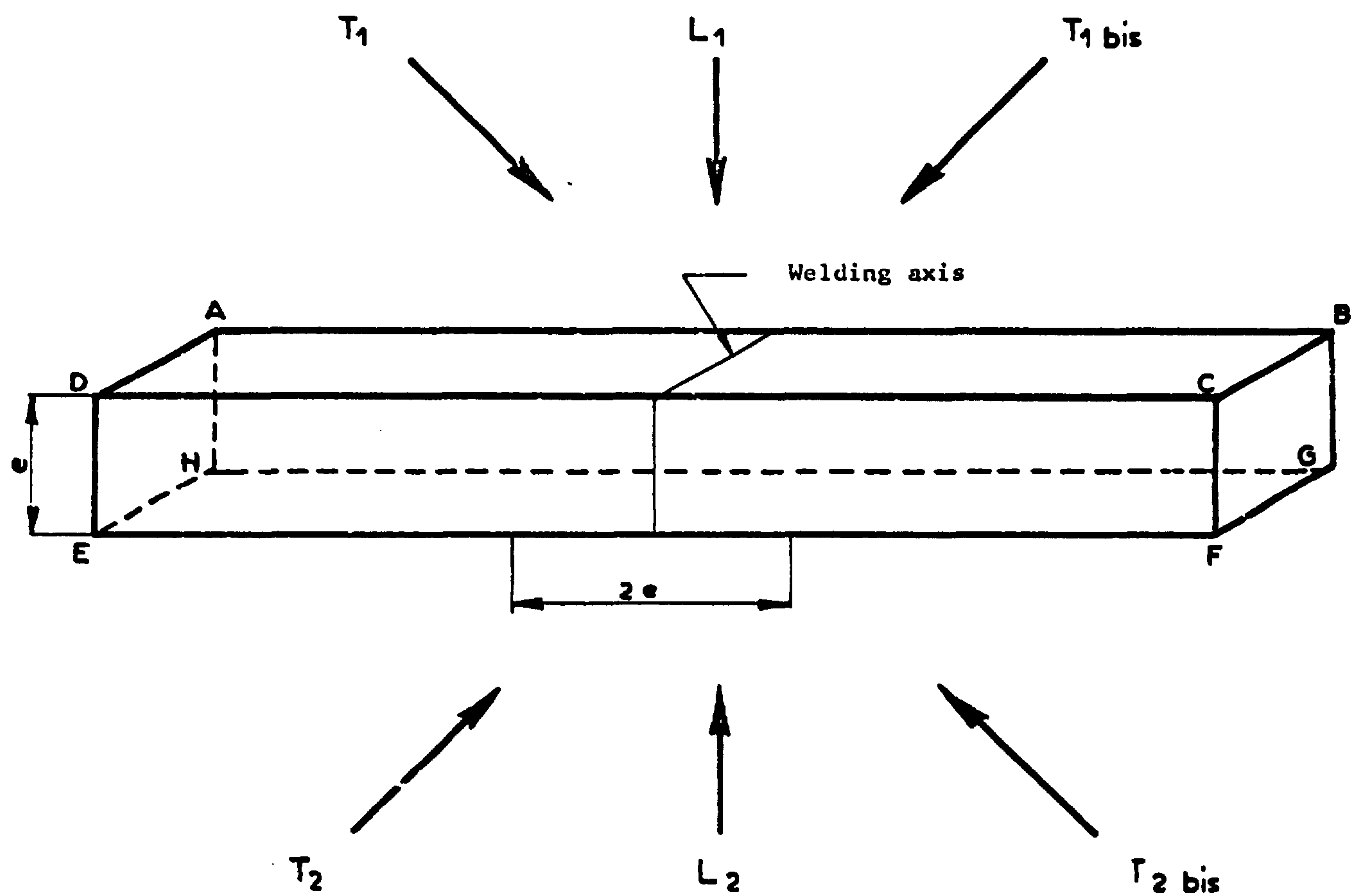


Fig. 1 - Directions of testing

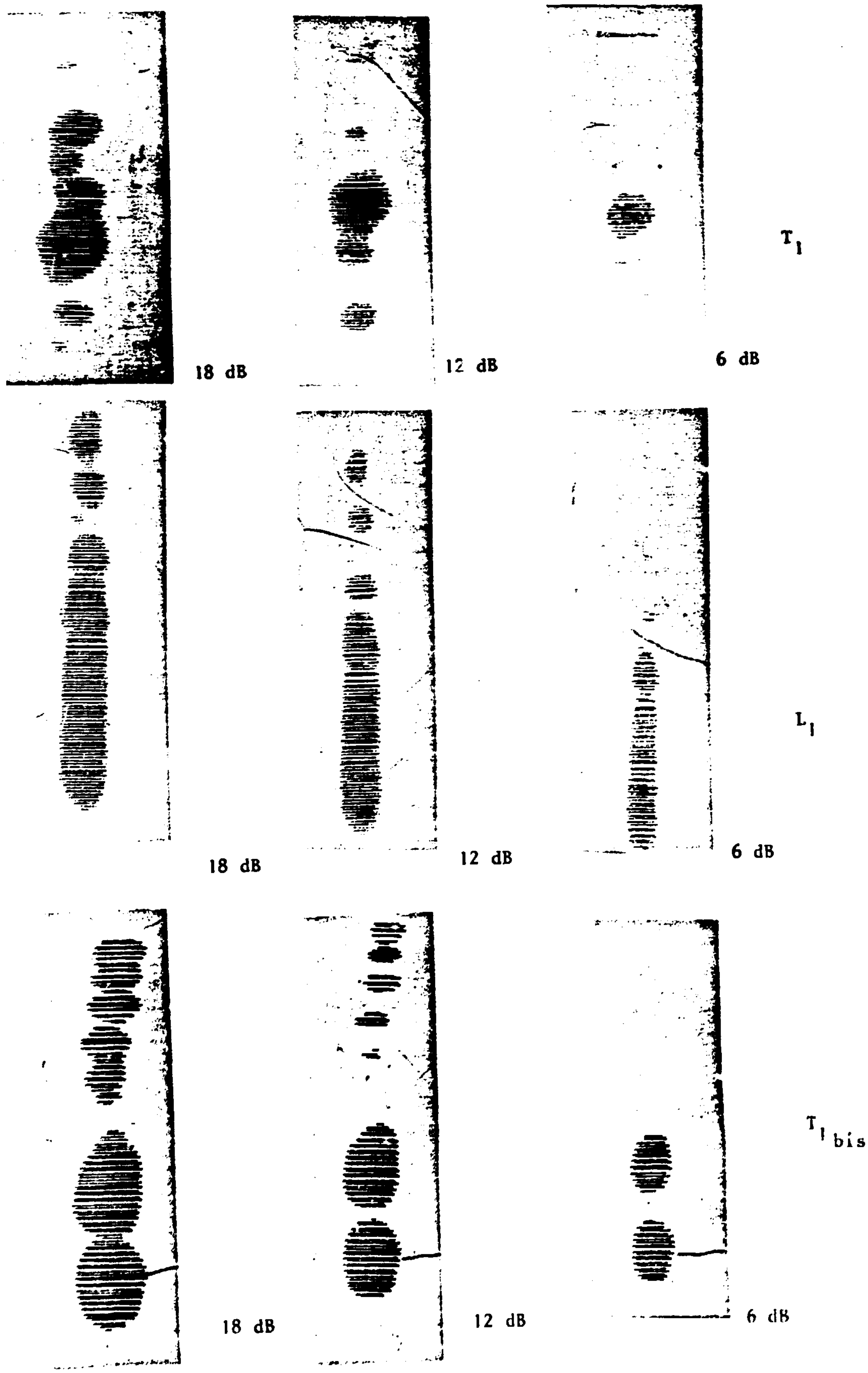


Fig. 2-1 - Test specimen 3/5 - Typical C-Scans obtained just before the beginning of the fatigue testing.

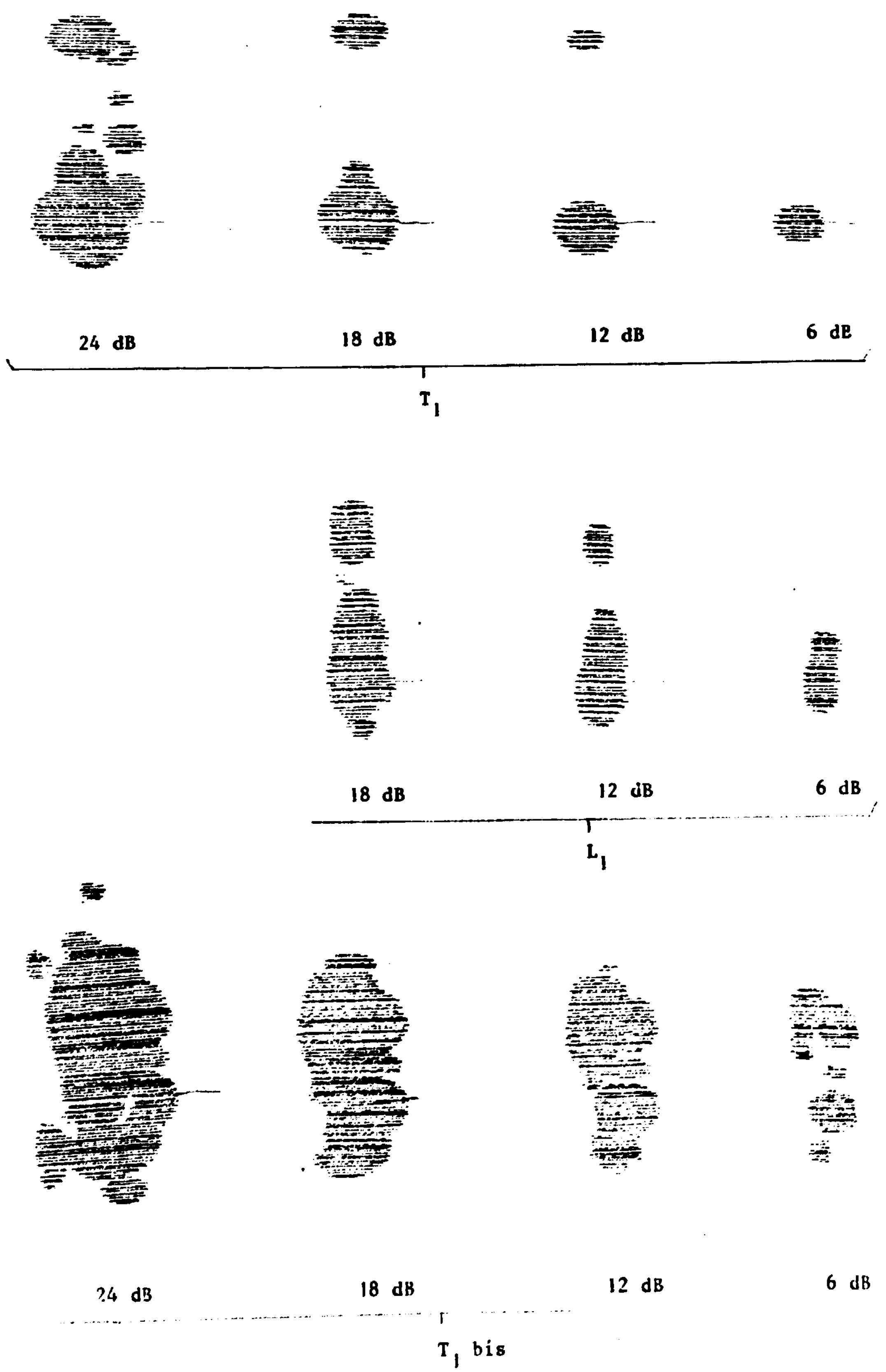


Fig. 2-2. Test specimen 4/5 - Typical C-Scans obtained just before the beginning of the fatigue testing.

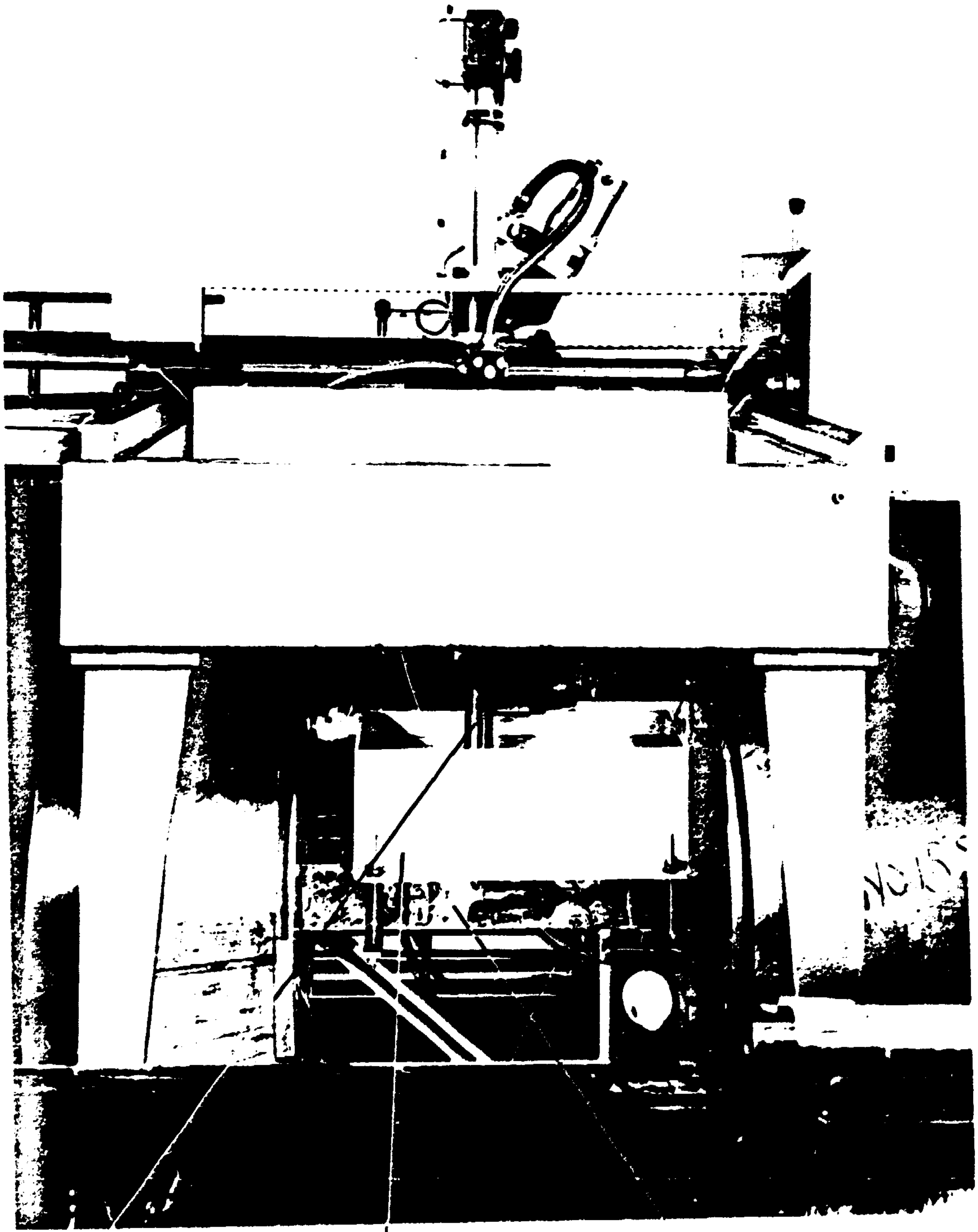


Fig. 3 - Fatigue machine equipped with immersion tank, test specimen 3/5 and ultrasonic focussed probe.

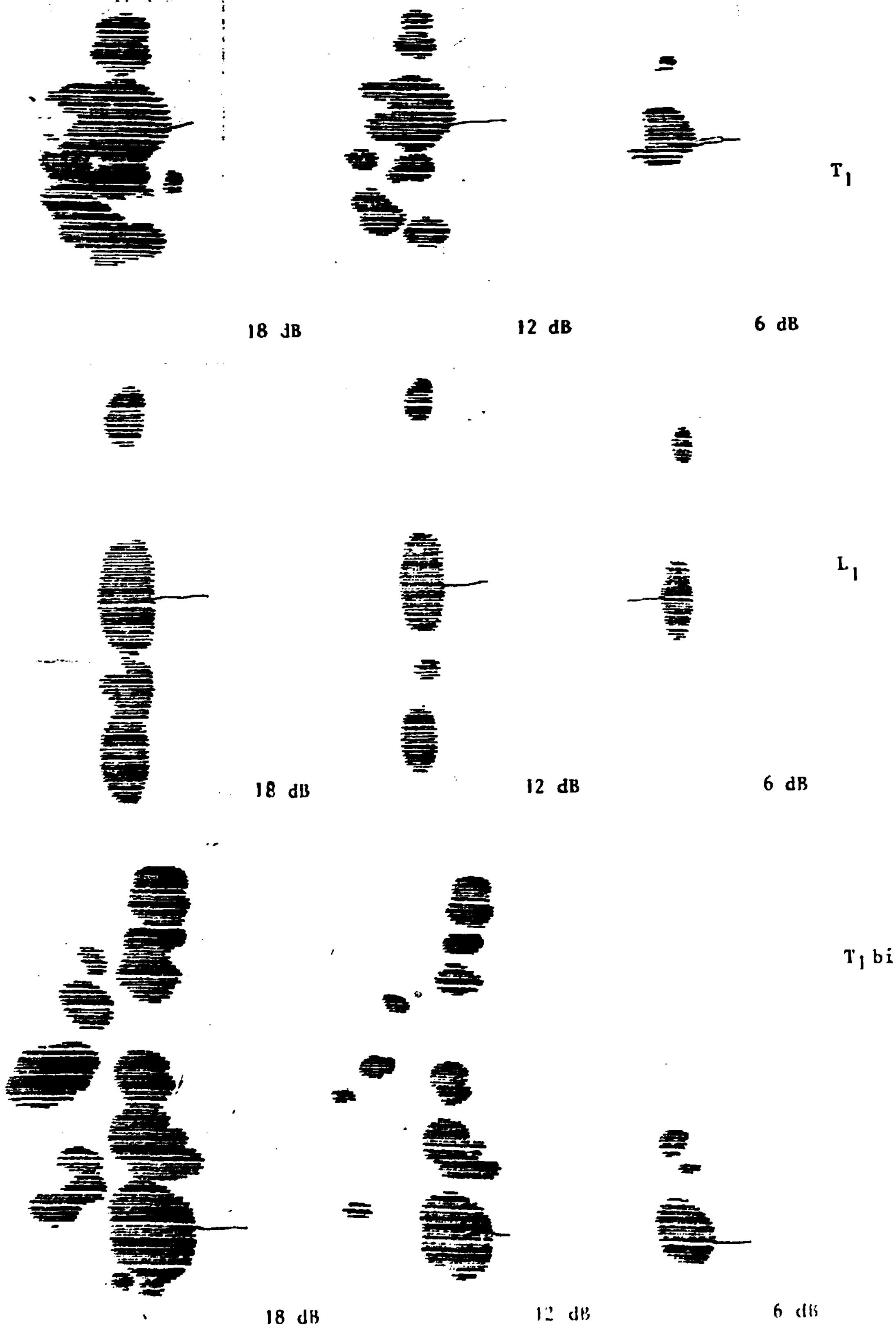


Fig. 4 - Test specimen 3/5 - Typical C-Scans after 107500 cycles just before rupture.

Fig. 5 - Test specimen 3/5
Surface of the defect after rupture.

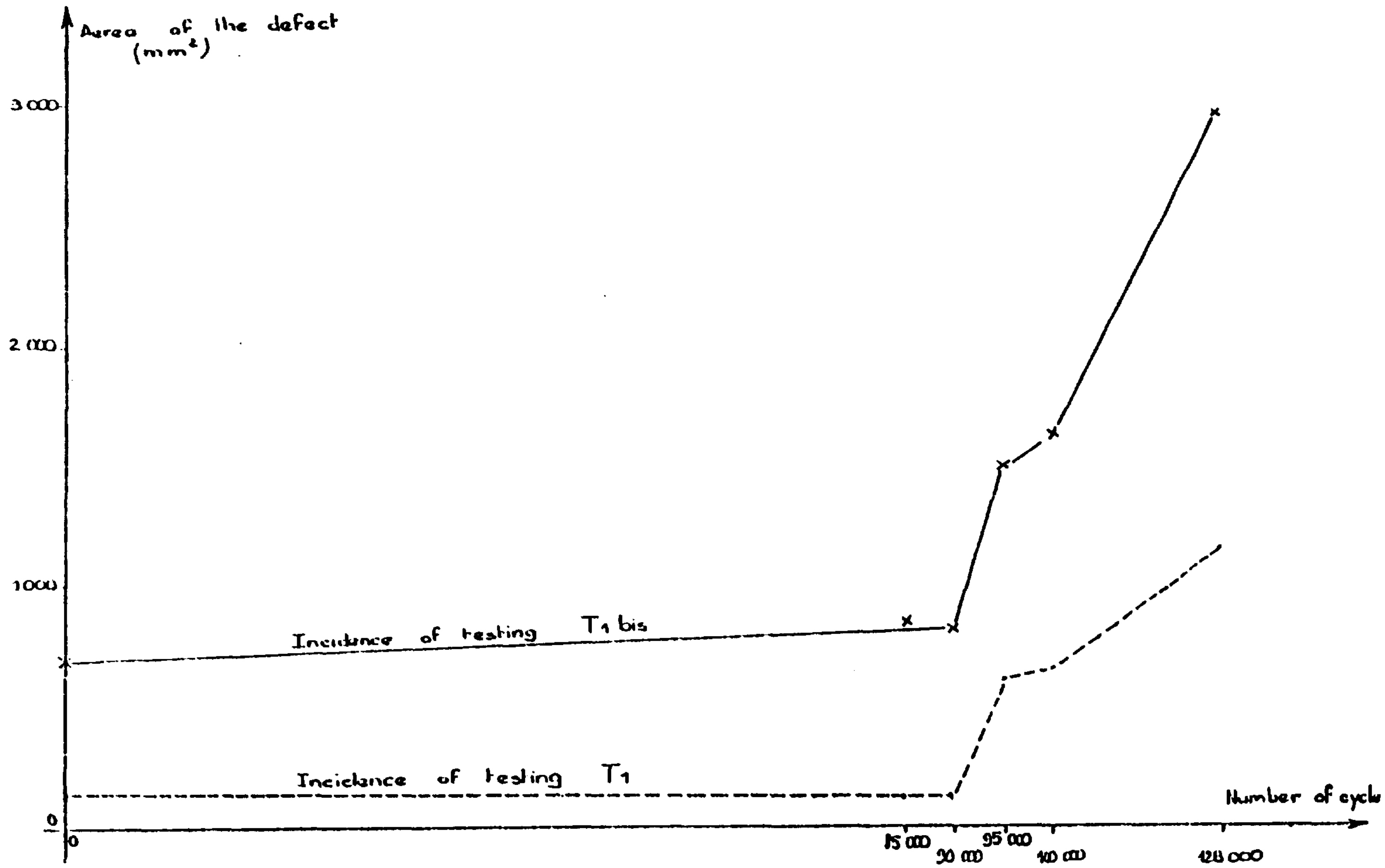
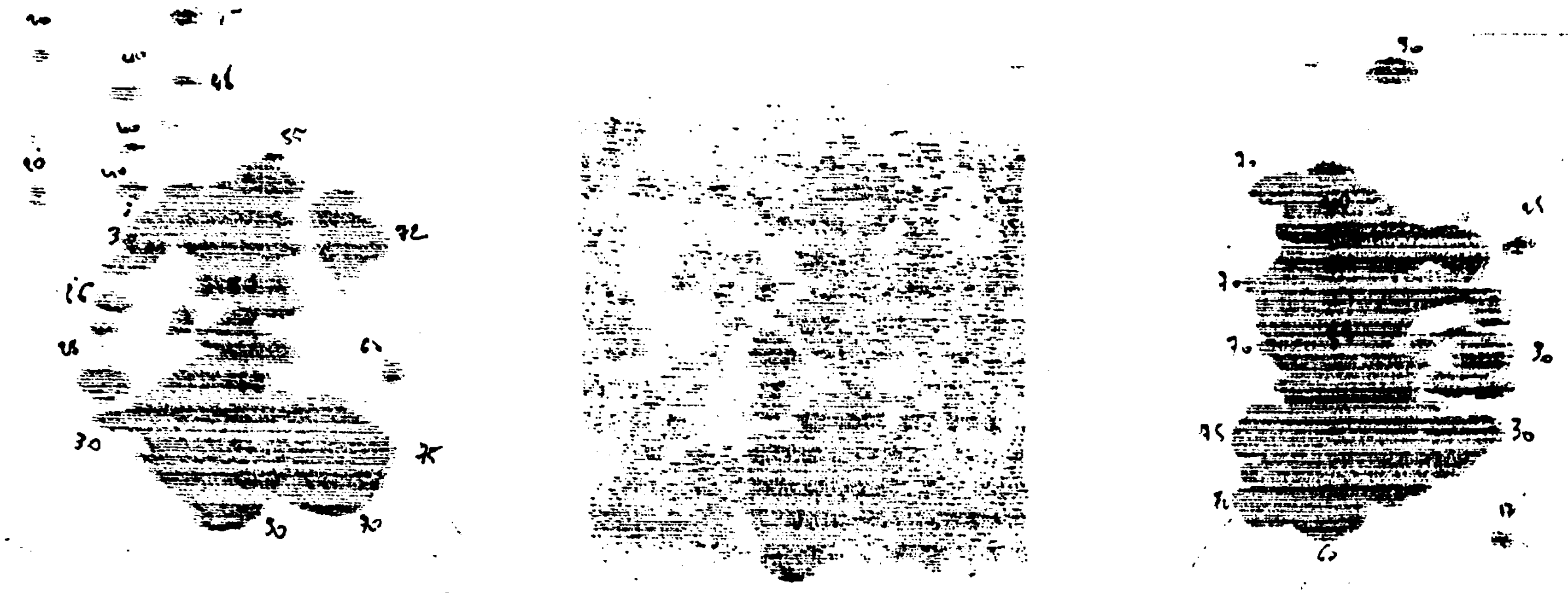


Fig. 6 : Test specimen 3/5
Evolution of the area of the defect

T_1 L_1 T_1bis



36 dB 18 dB 30 dB

Fig. 7 - Test specimen 4/5
Typical C-Scans obtained at 175 530 cycles
Load 0 kN (T_1 , L_1 , T_1 bis)

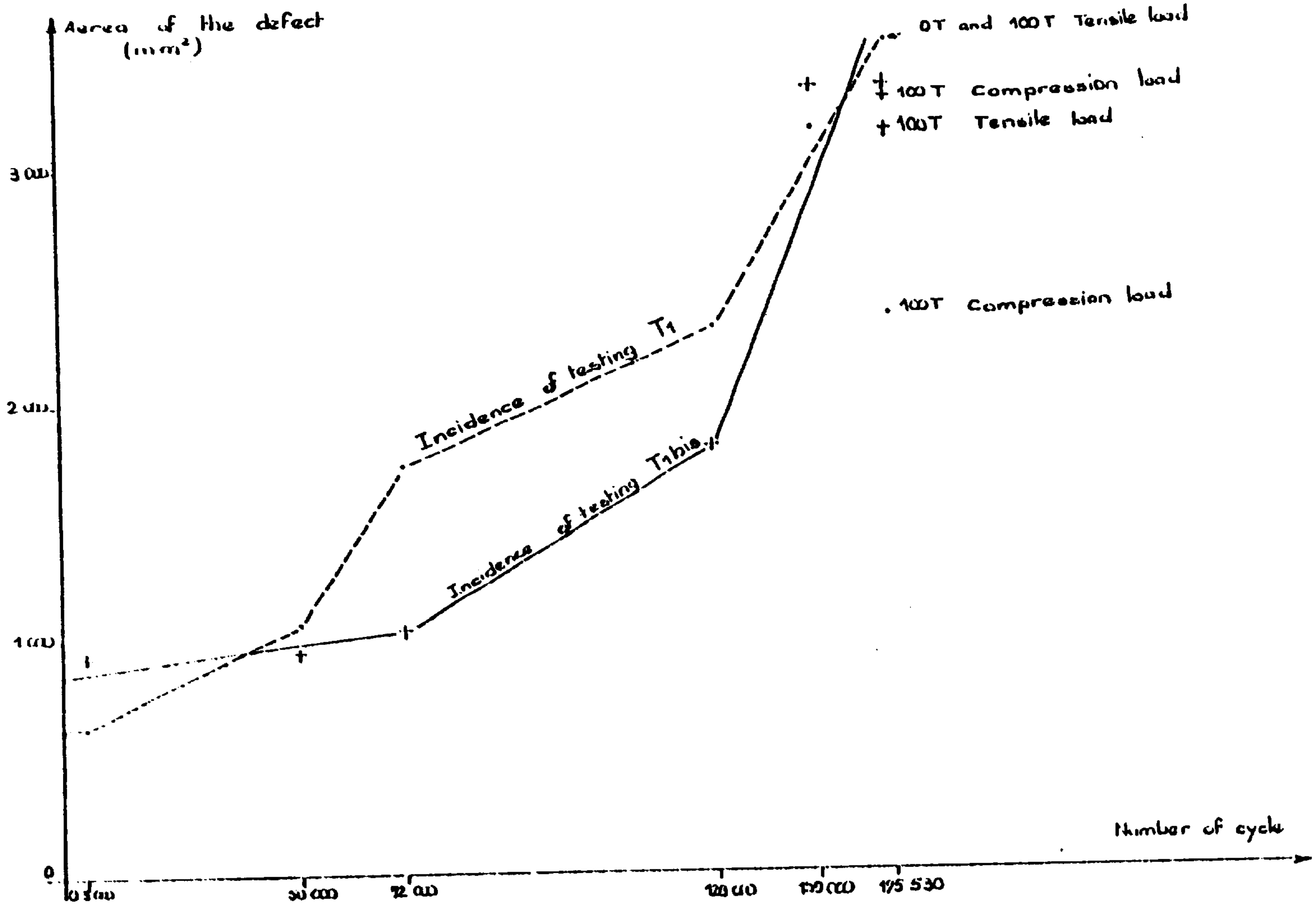


Fig. 8 : Test specimen 4/5
Evolution of the area of the defect

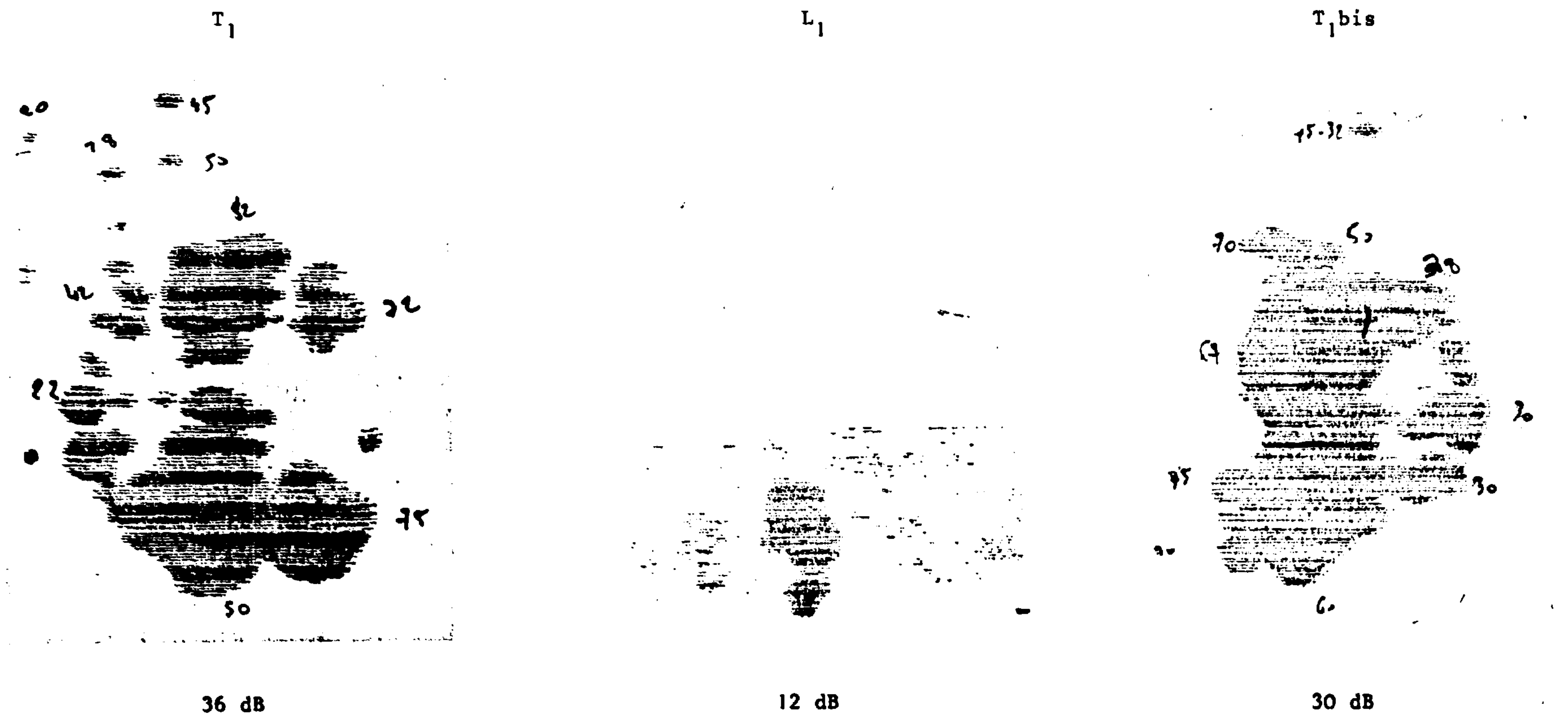
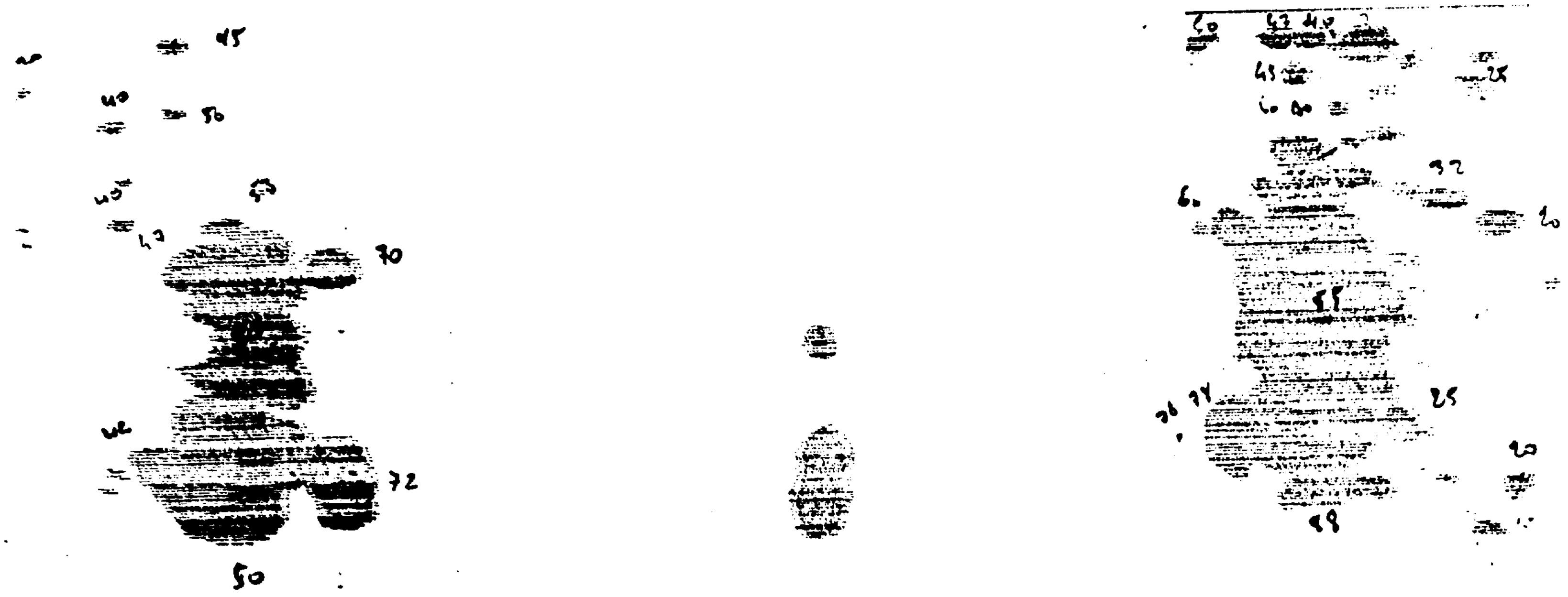


Fig. 9-1 - Test specimen 4/5
Typical C-Scans obtained at 175.530 cycles
Tension Load 1000 kN (T_1 , L_1 , T_1 bis)

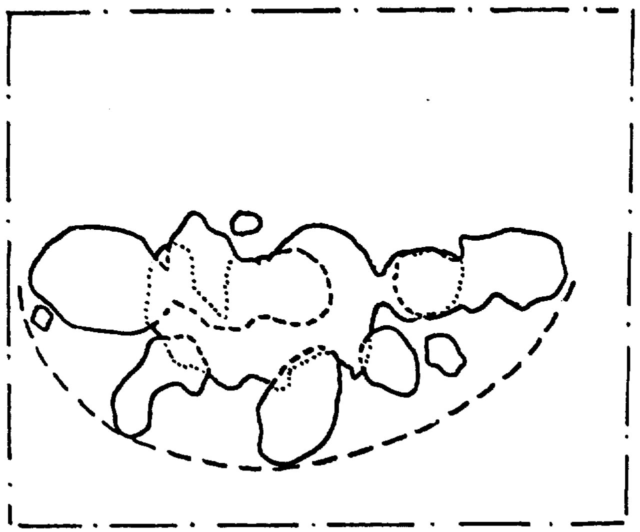
T_1 | L_1 | T_1 bis



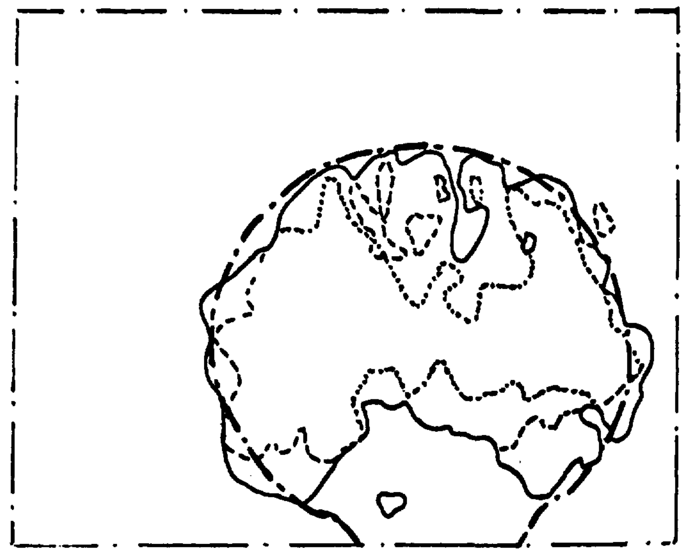
36 dB | 12 dB | 30 dB

Fig. 9-2 - Test specimen 4/5
Typical C-Scans obtained at 175.530 cycles
Compression Load 1.000 kN (T_1 , L_1 , T_1 bis)

Fig. 10 - Test specimen 4/5
Surface of the defect after rupture.



1 - Test specimen 3/5



2 - Test specimen 4/5

Fig. 11 - Superimposed crack bourdaries $T_1 + T_1$ bis
(No Load)