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BETREFFENDE:

Interim-report on low cycle fatigue
investigations with ship structural
components made of higher strength steel.

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INTERIM-REPORT ON LOW CYCLE FATIGUE INVESTIGATIONS WITH
SHIP STRUCTURAL COMPONENTS MADE OF HIGHER STRENGTH STEEL

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EGKS program 6210-55/2/162 of the Committee "Fatigue et Constructions Types".
Prepared for the meeting at Rome in April 1974.

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Section 1. Introduction.

This report serves two purposes.

First of all it makes available to the members of the committee "Fatigue et Constructions Types" the more important experimental data from the reports of the Belgian and French participants. (See extracts - appendix I and II).

The second intention of this report is to give the actual state of progress of the work of analysing and synthesising of all experimental results, which is done in the Delft Ship Structures Laboratory. This work is time-consuming because, as always, the results are sometimes incomplete and inaccurate due to experimental difficulties. A large part of the work consists of careful studies of *crack growth*. The greatest difficulties were:

- a) Many cracks developed from the surface in the width- and thickness-direction, while only the extension in the width-direction has been recorded during the tests.
- b) In various specimens of *one* type, cracks have developed in different ways. (See section 4).
- c) Many cracks have not been detected in the initial stage but only after they had developed to significant lengths. This handicapped greatly extrapolations to zero-crack-length.
- d) For the smaller specimens the data for relatively large crack lengths have to be corrected in order to allow comparisons with the data of the large specimens.
- e) Specimens of one type showed appreciable differences in weld forms.
- f) Some of the Delft specimens have been tested at +20°C, while others at -37°C. The influence of this difference had to be studied in order to be able to present reliable data. (See also /2/).

Altogether the analysis of the experimental results as presented in this report is thought to be sufficiently advanced to permit the committee to make critical observations and constructive suggestions. These will be of help for the preparation of the forthcoming first overall synthetical report, which will be ready in August.

It is hoped that eventual observations will be given in a written form to the authors.

Section 2. Observations concerning the fatigue experiments with small structural specimens carried out in France.

From the original French report the most characteristic and interesting pages have been copied. They can be found in the appendix I of this booklet under the name "Extrait du compte-rendu d'essais de fatigue"

In Delft the results of the French experiments are now plotted in diagrams for crack-growth as a function of numbers of cycles. (Figs. 2-1 and 2-2 show some examples). From the tables shown f.i. on page 27 and 32 of appendix I it will be understood that it was not easy to obtain reliable crack growth information.

The next step being plotting the crack growth data as a function of the local stresses (strains) of tables I and II of the "Extrait", (see also figs. 13 and 38), has also been started. Similar work is done for the test results obtained from the full-scale experiments carried out in Delft. Together with the results for the elementary specimens tested in Belgium and Germany, all these results will allow a study of the influence of macro-stress-concentration factor, local bending and weld shape (micro-stress concentration) on fatigue strength. (For information about the progress of work in connection to the Belgian experiments, see section 3).

In the Extrait some results of the experiments have already been given as numbers of cycles to *incomplete* fracture in function of amplitude of nominal stress. They confirm the tendency of the German test results that there is hardly any difference in fatigue-performance for St. 37 and St. 52-specimens. (Fig. 17 page 22; fig. 26 page 31, fig. 51 page 57; fig. 61 page 67). This becomes especially clear from fig. 62 page 70, where all results have been brought together. On the average St. 37 and St. 52 behaved similar.

In section 4 of this report it will be seen that for the *full-scale* welded specimens a distinct advantage for St. 52 has been observed. It amounts to some 10% on the average in terms of stresses.

It has been tried to present the French results in the form of rate of crack growth (da/dn) as a function of stress intensity (ΔK), fig. 2-3. The main difficulty was that the cracks start at points of structural (macro)

stress concentrations of inaccurately known magnitude. Therefore for the stress-factor in ΔK the nominal stress has been taken. In the formula $\frac{da}{dn} = C.(\Delta K)^m$ this will only influence the magnitude of C and not the more important m , (provided the cracks are relatively small). The result in fig. 2-3 of course is not very satisfactory, but it may be used carefully.

The value m for the French specimens proved to be equal to 2,8 for St. 52 which corresponded satisfactorily with the value 2,35 found for the same material with axially loaded elementary specimens. (See section 3).

Figures 2-4 and 2-5 give a presentation of the results in a final form. The curves are Wöhler curves for various crack lengths. The dotted curve "End of test" has not any practical significance because after 500 mm² crack area the specimen section had been reduced too much, resulting in very high nominal stresses. One of the actual tasks is to translate figures 2-4 and 2-5 into diagrams valid for infinitely wide specimens. Only these diagrams should be related to those obtained for large specimens.

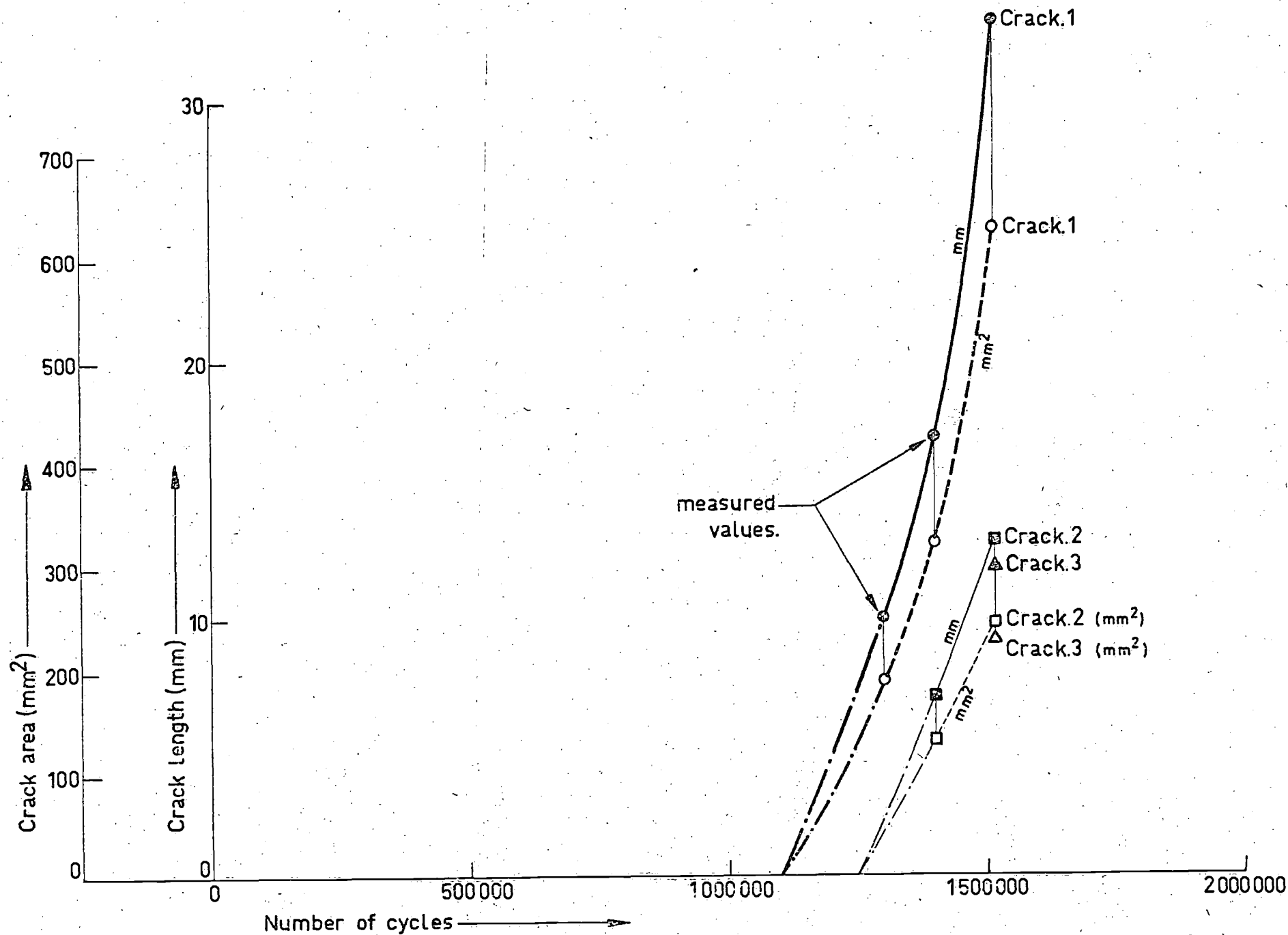


FIG. 2-1: FATIGUE CRACK PROPAGATION TYPE A; St. 52; N^o 13 REPEATED LOADING; $\sigma = 0,5/4 \text{ kg/mm}^2$

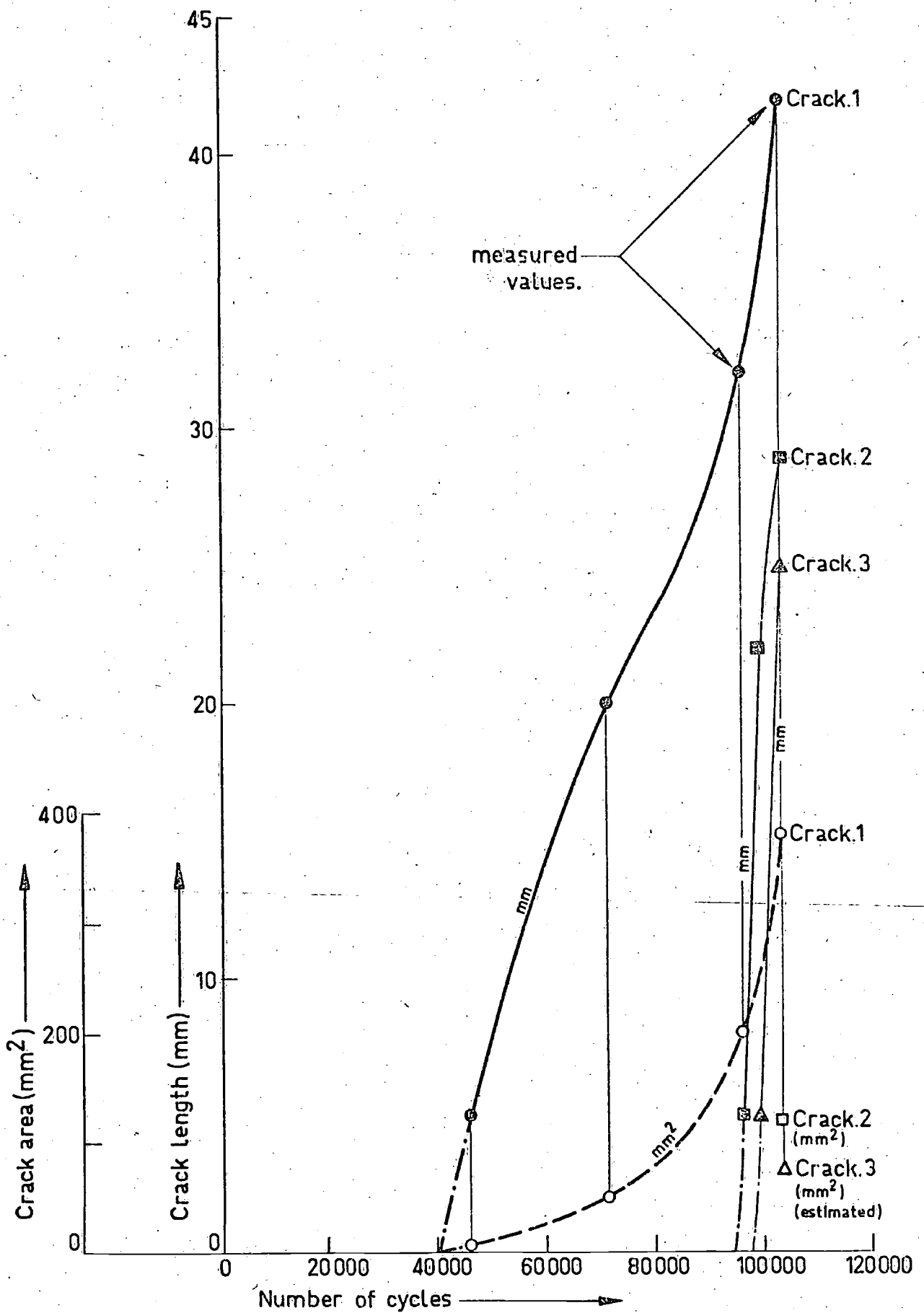


FIG. 2-2. FATIGUE CRACK PROPAGATION TYPE.B ; St.37 ; № 4
REPEATED LOADING ; $\sigma = 0,5/16 \text{ kg/mm}^2$.

- Specimen 13 □
- " 14 ▲
- " 15 ○
- " 24 ◇
- " 25 ▼

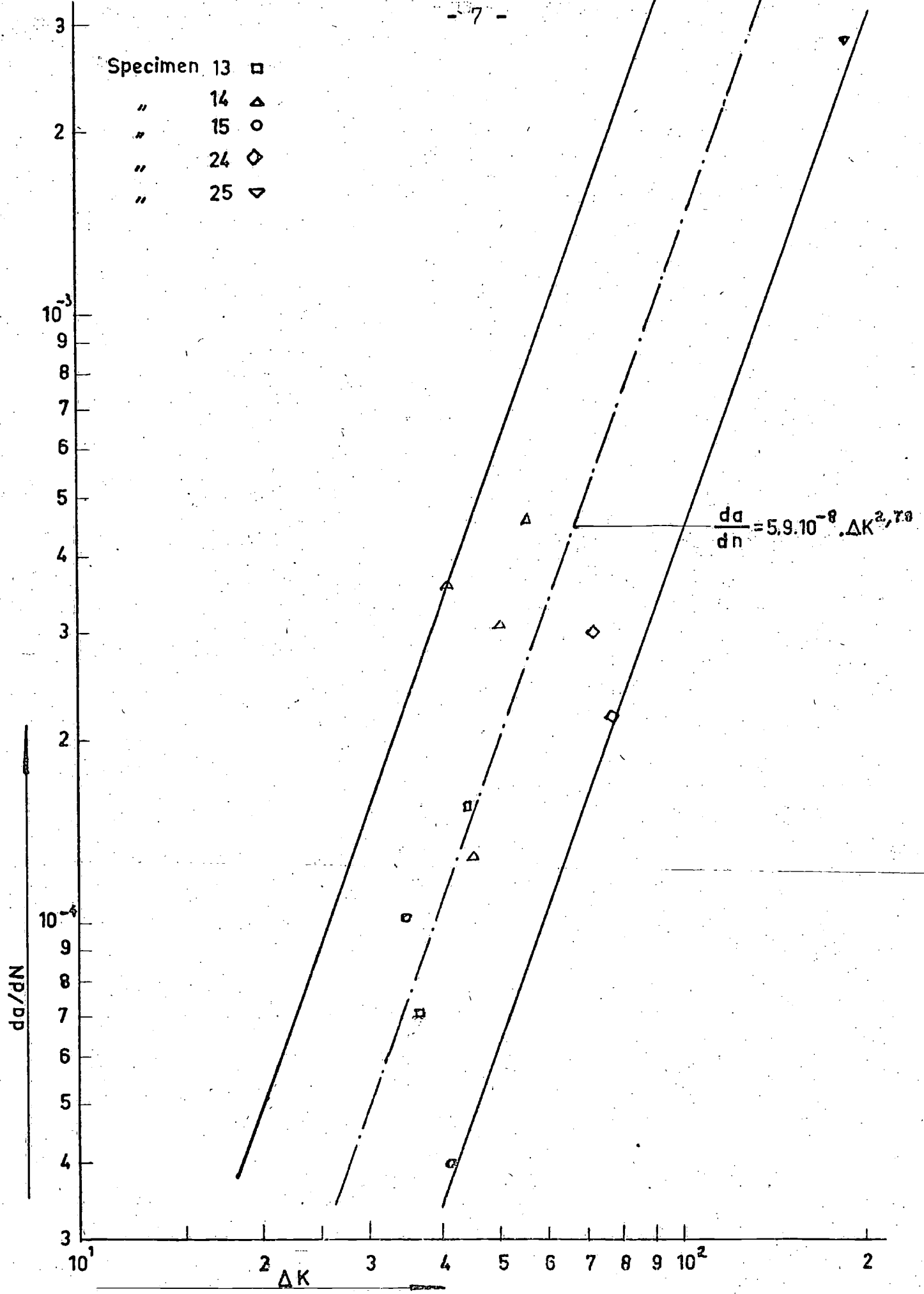


Fig. 2-3.

Fatigue crack growth rate.

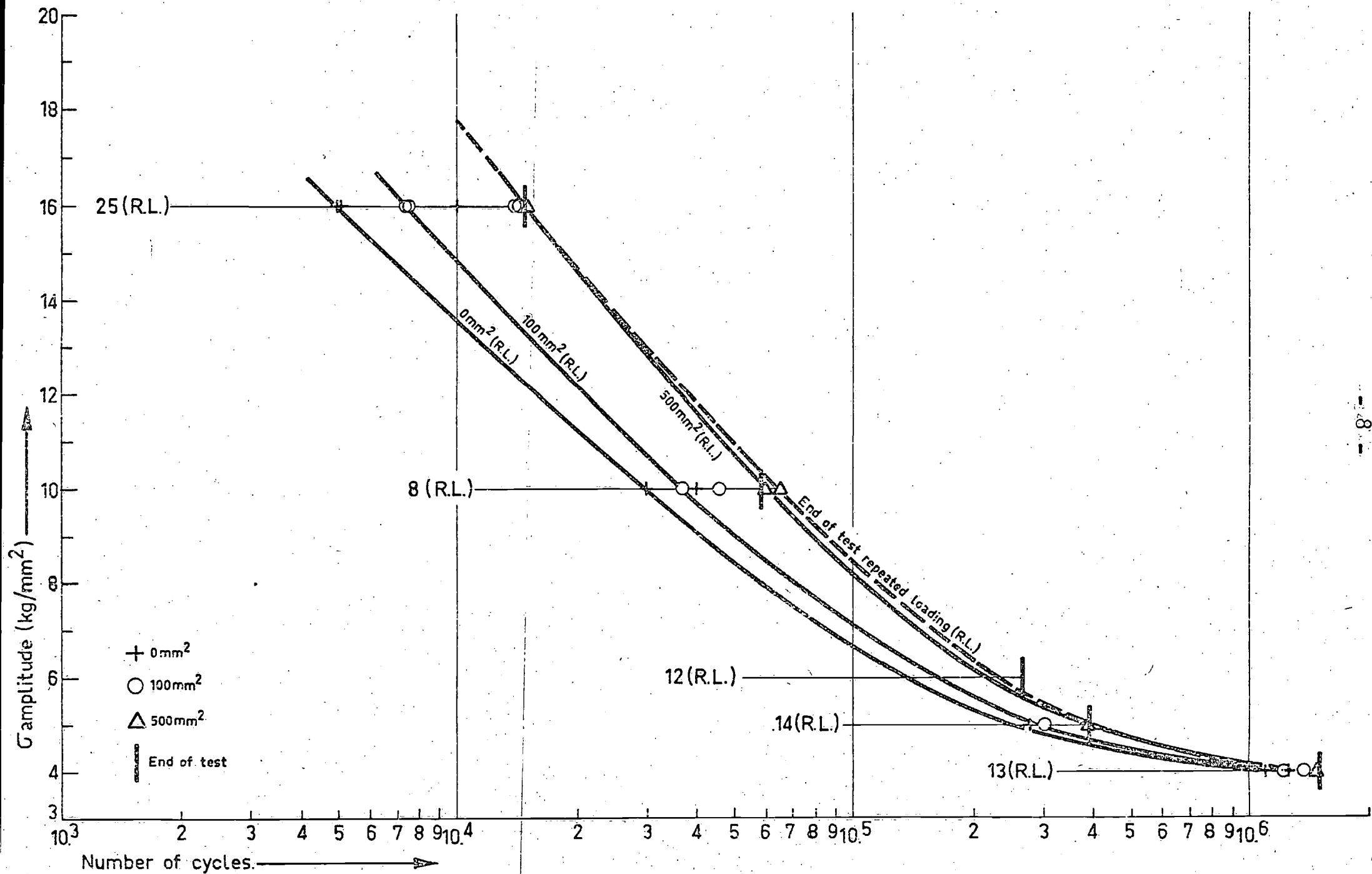


FIG.2-4 FATIGUE CURVES OF DIFFERENT CRACK AREAS FOR REPEATED LOADING ; TYPE.A ; St.52.

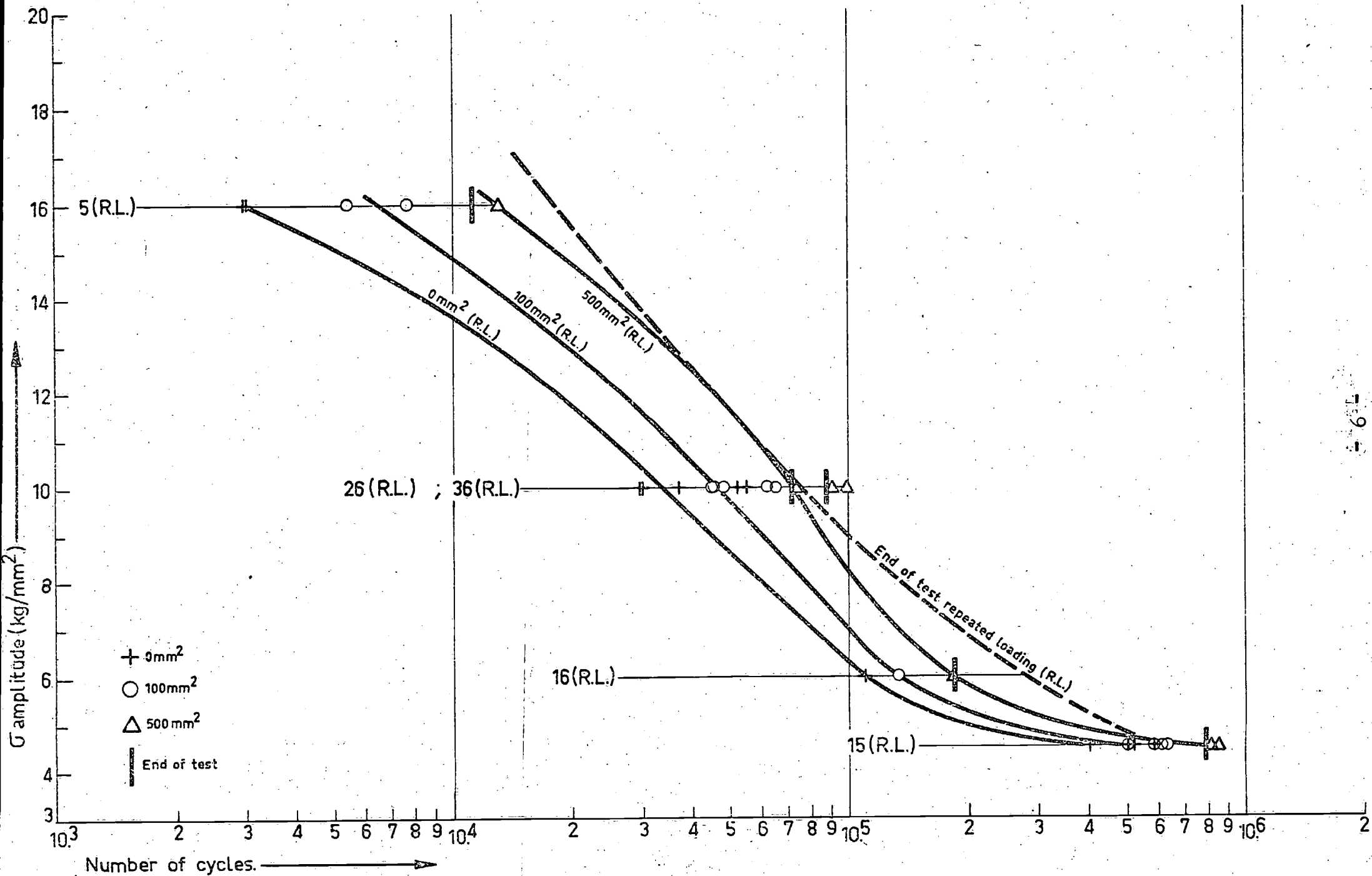


FIG. 2-5 FATIGUE CURVES OF DIFFERENT CRACK AREAS FOR REPEATED LOADING ; TYPE.A ; St.42.

Section 3. The experiments carried out in Belgium.

In Belgium two kinds of experiments have been carried out.

- a) Fatigue-experiments with elementary, axially loaded or bent, specimens. (Report Lab. v. Weerstand van Materialen Ghent, no. 153/4585).
A few pages of this report have been copied for information (see appendix II). The results have been presented as on page 2. On page 3 the method of measuring crack length is demonstrated. Page 4 shows the specimens and gives a summary of the test program.
- b) The second type of experiments carried out in Ghent consisted of fatigue-bending of full scale specimens. (Report Lab. v. Weerstand van Materialen no. 153/4706).

The results in the form of tables giving crack lengths as function of numbers of cycles are actually transformed to diagrams. Furthermore the specimens have all been broken in order to make the fatigue-cracks visible. This makes it possible to transform the beforementioned diagrams for crack lengths into diagrams for crack surfaces. A picture of the test-set-up and of some characteristic fractures are given in appendix II, (page 5, 6, 7).

Returning to the fatigue-tests with elementary specimens under a), figures 3-1, 3-2, 3-3, 3-4 and 3-5 show the crack growth for *fatigue-bending*. From these diagrams the rate of crack growth da/dn has been determined as a function of crack length, and this transferred to $da/dn - \Delta K$ curves. The latter diagrams have not been included in this report, but the next table summarizes the results.

$da/dN = C(\Delta K)^m$	m		C	
	St. 52	St. 42	St. 52	St. 42
bending	2,2* - 2,3* - 2,0*	4,5 - 3,5	$9,3-5,4-7,2 \times 10^{-9}$	$1,02 \times 10^{-14}; 3,4 \times 10^{-14}$
axial repeated loading	2,35	4,3	$9,94 \times 10^{-9}$	1×10^{-12}

* three plate thicknesses tested.

Both for bending and axial loading a significant difference has been found for m for St. 52 and St. 42, (2,3 ↔ 4,1 as an average).

Figures 3-6 to 3-14 are a complete set of Wöhler-curves for 0, 1 and 5 mm crack-length for 19 mm plate thickness. They have been developed from figures 3-1 to 3-5 and are for repeated bending. Figure 3-8 allows a comparison for both types of steel, (grade D = St. 42; grade DH 36 Nb = St. 52). Similar figures are given for axial alternating and repeated loading.

From figures 3-8, 3-11 and 3-14 it can be concluded that on the average, and especially in the region of lower stresses, St. 52 did not behave better than St. 42. But the higher the stresses, the more advantageous becomes St. 52.

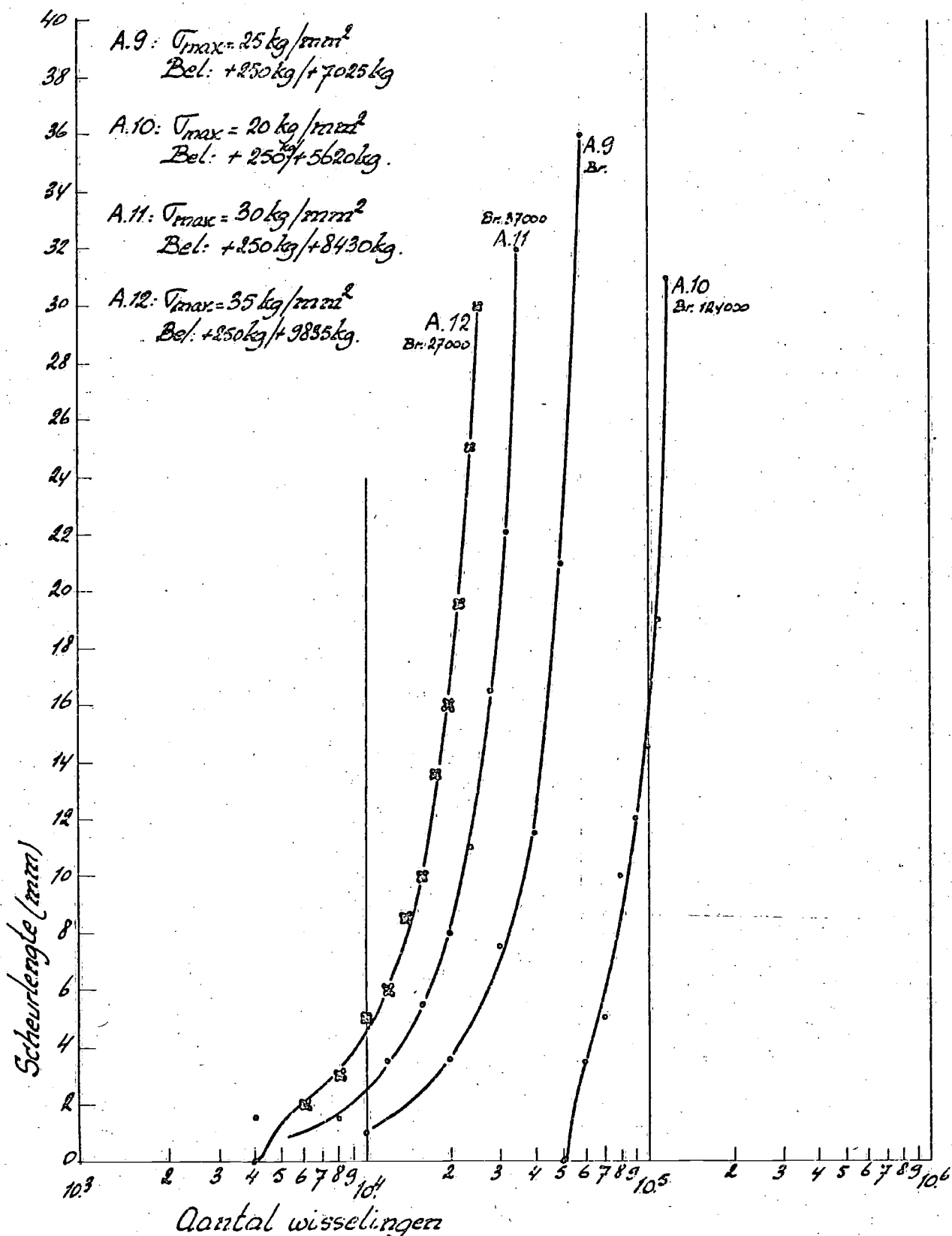


Fig. 3-1. Results of fatigue-bending with 25 mm thick St. 52-specimens.

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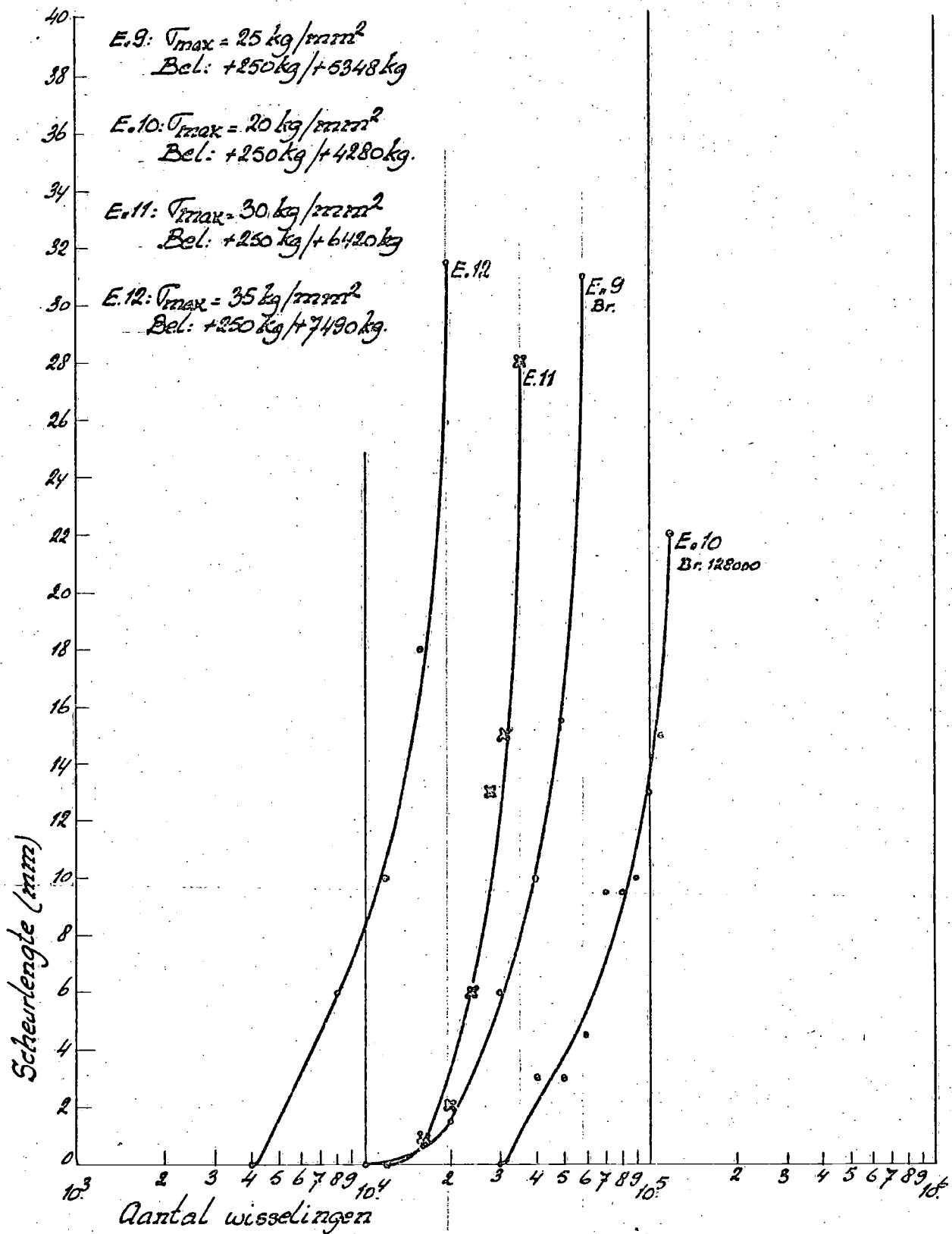


Fig. 3-2. Results of fatigue-bending with 19 mm thick St. 52-specimens.

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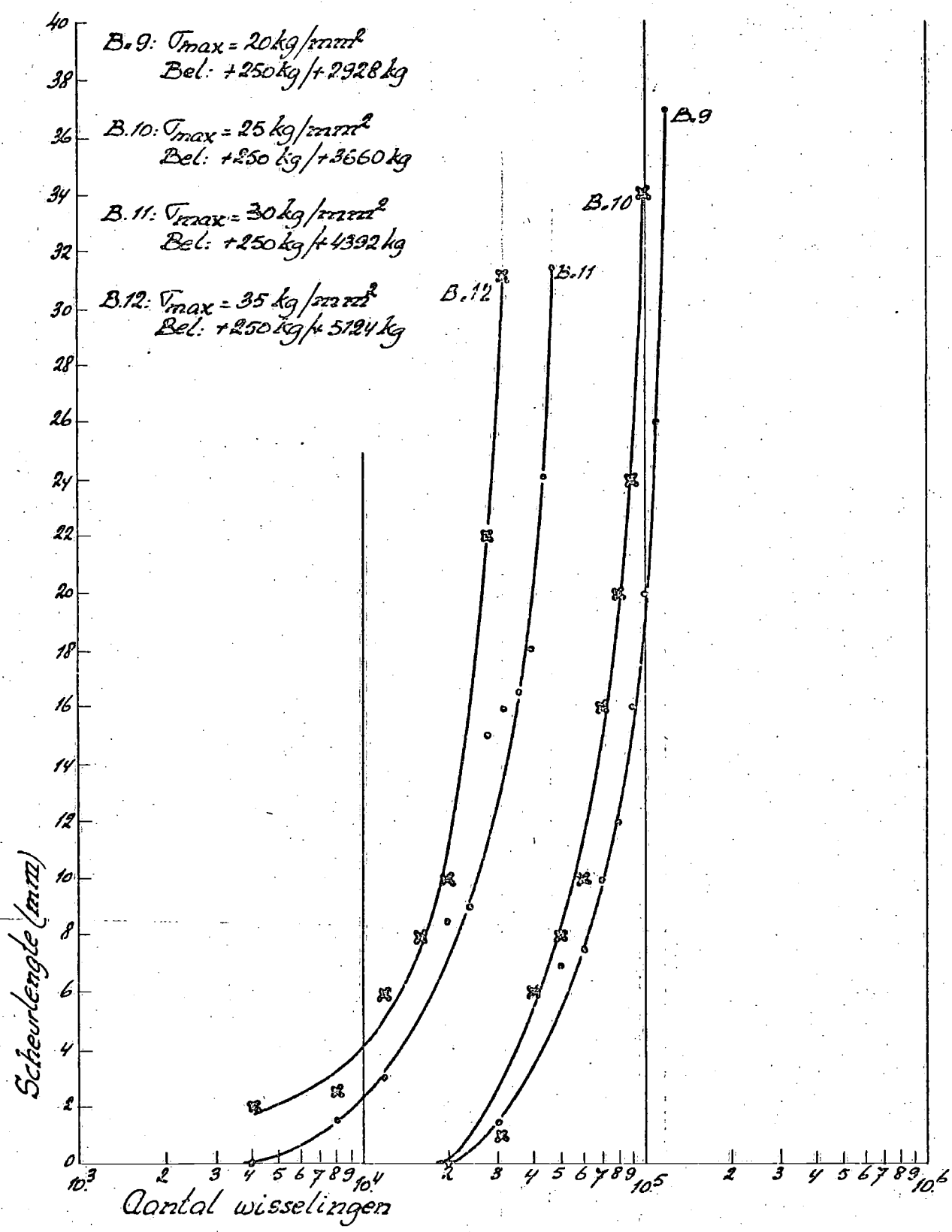


Fig. 3-3. Results of fatigue-bending with 13 mm thick St. 52-specimens.

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15-3-'74

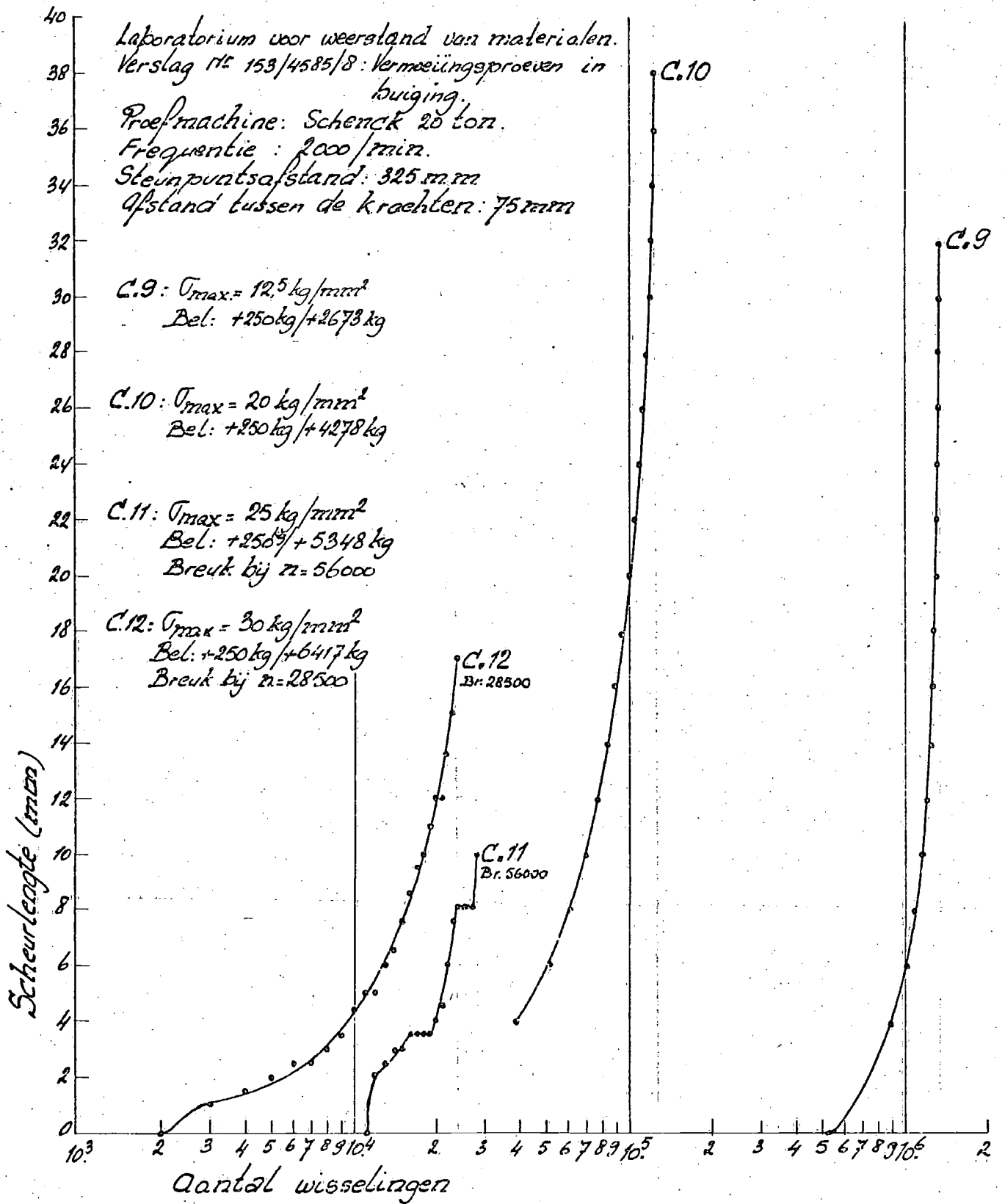


Fig. 3-4. Results of fatigue-bending with 19 mm thick St. 42-specimens.

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 15-3-74

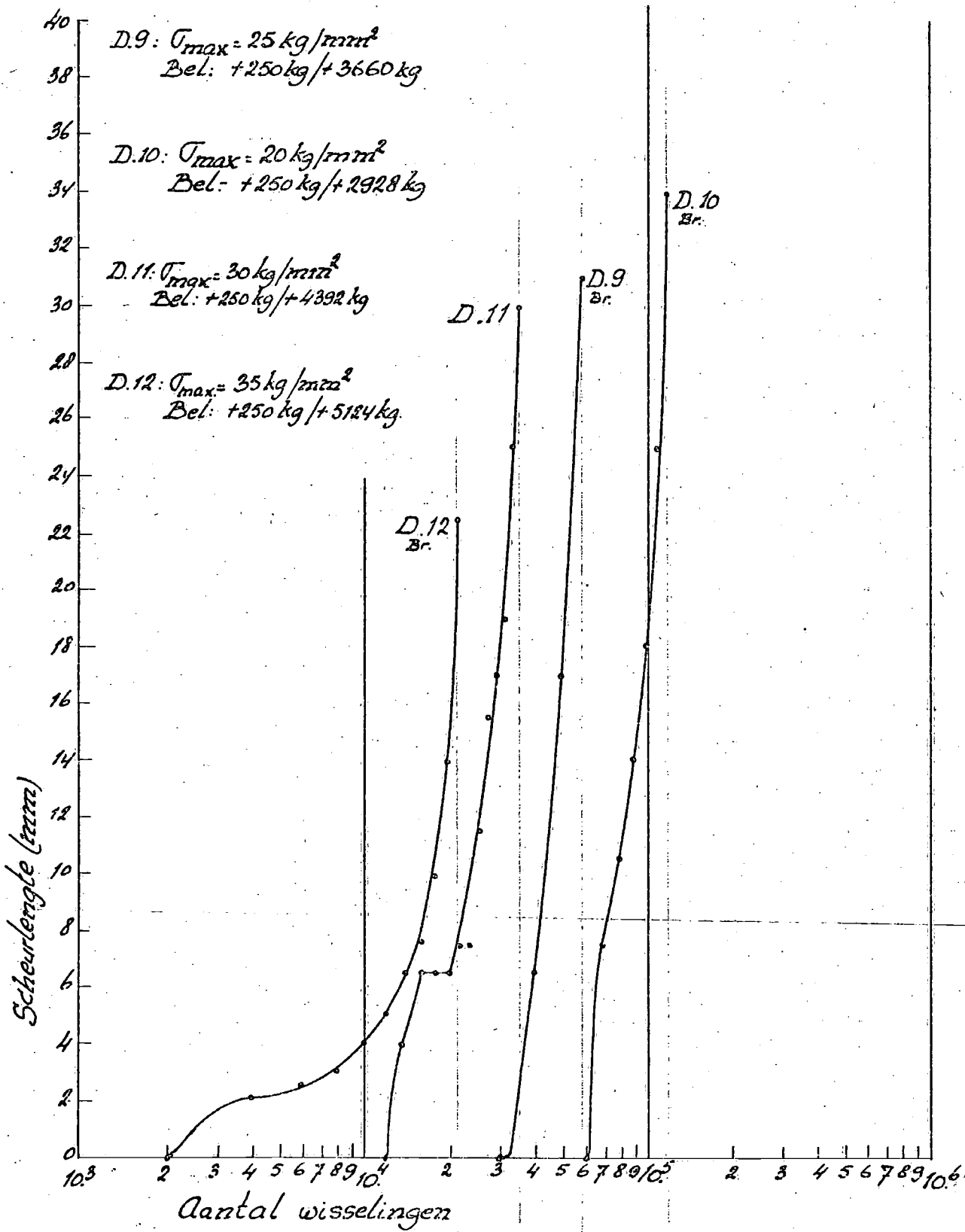


Fig. 3-5. Results of fatigue-bending with 13 mm thick St. 42-specimens.

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15-3-'74

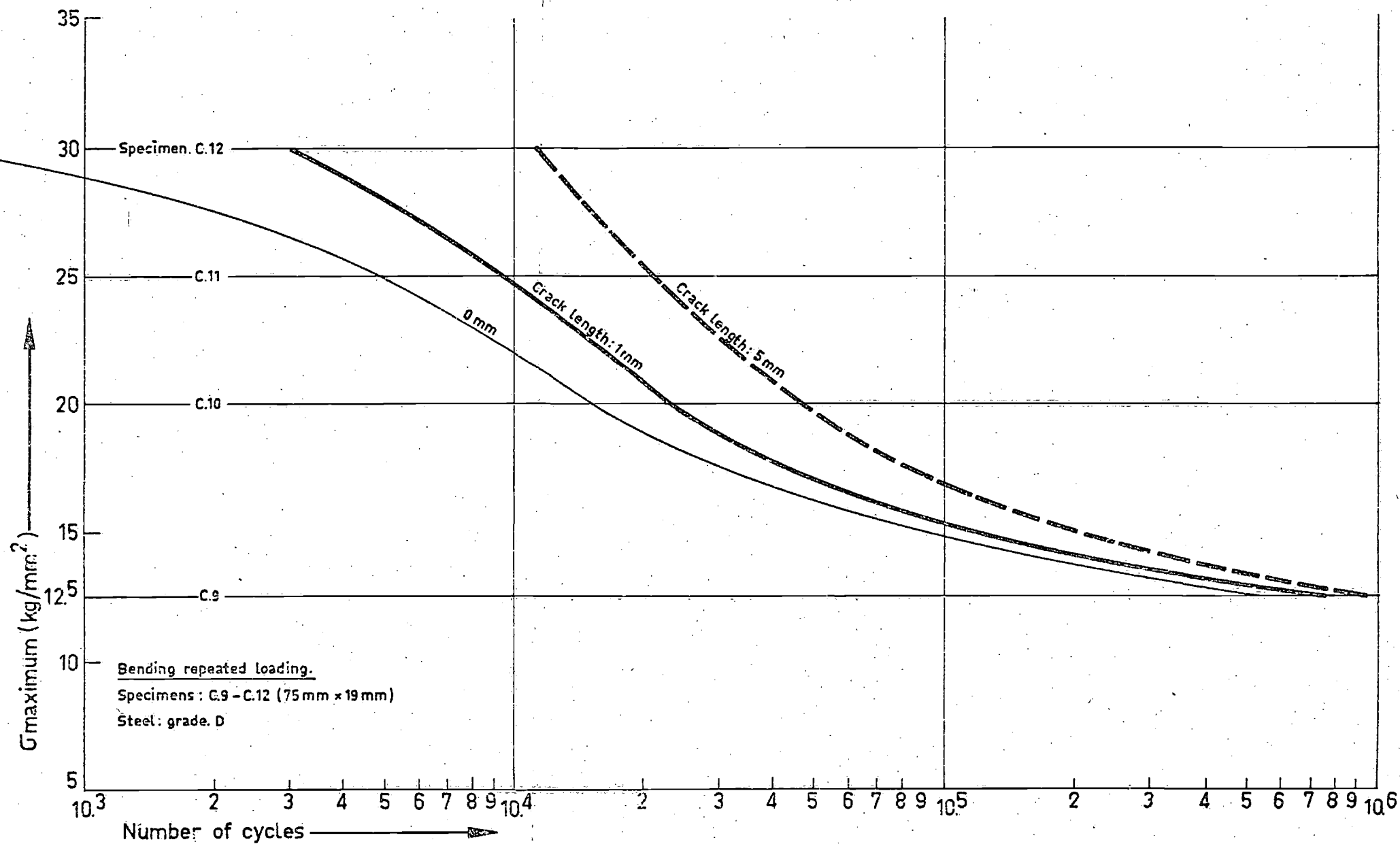


FIG.3-6 FATIGUE CURVES FOR 0mm,1mm AND 5mm CRACK LENGTH.

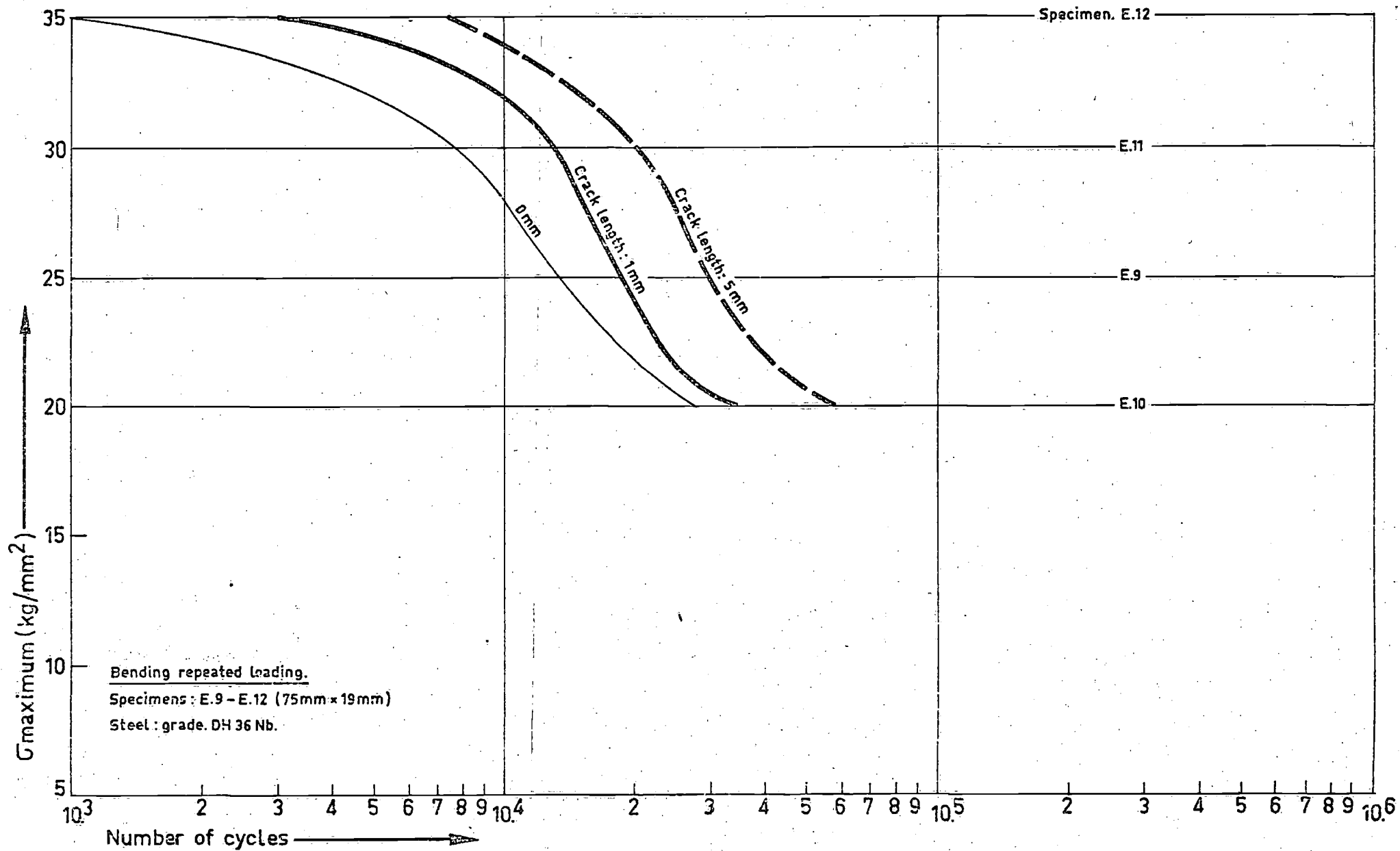


FIG.3-7 FATIGUE CURVES FOR 0mm, 1mm AND 5mm CRACK LENGTH.

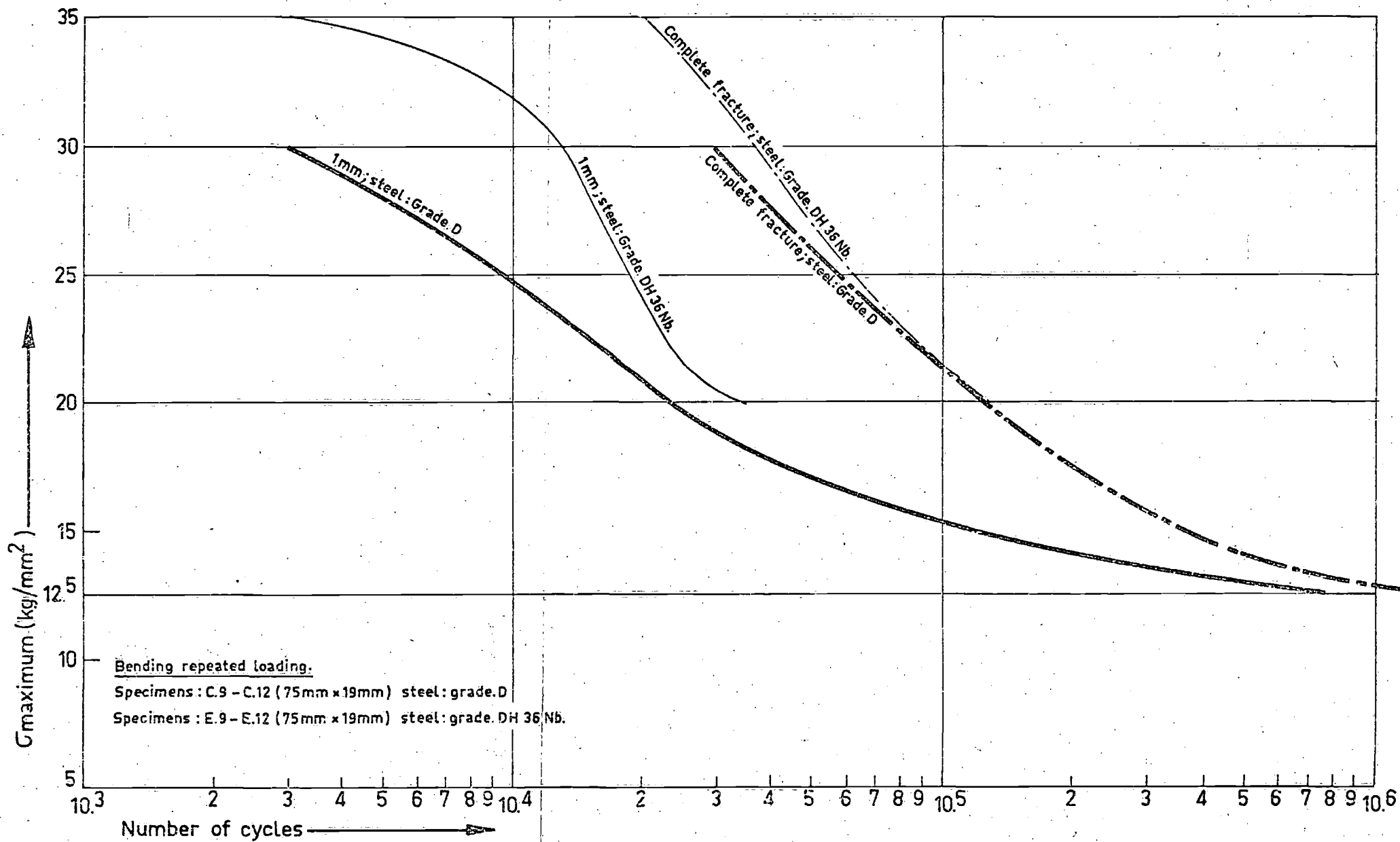


FIG.3-8 FATIGUE CURVES FOR 1mm CRACK LENGTH AND FOR COMPLETE FRACTURE.

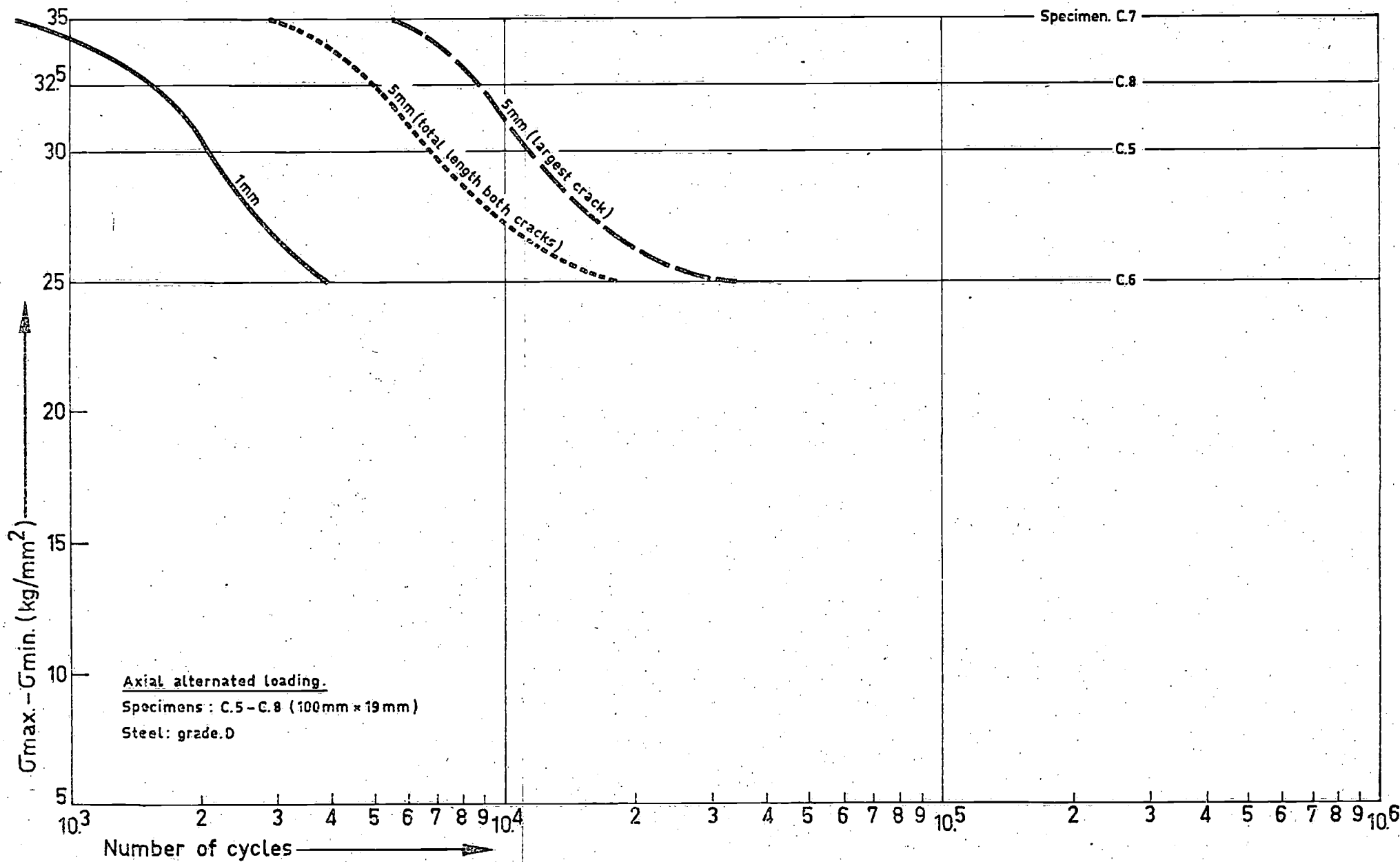


FIG.3-9 FATIGUE CURVES FOR 1mm AND 5mm CRACK LENGTH.

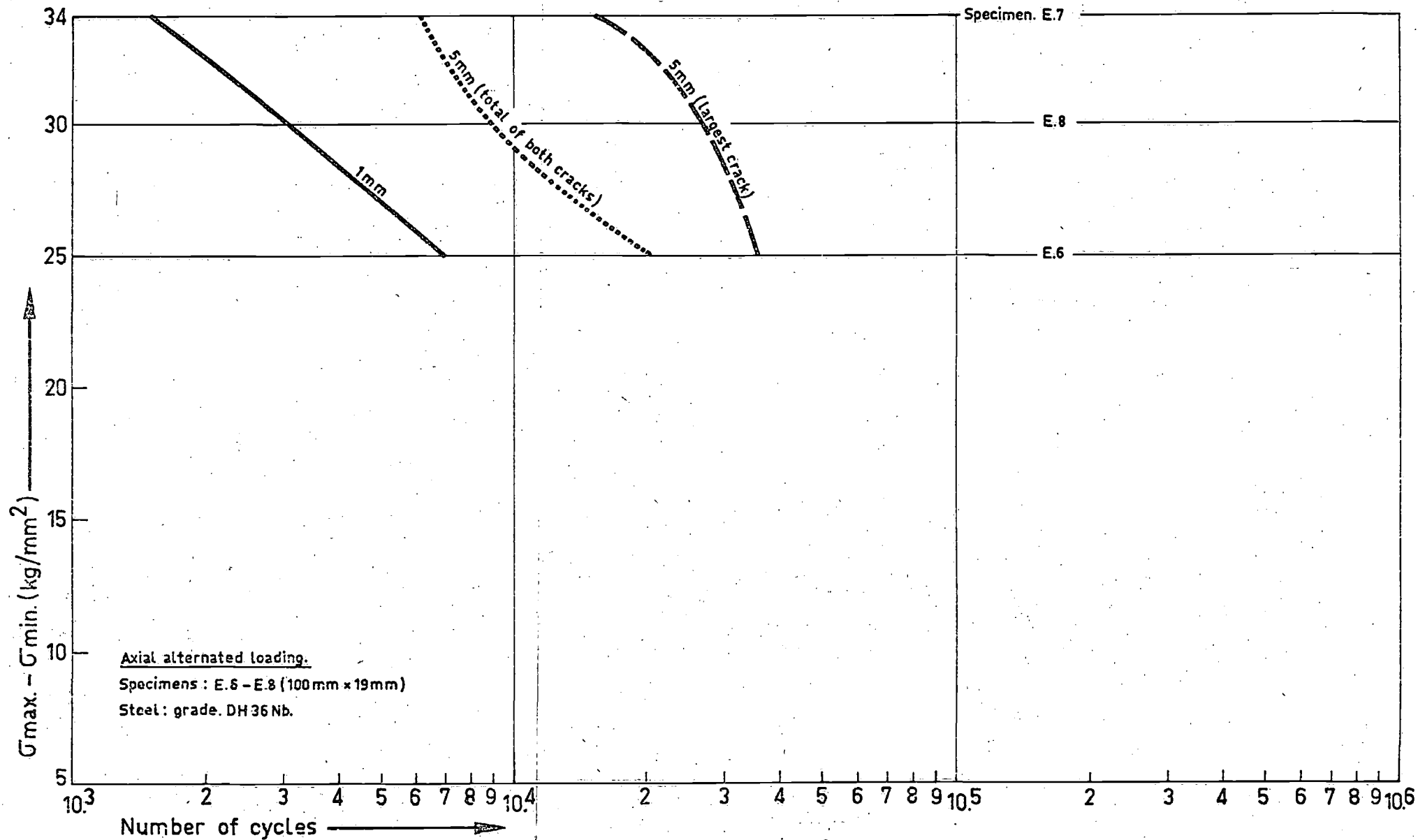


FIG.3-10 FATIGUE CURVES FOR 1mm AND 5mm CRACK LENGTH.

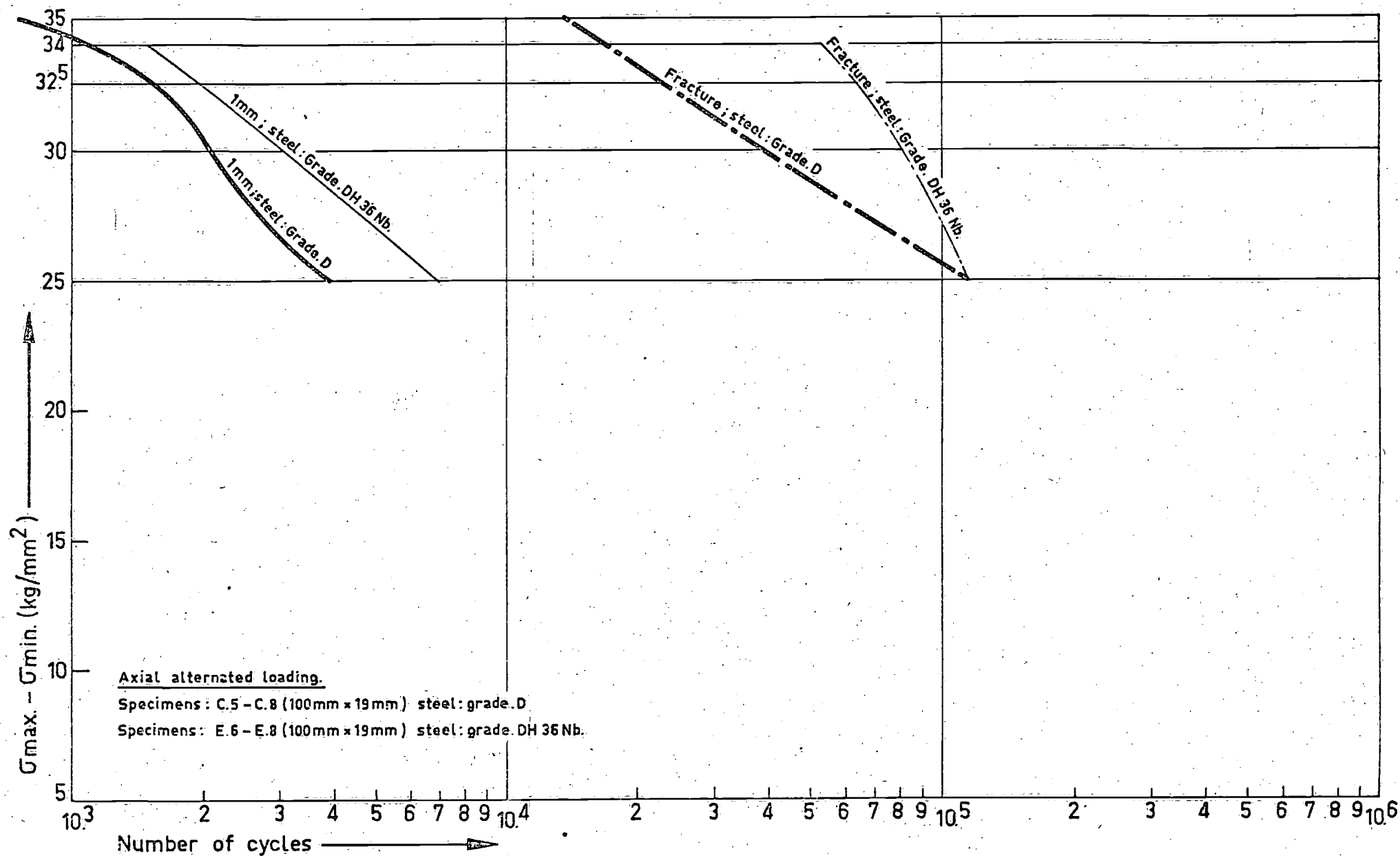


FIG.3-11 FATIGUE CURVES FOR 1mm CRACK LENGTH AND FOR COMPLETE FRACTURE.

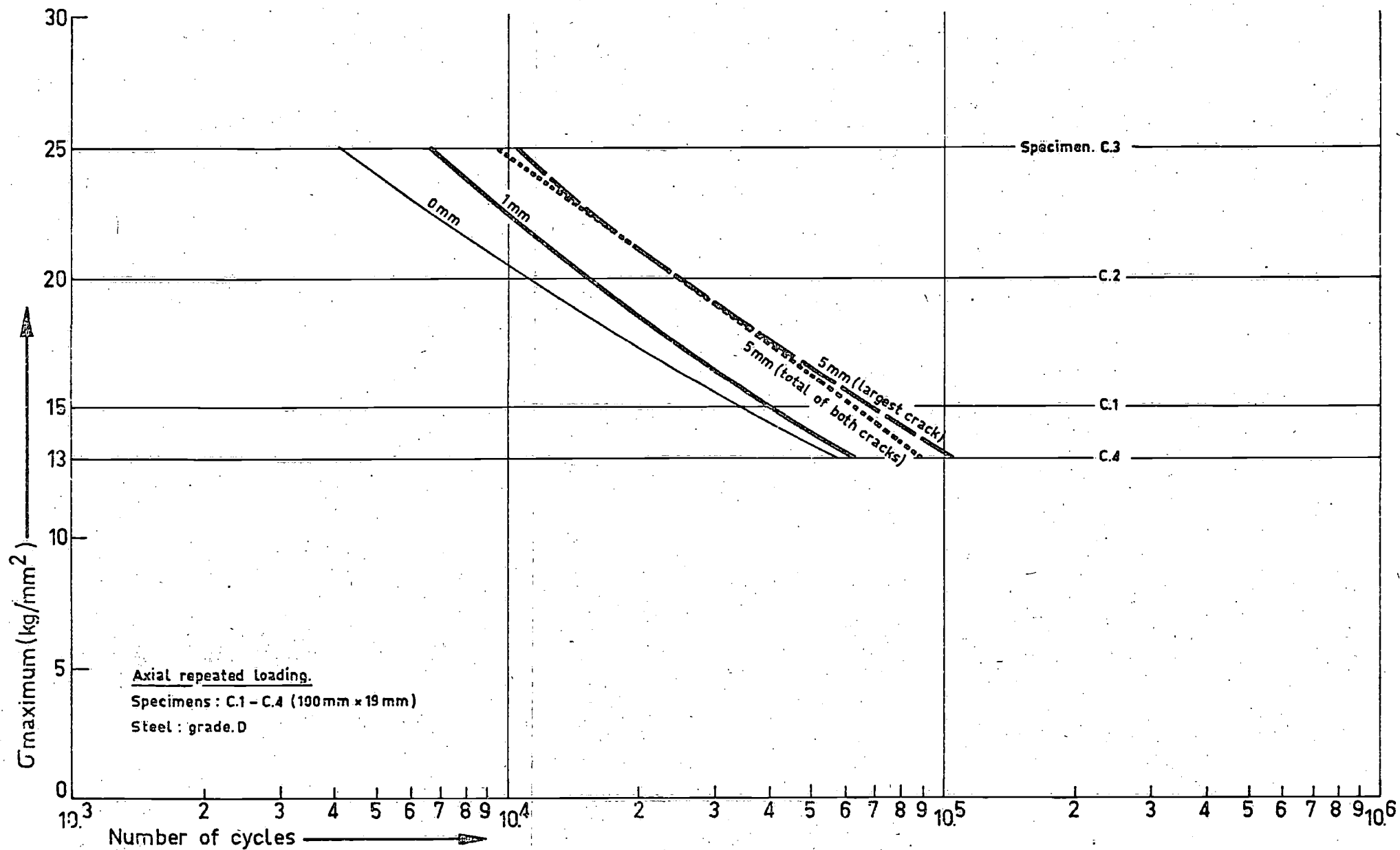


FIG.3-12 FATIGUE CURVES FOR 0mm,1mm AND 5mm CRACK LENGTH.

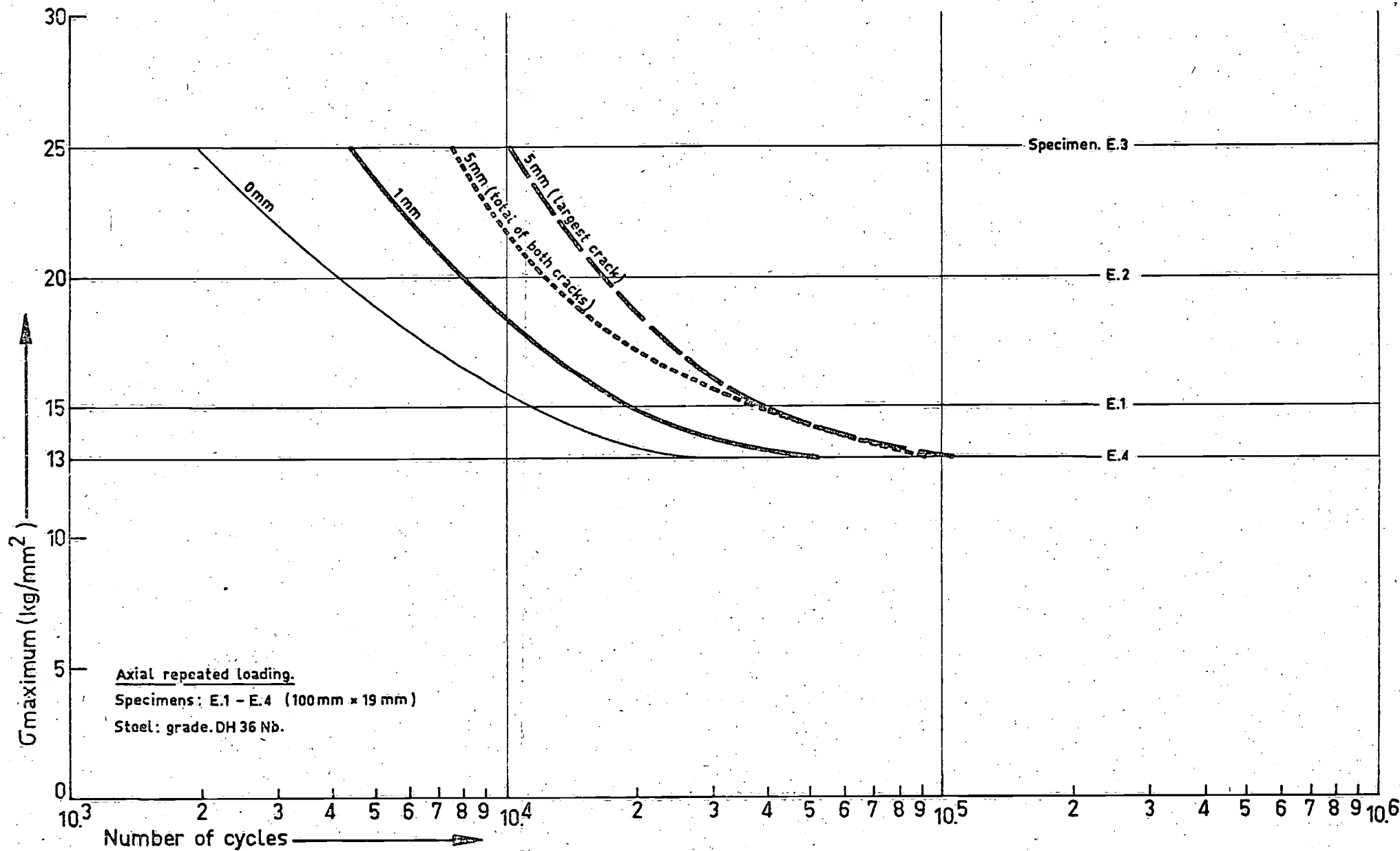


FIG.3-13 FATIGUE CURVES FOR 0mm, 1mm AND 5mm CRACK LENGTH.

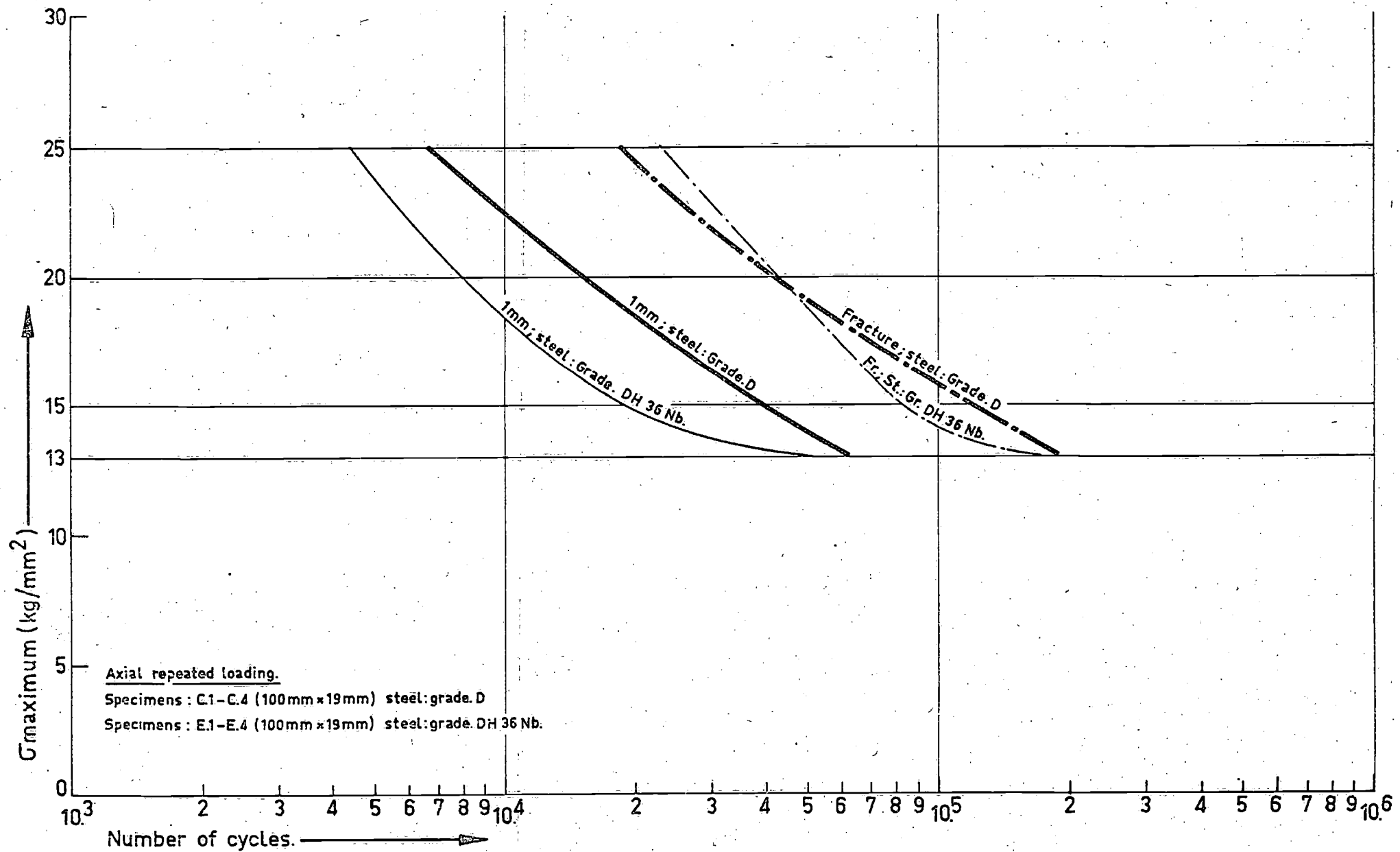


FIG.3-14 FATIGUE CURVES FOR 1mm CRACK LENGTH AND FOR COMPLETE FRACTURE.

Section 4. Analysis of the experimental results obtained with the full-scale specimens tested in Delft.

a. Crack growth.

The difficulties mentioned in the introduction concerning the analysis of the experimental data have also been met when studying the behaviour of the full-scale specimens. The greatest problem was that in specimens of one type the cracks could propagate in essentially different ways. This especially applied to the bottom details. The influence of this complication on the presentation of the results is still studied. But it may be taken that eventual corrections will not change the figures in this report significantly. Therefore they have been included in the present report. They replace figures 1 to 8 of /2/ on account of new test data and improved analysis of results.

Figures 4-1 a, b, c show the results for the bracketparts of the specimens for +20°C, -37°C and combined. Figures 4-2 a, b, c apply to the bottomparts.

From figures 4-1-c and 4-2-c it remains clear that the fatigue-strength is better the lower the temperature, as already observed in /2/.

In figures 4-1-a and 4-2-a the dotted lines indicate the fatigue lives of the formerly tested specimens made of St. 42, /3/. A distinct advantage for St. 52 can be observed for 100 and 500 mm² crack area. (The dotted lines for 0 mm² crack area should not be compared with the full ones (St. 52) because it is certain that the first have not been determined as carefully as the second).

In fig. 4-1-b is demonstrated how a minor weld detail may influence the results. The points on the line 703-03 are situated more favourable than the other ones. This may be attributed to the fact that in the specimen concerned the connecting weld between bracket and longitudinal frame had been interrupted (did not exist) at the end of the longitudinal frame.

In the brackets the cracks generally propagated in the direction shown in fig. 4-3-b-c. Only in one case the crack propagated parallel to the fusion line, (see fig. 4-4-c). In the bottom 3 types of crack propagation have been

observed: see fig. 4-6.

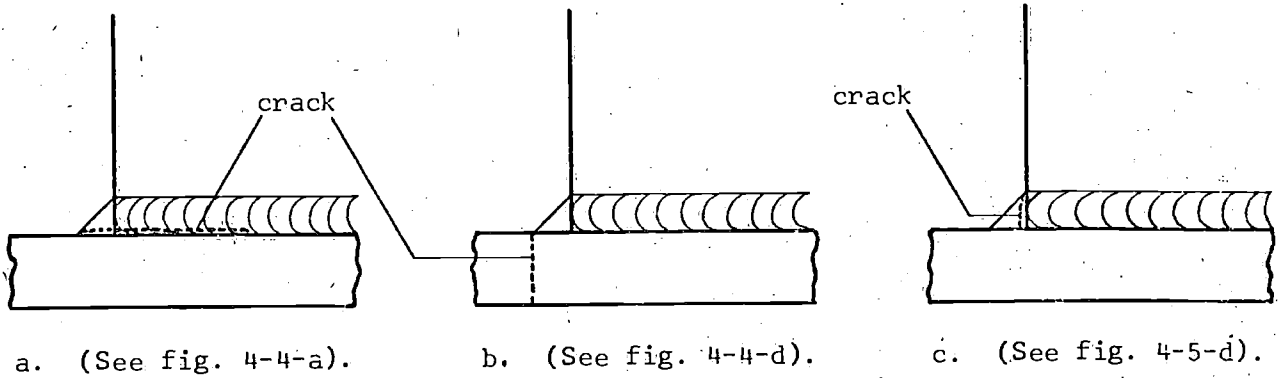


FIG. 4-6.

Mixed forms of fig. 4-6-a and b were quite common, (fig. 4-4-a). The peculiarities in crack path are often reflected in curves, representing crack growth as function of numbers of cycles. Figures 4-7, 4-8 and 4-9 may give some idea of this.

In order to make possible comparisons between the behaviour of the present specimens and those of St. 42 formerly tested, the numbers of cycles connected to the horizontal part of the crack paths may be eliminated. As said before, this point is still under consideration.

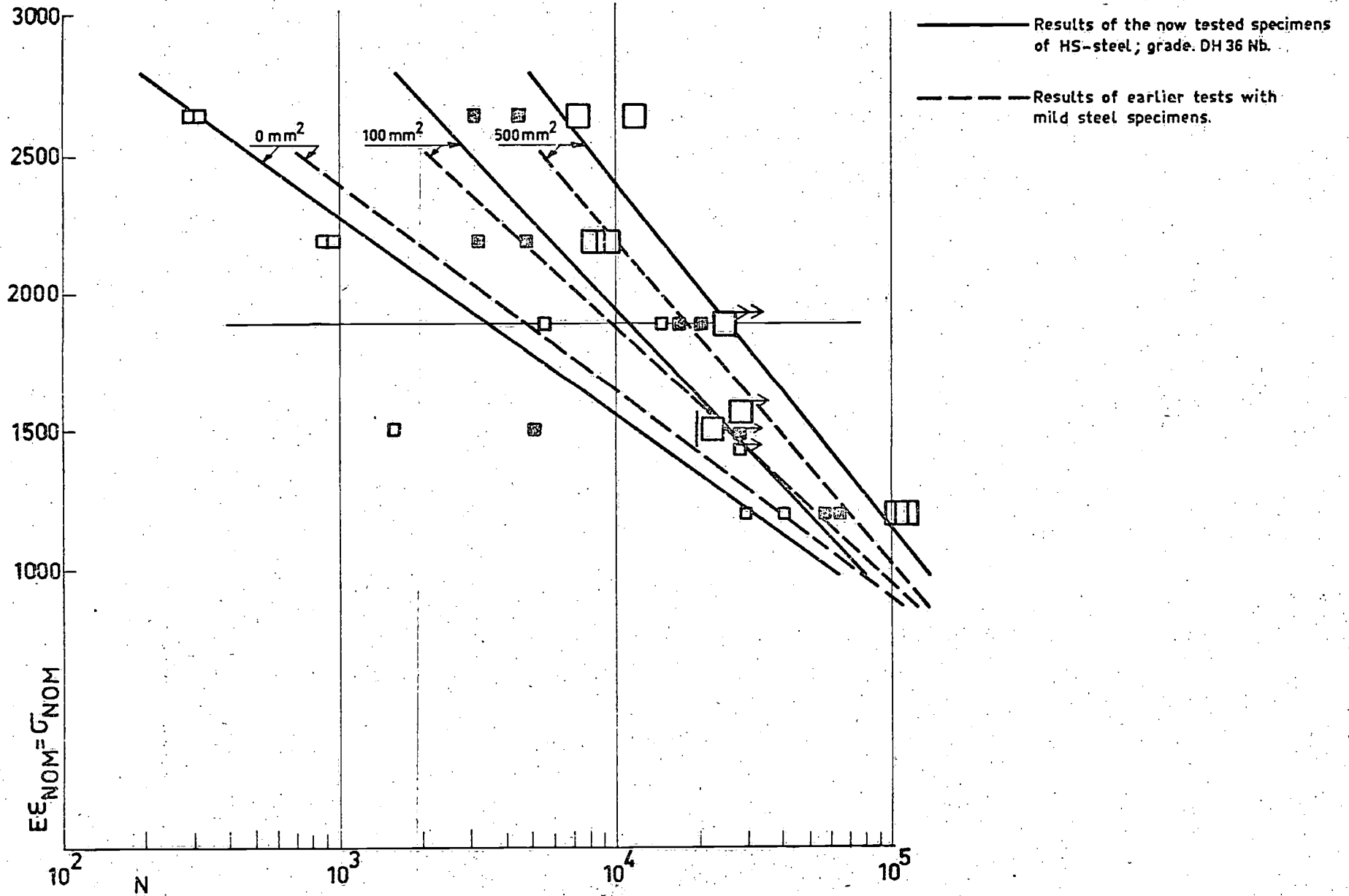


FIG.41-a FATIGUE-LINES FOR 1A-BRACKETS AT ROOM TEMPERATURE. CRACK-AREA OF 0, 100 AND 500 mm².

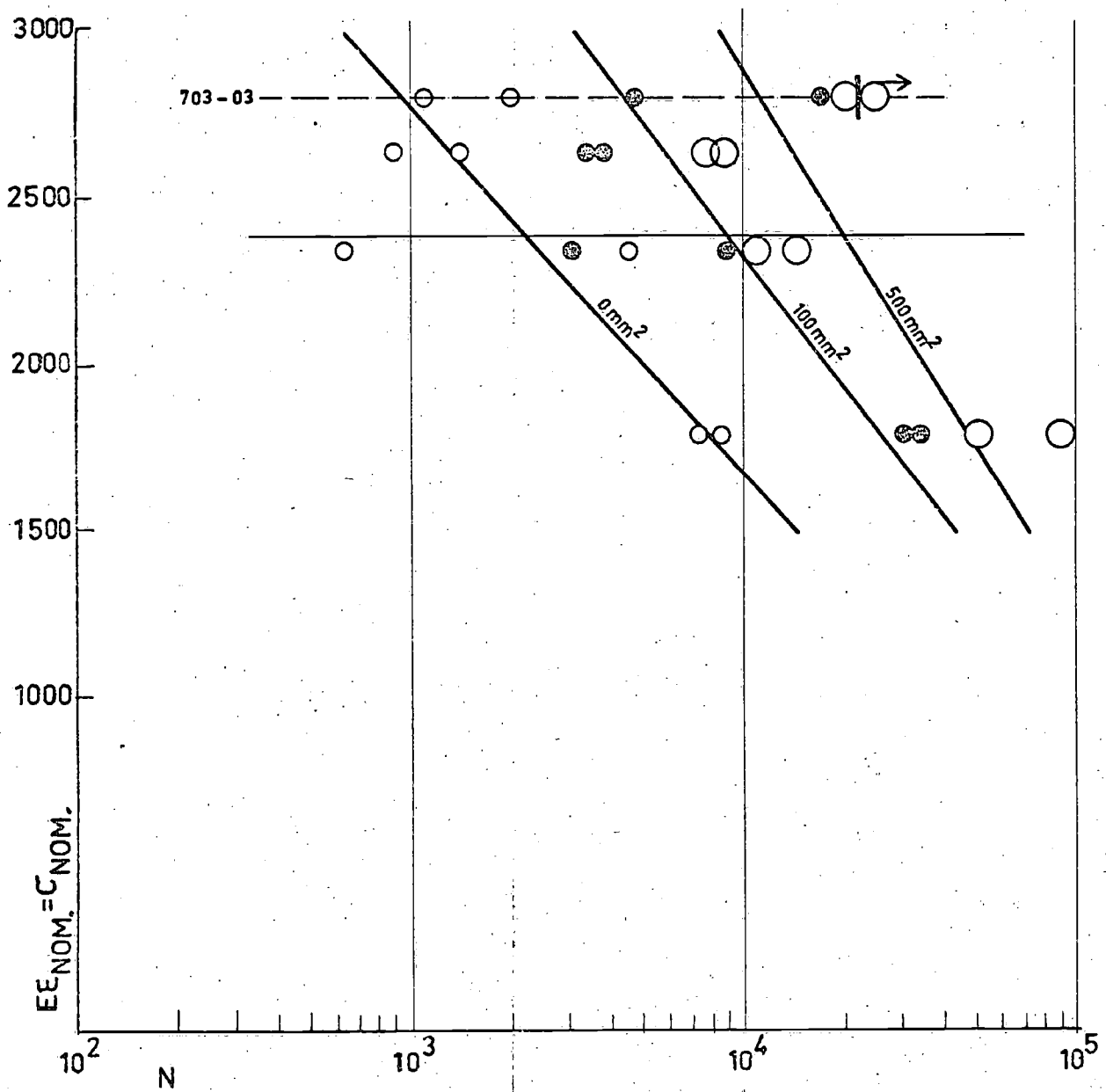


FIG.4-1-b FATIGUE-LINES FOR 1A-BRACKETS AT TEMPERATURE OF -37°C.
 CRACK-AREA OF 0, 100 AND 500 mm² (HS-STEEL; GRADE. DH 36 Nb.).

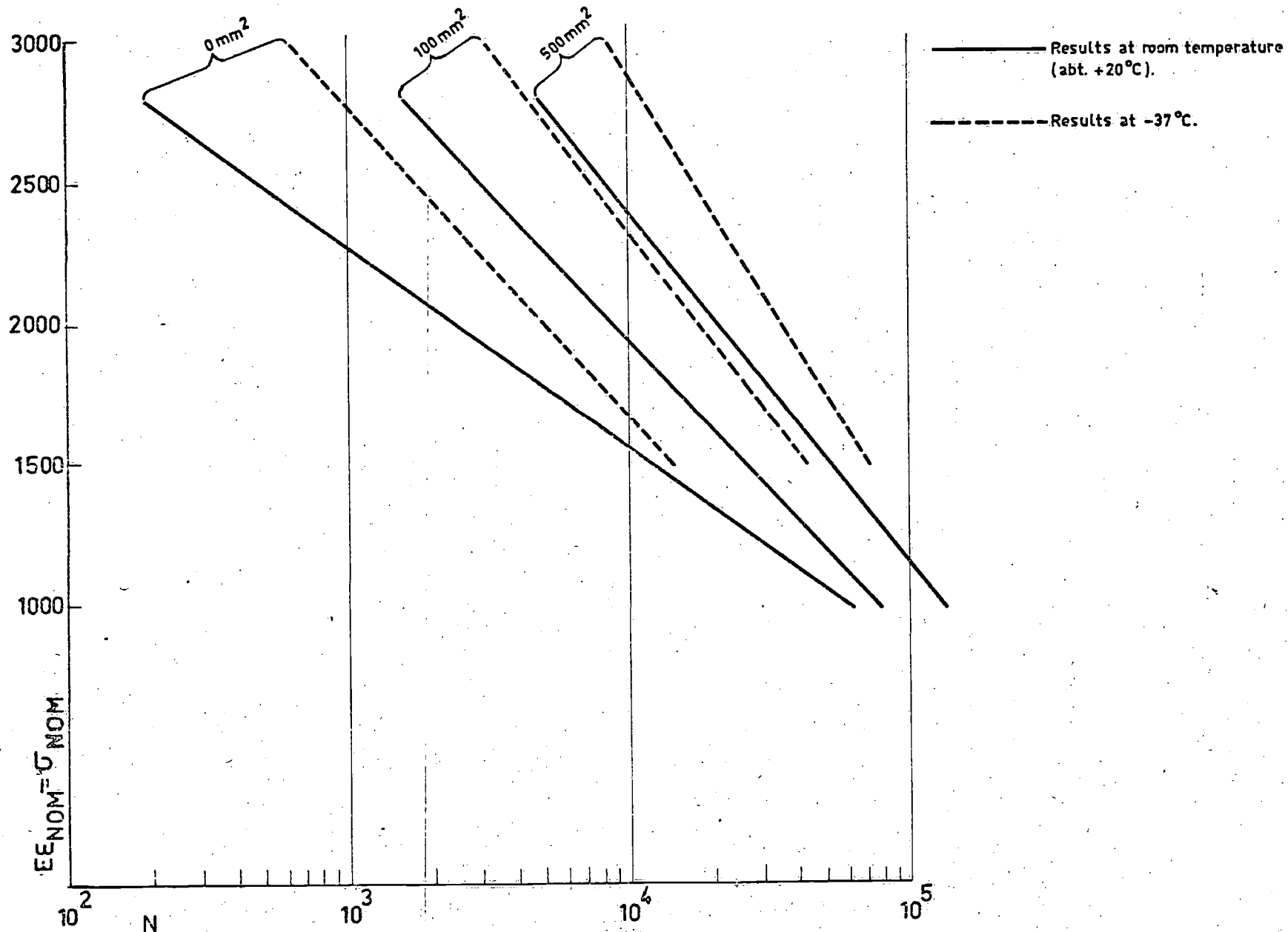


FIG.4-1-c COMPARISON OF FATIGUE-LINES FOR 1A-BRACKETS AT DIFFERENT TEMPERATURES. CRACK-AREA OF 0,100 AND 500 mm². (HS-STEEL; GRADE. DH 36 Nb.).

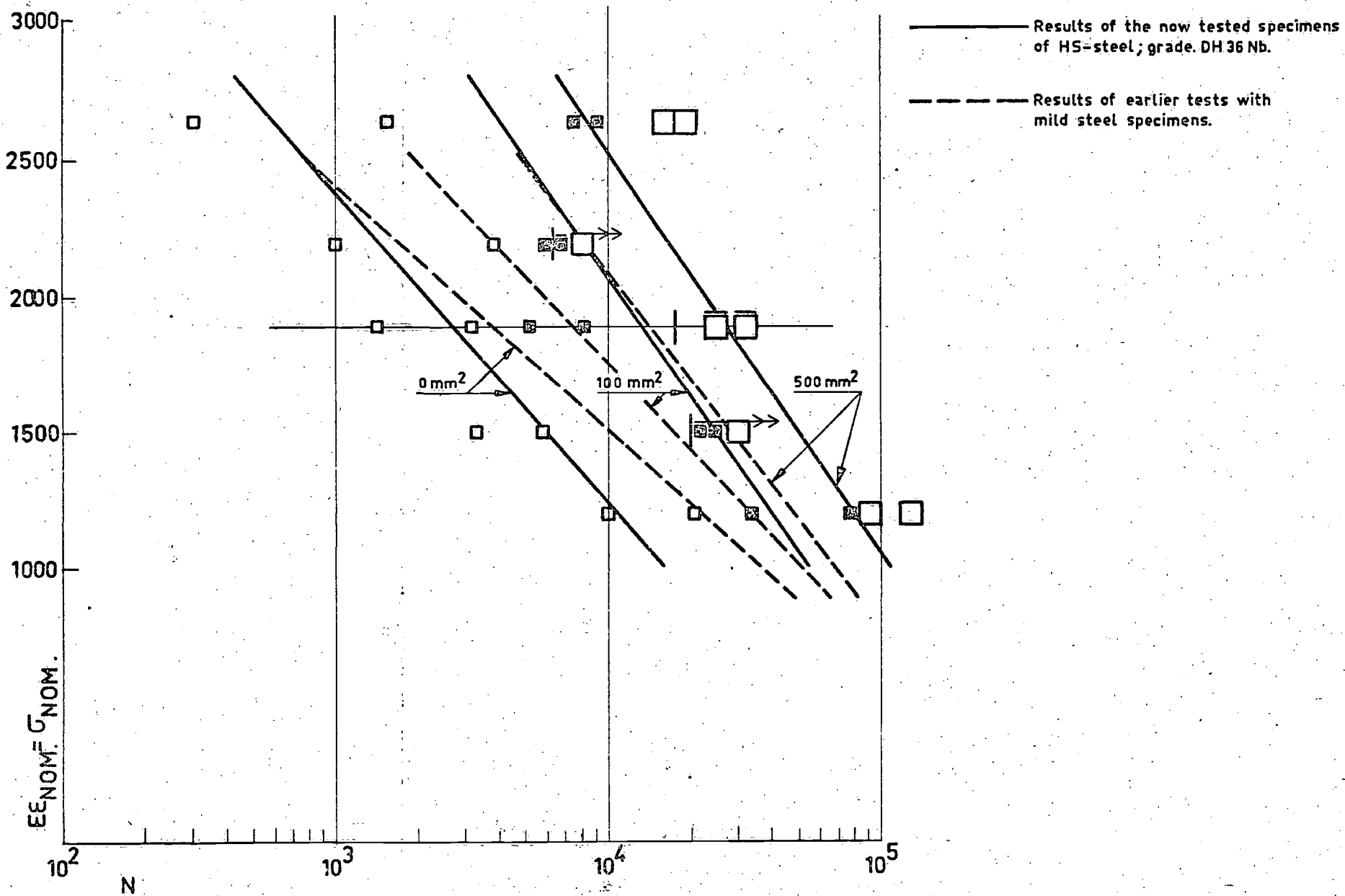


FIG.4-2-a FATIGUE-LINES FOR 1A-BOTTOMS AT ROOM TEMPERATURE. CRACK-AREA OF 0, 100 AND 500 mm².

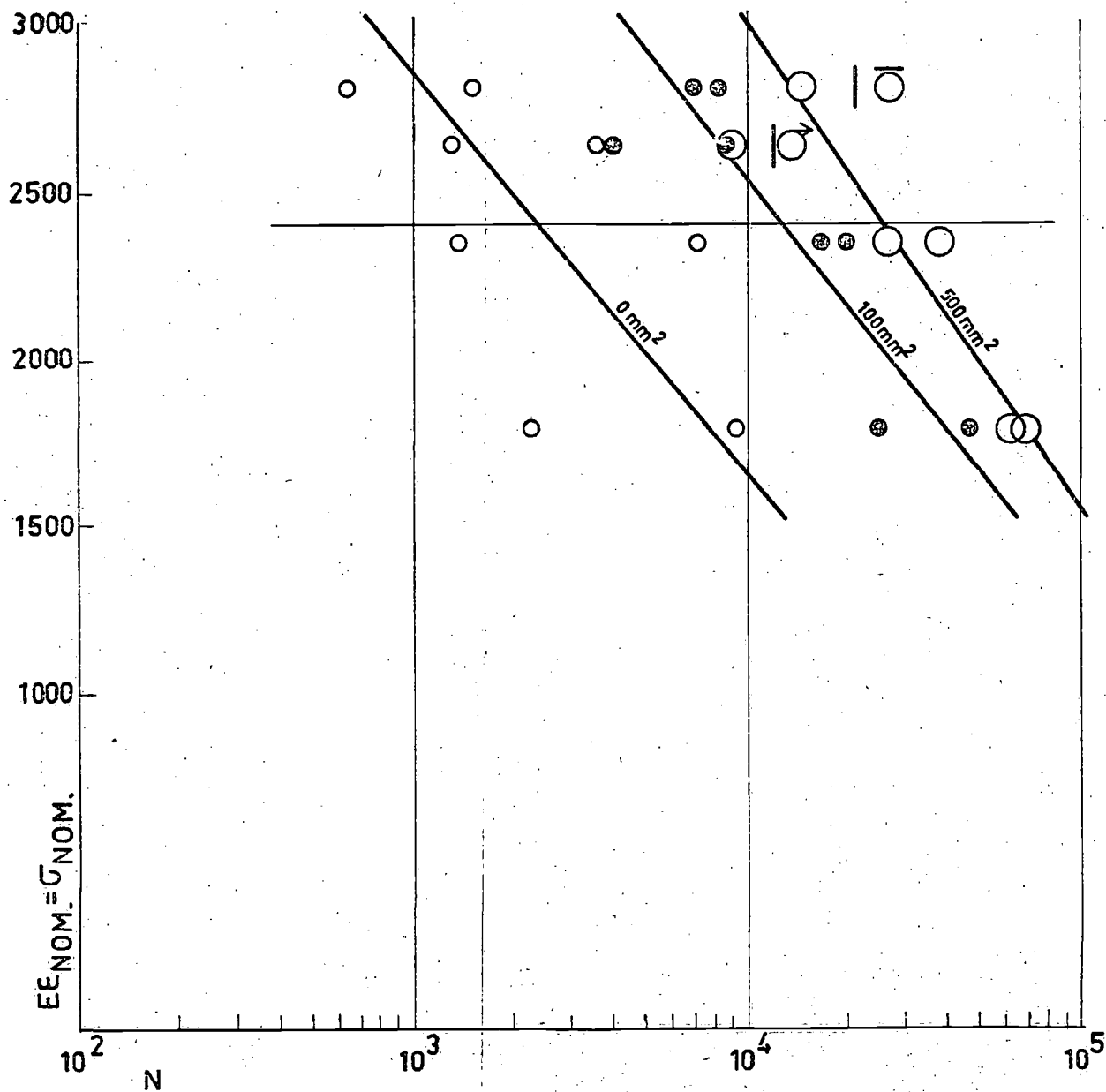


FIG.4-2-b FATIGUE-LINES FOR 1A-BOTTOMS AT TEMPERATURE OF -37°C .
 CRACK-AREA OF 0,100 AND 500 mm^2 (HS-STEEL ; GRADE. DH 36 Nb.).

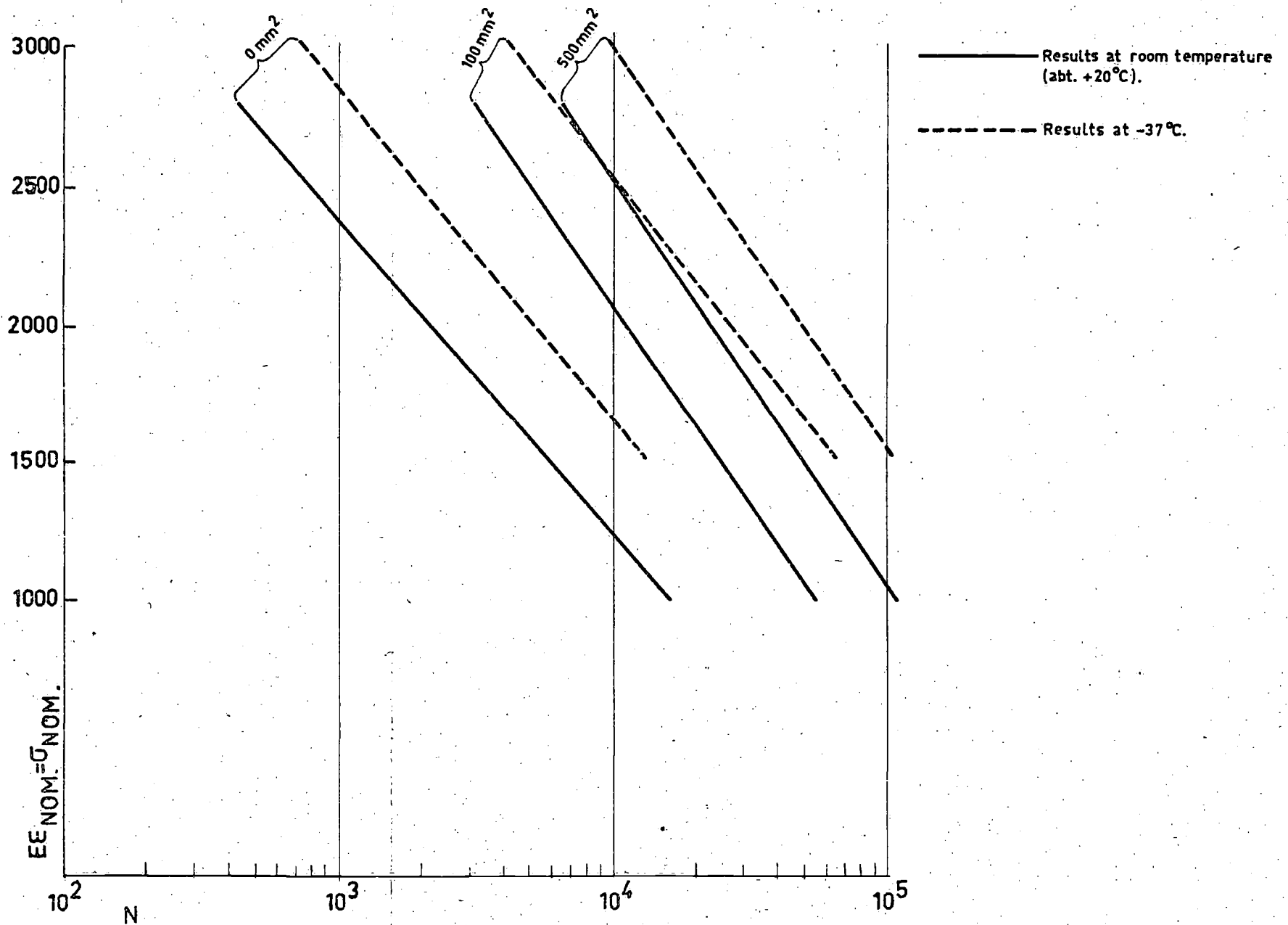
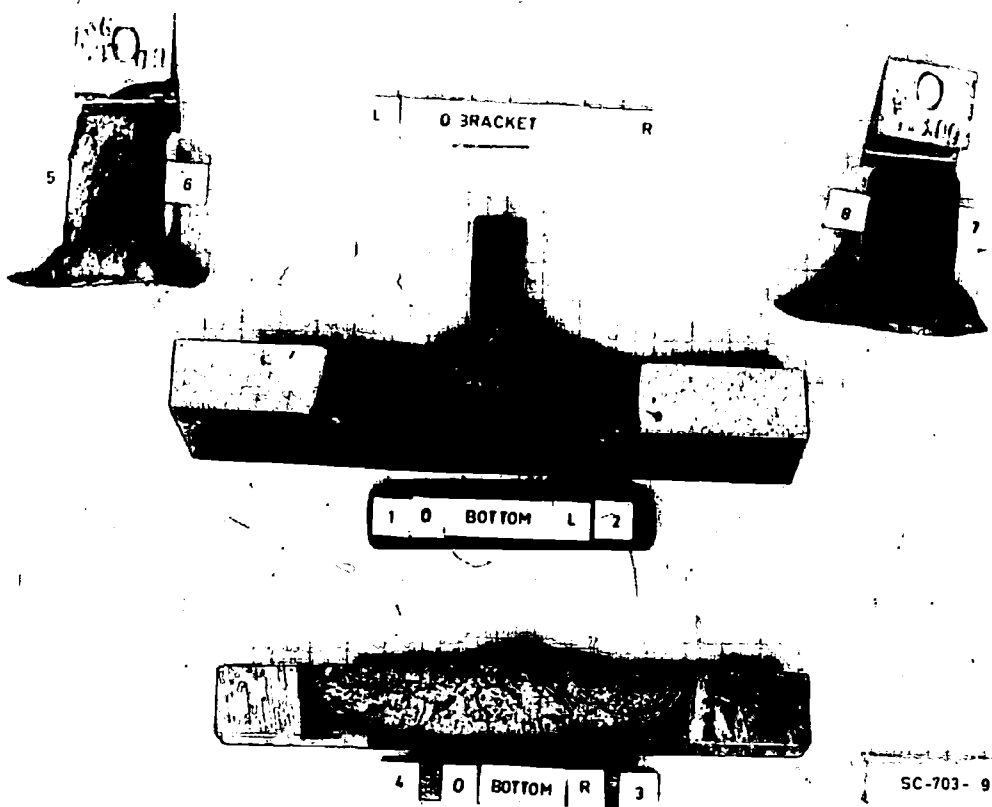
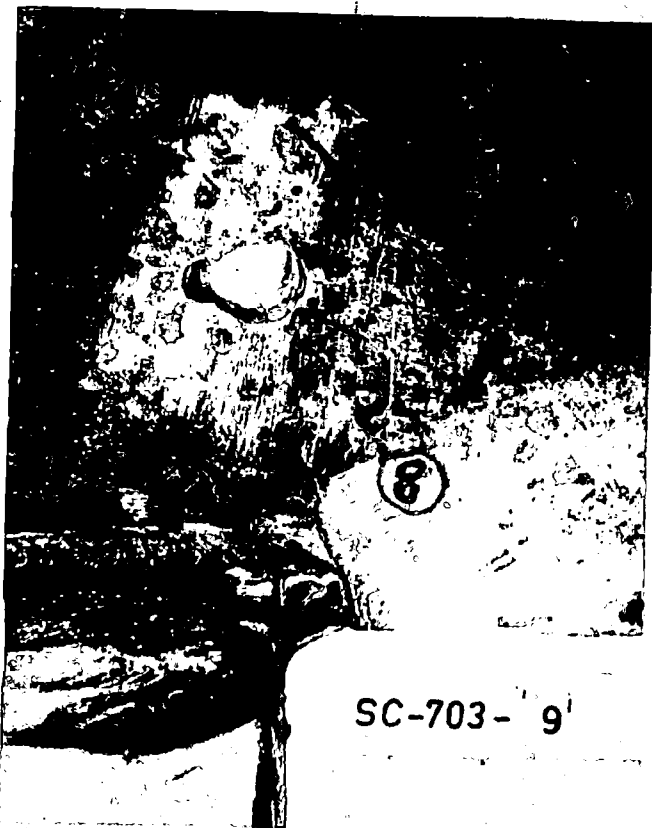


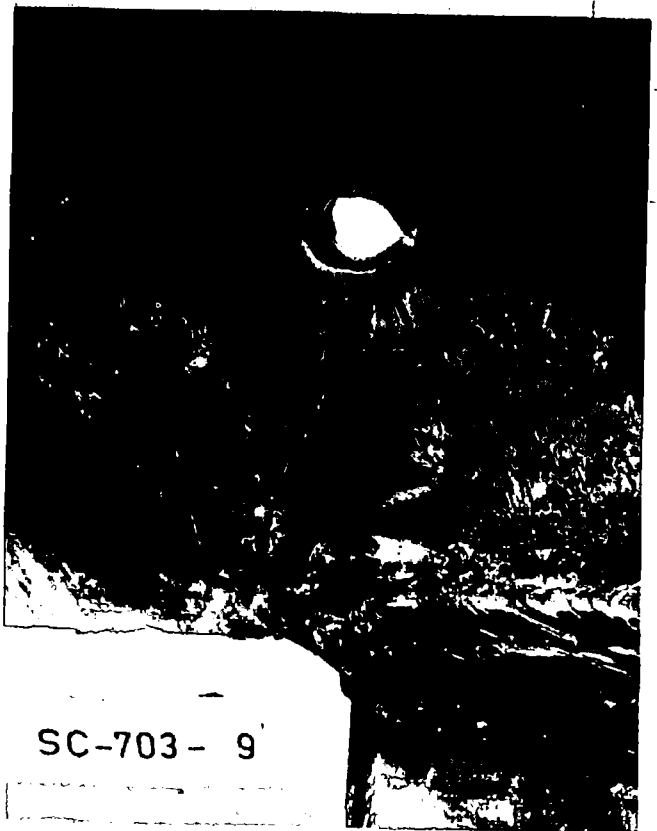
FIG.4-2-c COMPARISON OF FATIGUE-LINES FOR 1A-BOTTOMS AT DIFFERENT TEMPERATURES. CRACK-AREA OF 0, 100 AND 500 mm². (HS-STEEL; GRADE. DH 36 Nb.)



A. General view of fatigue cracks.

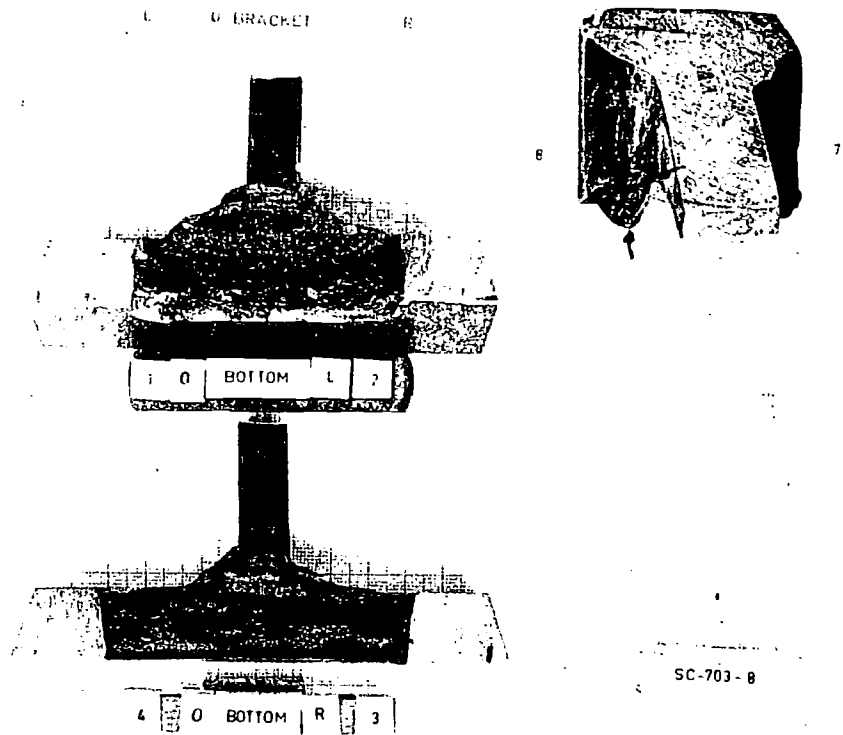


B. Bracket right (backside).

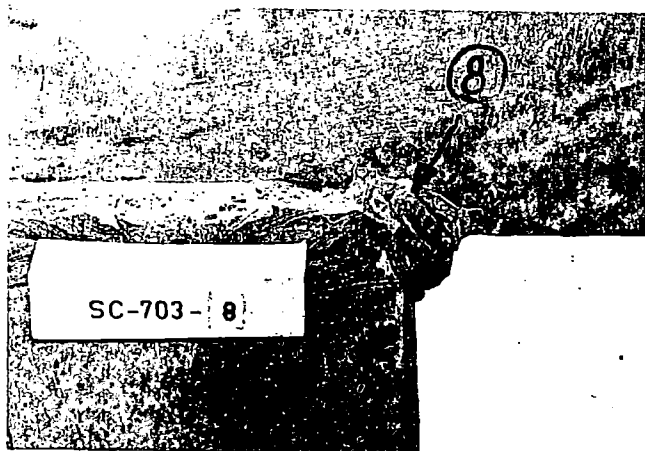


C. Bracket left (backside).

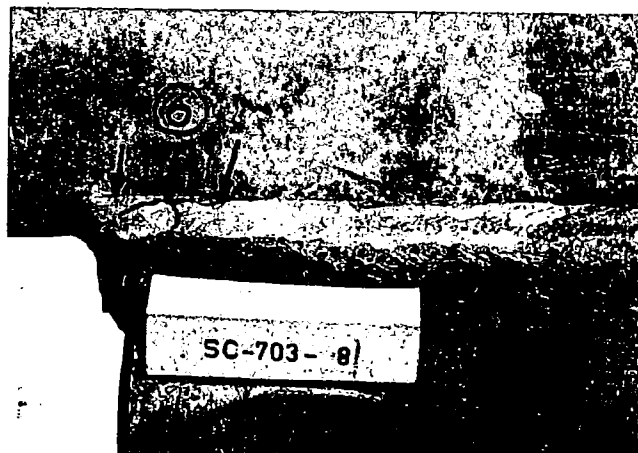
Fig. 4-3 Fatigue cracks of specimen nr. 9.



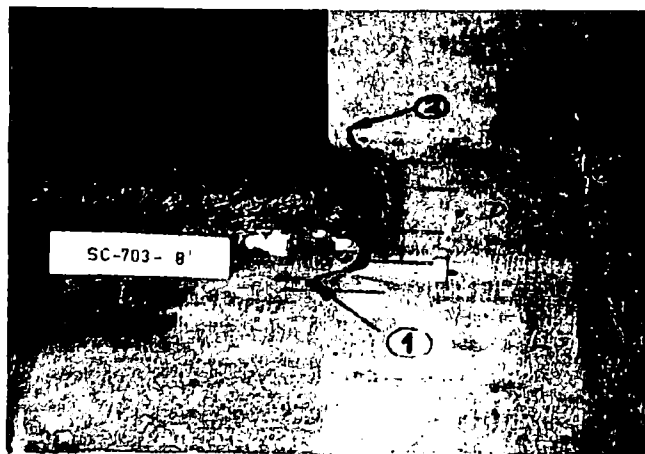
A. General view of fatigue cracks.



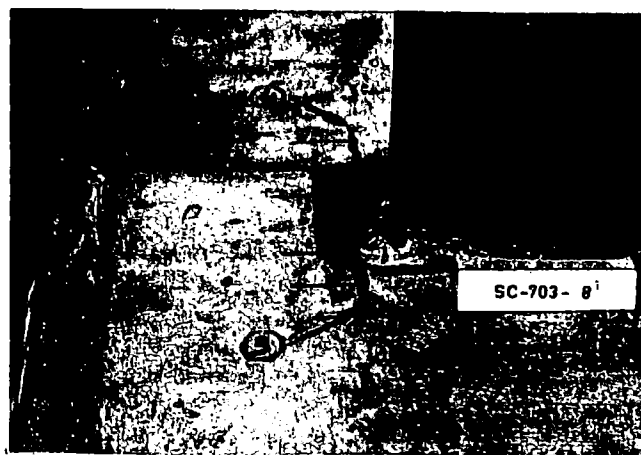
B. Bracket right (backside).



C. Bracket left (backside).

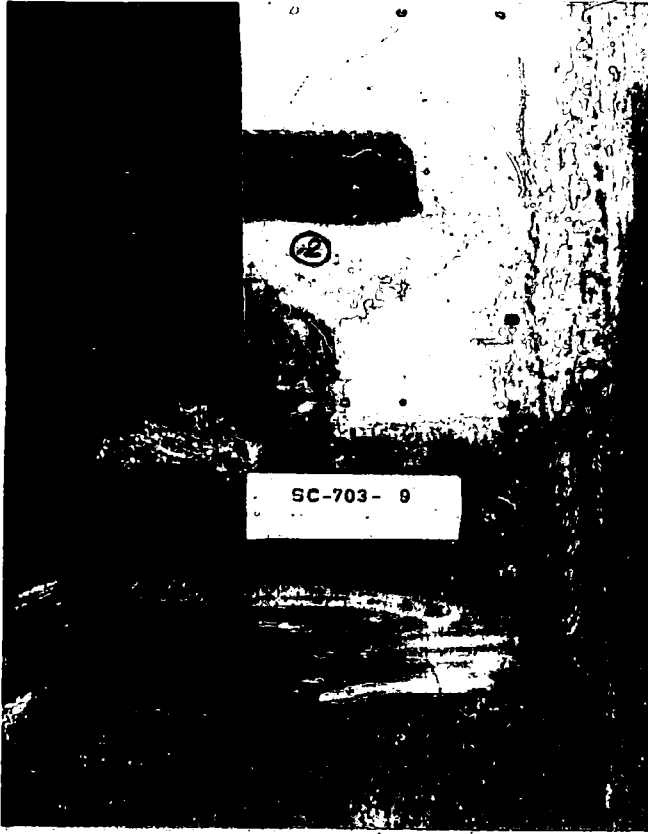


D. Bottom left.

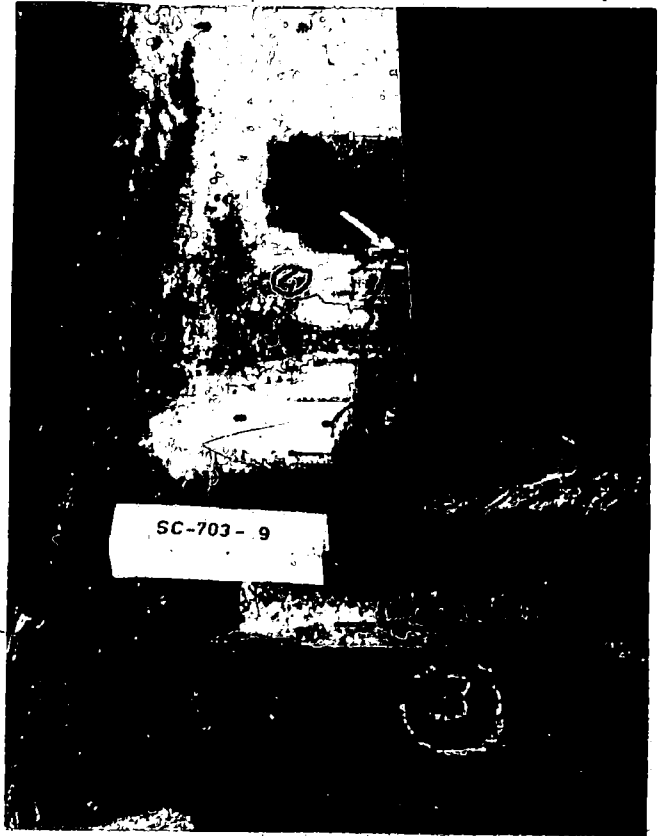


E. Bottom right.

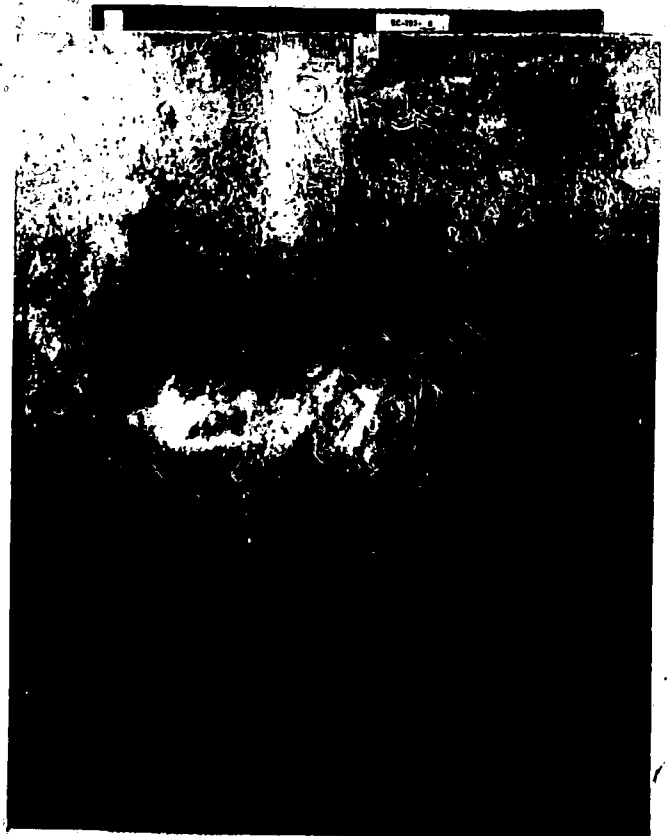
Fig. 4-4 Fatigue cracks of specimen nr. 8.



D. Bottom left.



E. Bottom right.



F. Bottom right lower side.

Fig. 4-5 Fatigue cracks of specimen nr. 9.

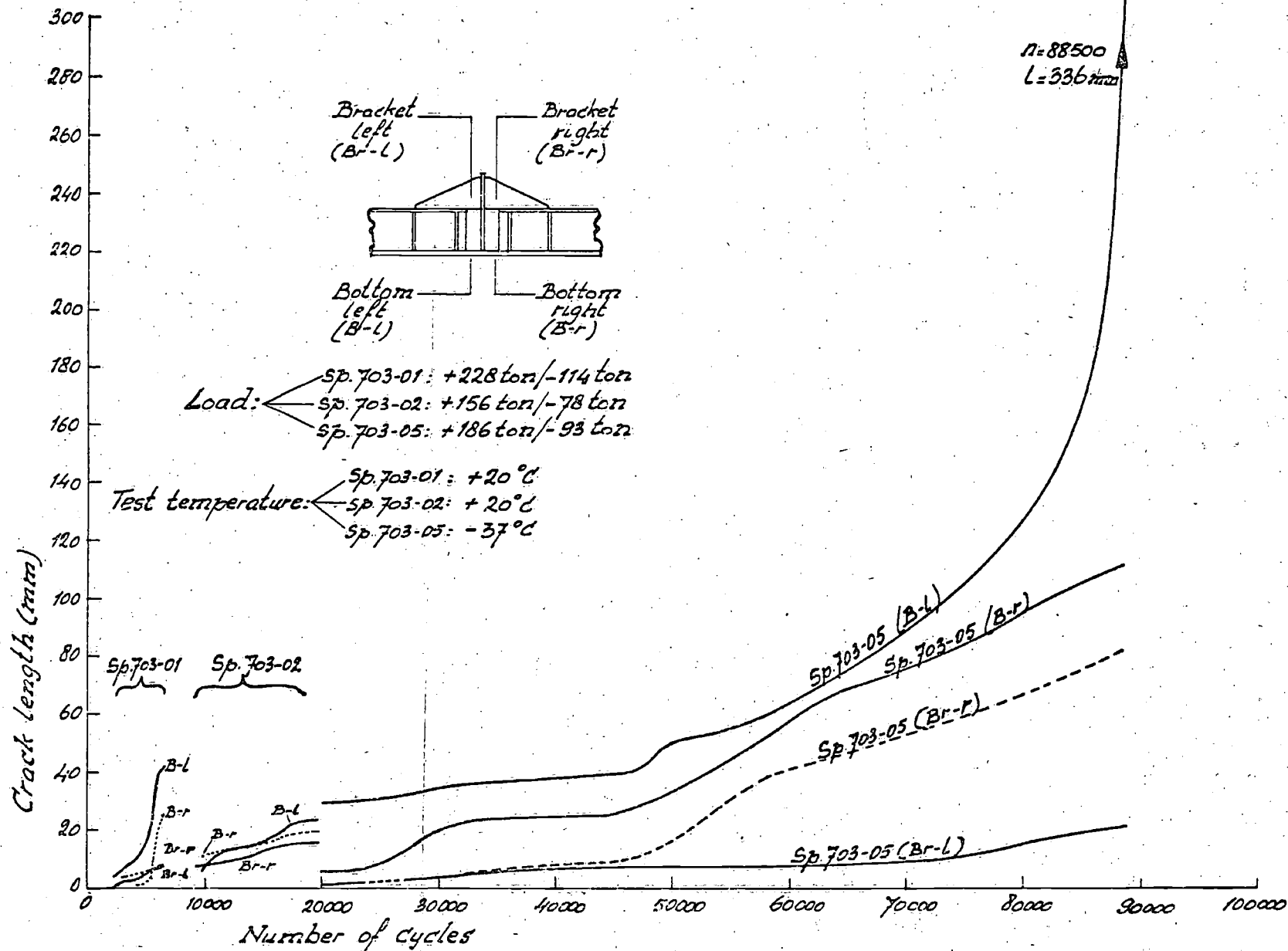


Fig. 4-7 Crack development in function of number of load cycles.

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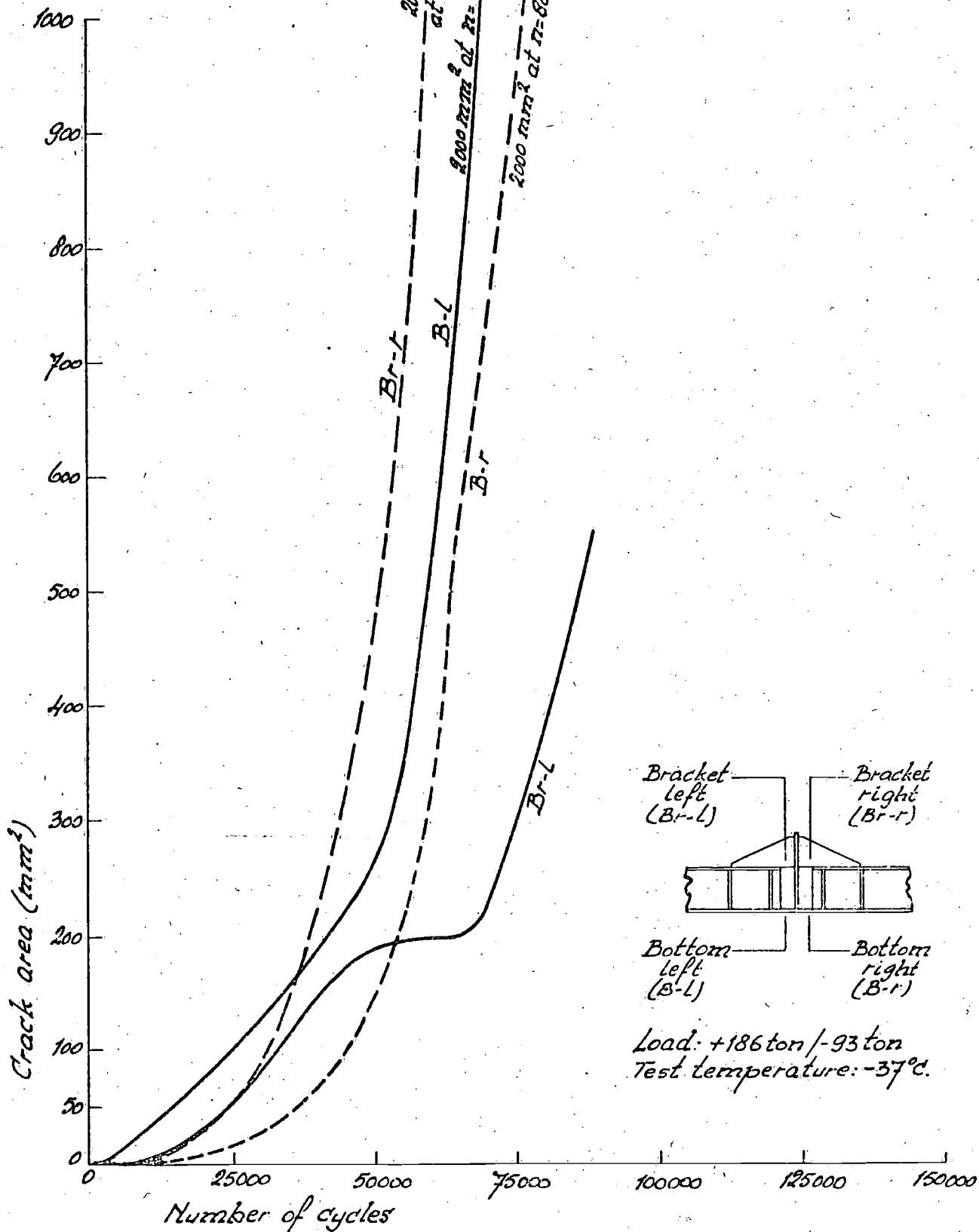


Fig. 4-8 Curves of crack-area in function of number of cycles, constructed from fig. 4-7 and observations of crack-surface.

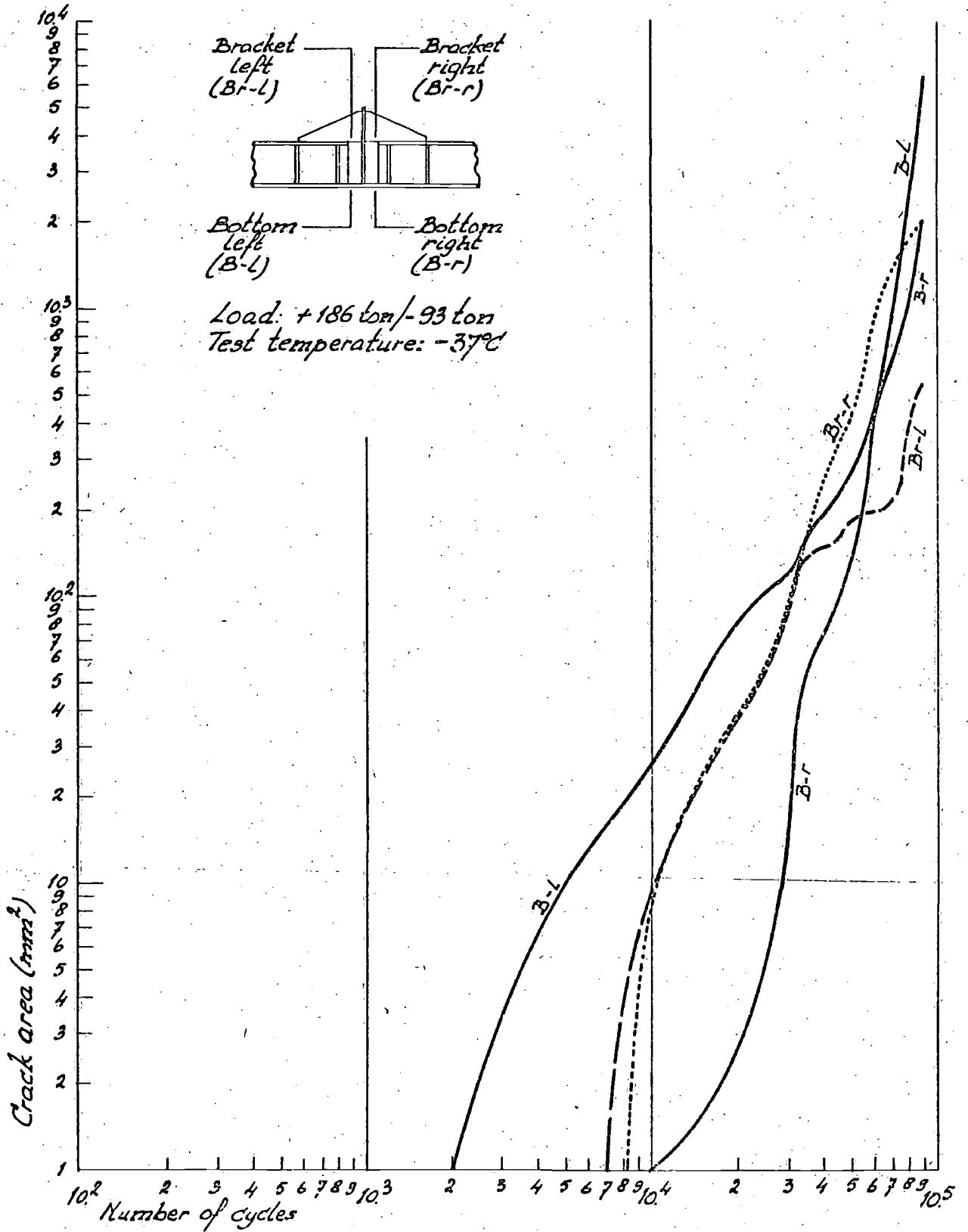


Fig. 4-9 Curves of fig. 4-8 on bi-logarithmic scales.

14-11-73
15-3-74

Section 5. Final observations.

It is hoped that the committee has obtained a satisfactory idea about the experimental work carried out in the various countries, the scope and progress of the analyzing and synthesizing work, and the form which the final report will get.

One intriguing problem, which emerged from the German part /6/ of the investigations is worth mentioning in view of possible extra work. A significant difference has been observed between the results of the programmed fatigue tests with elementary specimens for St. 42 and St. 52. It would be interesting to know whether that tendency also will appear for welded structural specimens. A number of these specimens are still available in France. They will be transported to Delft. It would be welcome when some financial support for program testing with these specimens could be obtained, preferably from the CECA.

The main conclusion from all results remains that for constant amplitude loading, as well in axial repeated and alternating loading, as in repeated bending, the advantage of St. 52 over St. 42 is small. In the high-cycle region there is virtually no advantage. In the low-cycle region a fair difference between St. 52 and 42 is obvious.

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/2/ H.G. Scholte.

"Interim-report on low cycle fatigue investigations with ship structural components made of higher strength steel".

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"Low cycle fatigue of steel structures".

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/5/ Report no. 153/4585, Lab. v. Weerstand van Materialen Ghent.

/6/ Report no. 153/4706, Lab. v. Weerstand van Materialen Ghent.

/7/ H. Paetzold.

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Bericht Nr. 33/1973, Forschungszentrum des Deutschen Schiffbaus, Hamburg.

APPENDIX I

COMPTE-RENDU D'ESSAIS DE FATIGUE EN TRACTION ONDULEE
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ET TRACTION-COMPRESSION D'ELEMENTS SOUDES EN ACIER
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ORDINAIRE ET ACIER A HAUTE RESISTANCE
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MSN/RS/GL/NF

I. - OBJET DE L'ETUDE

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1,1. - Dans le cadre d'un programme général d'essais réalisé en coopération avec l'Italie, la Belgique, la Hollande, l'Allemagne, sous l'égide de l'Institut de Recherches de la Construction Navale, cet organisme a demandé, par lettre EC/ER N° 19832 du 12/10/70, au Groupe MATERIAUX et STRUCTURES NAVALS du Service Technique des Constructions et Armes Navales, d'effectuer des essais de fatigue sur deux types d'éléments soudés, confectionnés à partir de tôles d'acier de deux nuances différentes, afin de comparer les comportements en fatigue de ces assemblages.

1,2. - Le présent compte-rendu relate ces essais et en présente les résultats.

II. - EXECUTION DES ESSAIS

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2,1. - Eléments d'essais :

2,11 - Les éléments d'essai ont été réalisés en tôles d'acier ST37 (acier ordinaire) et ST52 (acier HR).

2,12 - Deux types d'éprouvettes ont été testées : type A (figure 1), type B (figure 2) -. Elles sont au nombre de 13 par type et par nuance d'acier.

2,2. - Définition des essais

2,21 - Les éléments d'essais étaient soumis à un essai de fatigue suivant deux modes de sollicitation (traction ondulée : $\frac{P_{\min}}{P_{\max}} = 0$

ou

traction-compression : $\frac{P_{\min}}{P_{\max}} = -\frac{1}{2}$)

pour deux niveaux d'endurance (environ 50 000 cycles et 1 million de cycles), suivi pour la presque totalité, d'un essai de rupture statique à température ambiante et à 0°C pour une éprouvette de chaque type.

2,22 - Le critère de fin d'essai était l'apparition d'une fissure de fatigue de l'ordre de 25 mm de longueur, le contrôle de la propagation de cette fissure se faisant visuellement.

2,23 - Les essais de fatigue ont été effectués sur la machine verticale Amsler de 100 tonnes, les essais de rupture statique sur la machine MAN de 500-1 000 tonnes.

2,24 - Pour chaque type d'éprouvette, la répartition des contraintes a été déterminée à l'aide de jauges de déformation. Le nombre, le type et la position des jauges sont définis sur les figures 13 et 38, les résultats obtenus sont consignés dans les tableaux I et II.

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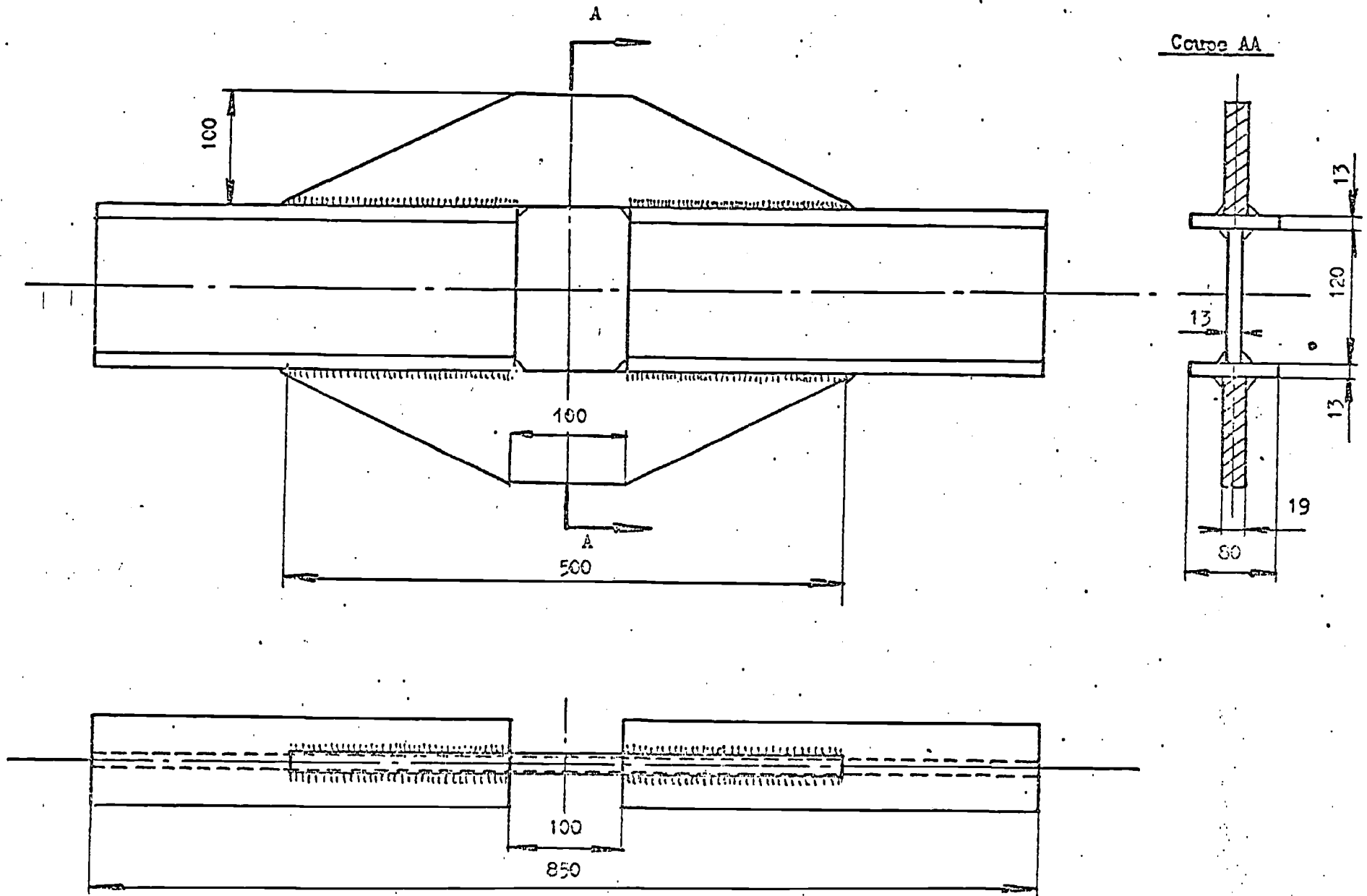


Fig.1 - Eprouvette type A .

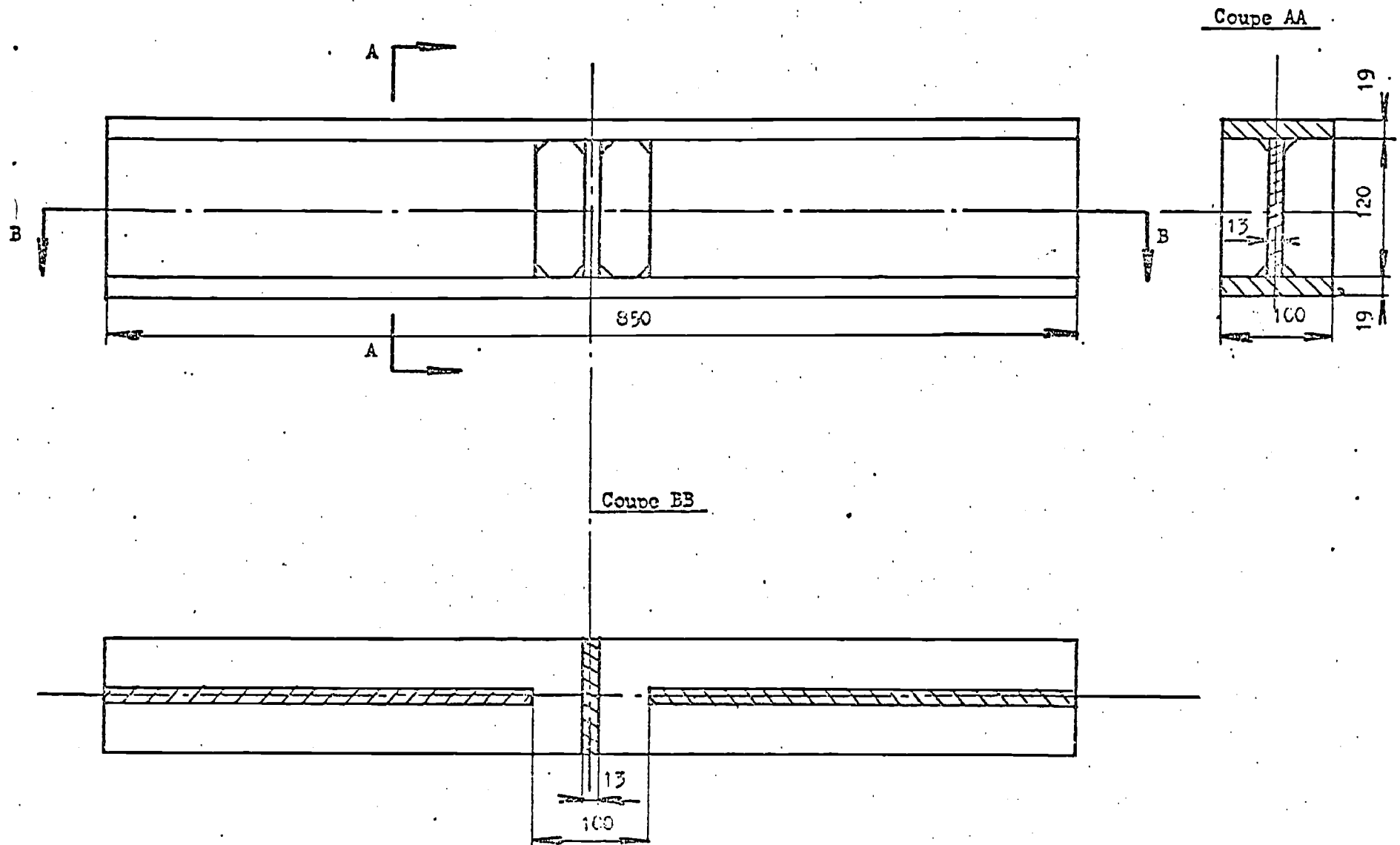


Fig.2 - Eprouvette type B .

III. - RESULTATS OBTENUS

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3,1 - Les tableaux III et IV récapitulent les résultats obtenus sur les éprouvettes testées.

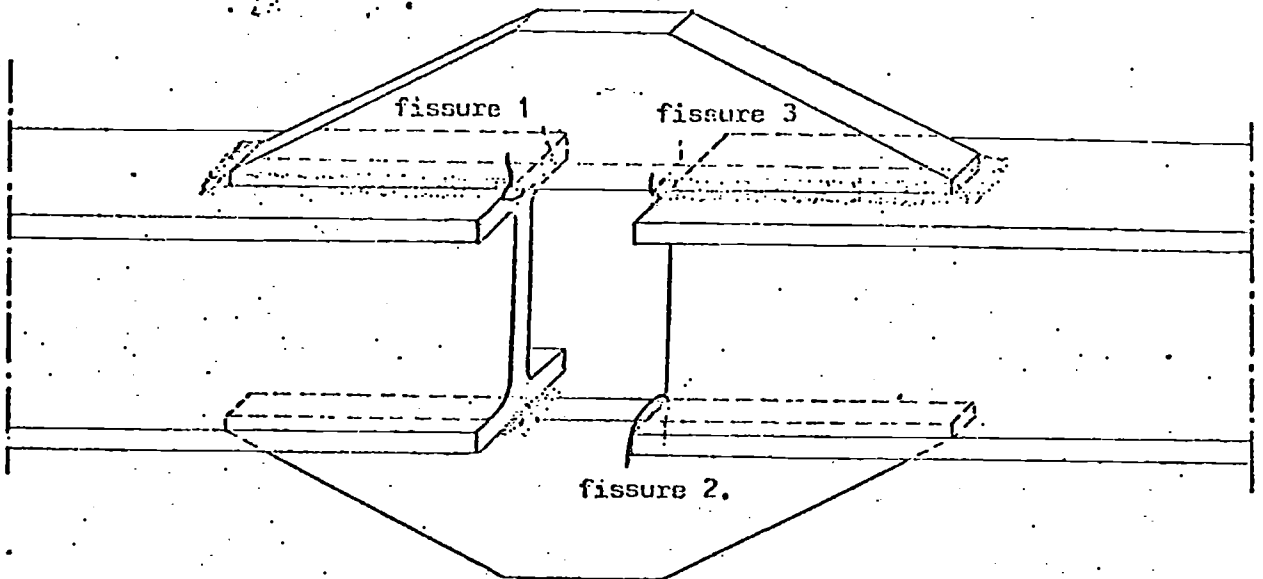
3,2 - La figure 62 montre les positions relatives des courbes de Woehler pour chaque type d'éprouvette, par nuance d'acier et suivant le mode de sollicitation.

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Epavelette type A en acier ST 37

Repere de l'epavelette : DE 9556-96-71A.

Mode de sollicitation : traction ondulée.



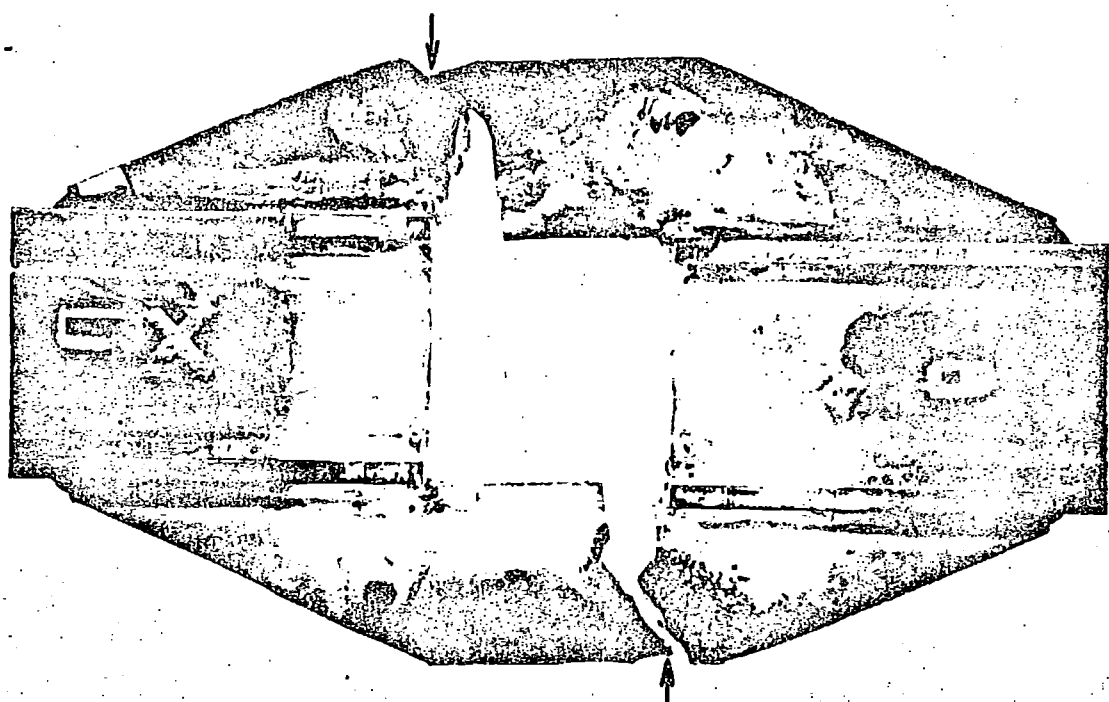
Position des fissures

Fig 3 - Repere MSN de l'epavelette : 5

Charge de rupture statique : { à l'ambiante : 100,5 tonnes.
à zéro degré :

Repere MSN de l'epavelette	Taux de travail en kg/mm ²		Nombre de cycles supportés	Observations
	Mini	Maxi		
5	0,5	16	11 400	<p>Après 8 000 cycles, trois fissures représentées sur la figure apparaissent. Elles sont toutes situées dans la tôle de renfort, amorcées au pied du cordon de soudure.</p> <p>Les fissures 1 et 2 ont 8 à 9 mm de longueur, la fissure 3, 2 mm environ.</p> <p>Elles se sont propagées dans toute l'épaisseur de la tôle.</p> <p>Après 11 400 cycles, la longueur des fissures 1 et 2 est portée à 17 mm environ.</p>

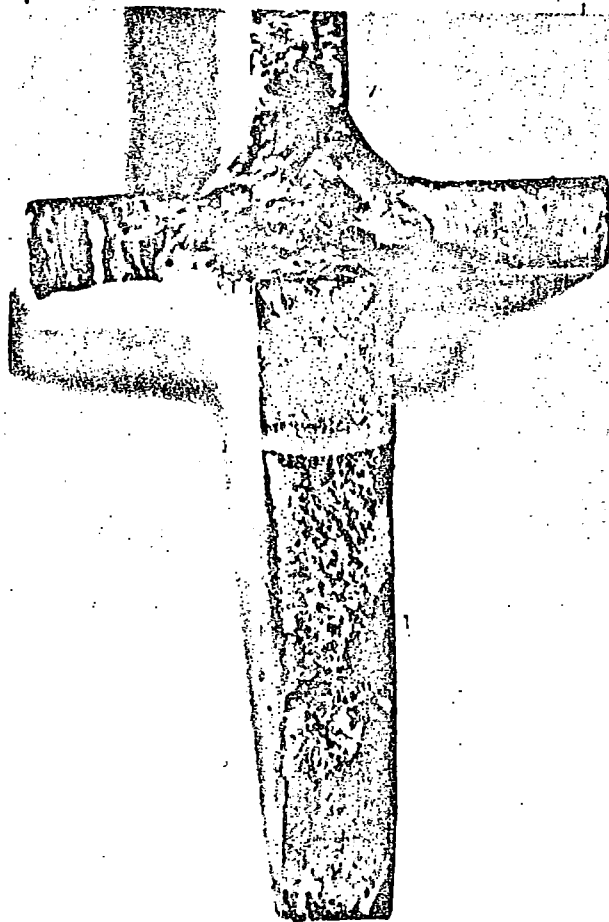
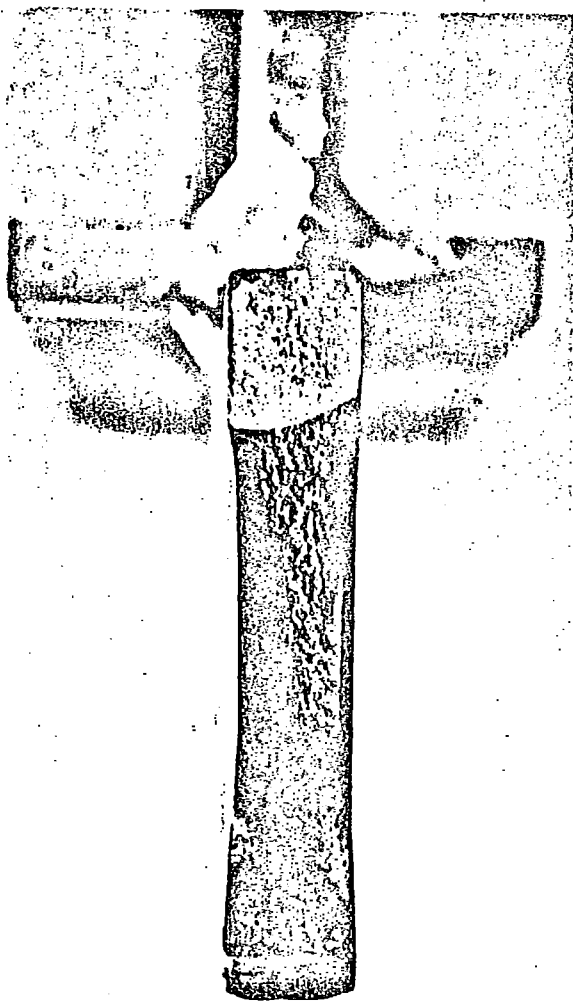
cassure 1.



cassure 2.

Positions des cassures.

x0,25



Surface de cassure 1.

x1.

Surface de cassure 2.

x1.

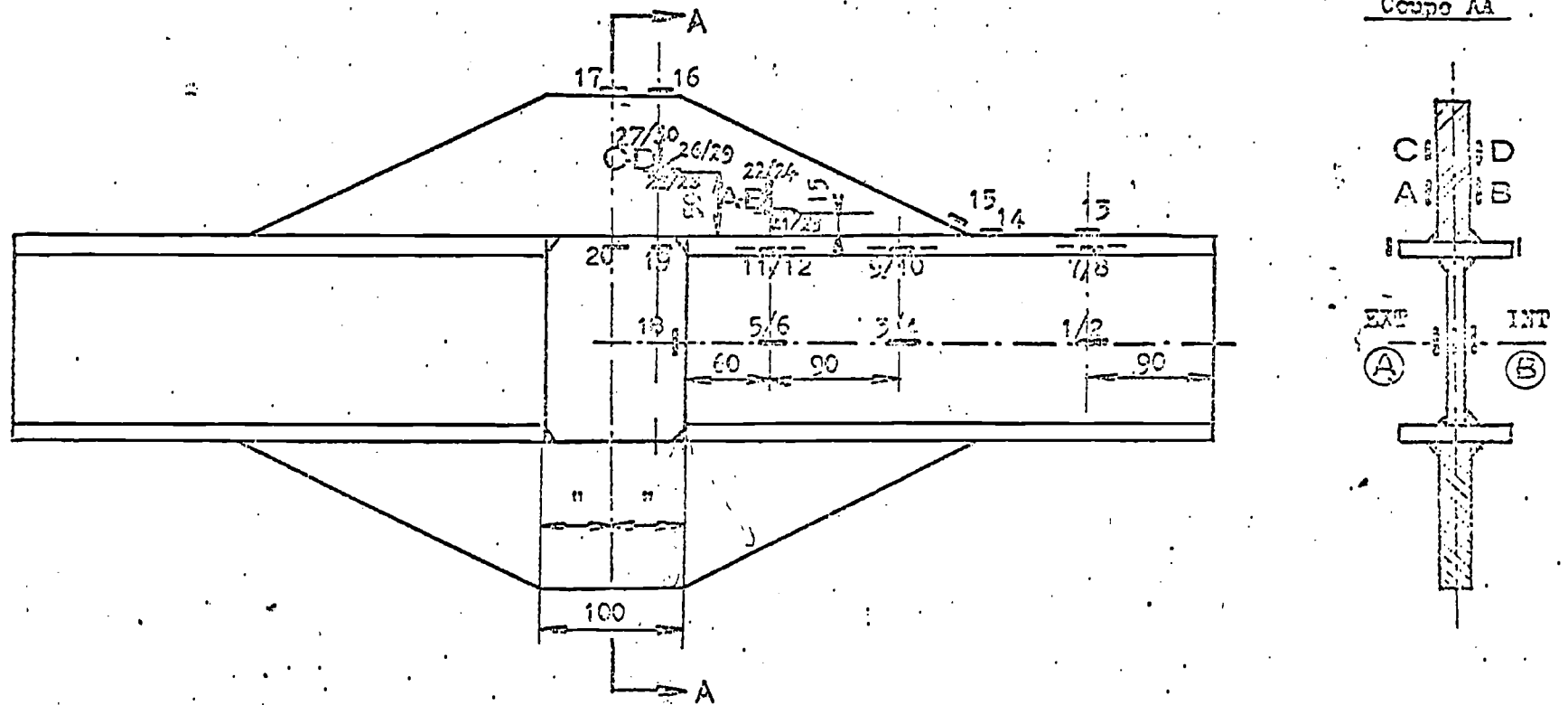


Fig.13 - Position des jauges pour l'éprouvette type A - (repère MSN : 6).

TABLÉAU I

- Résultats des mesures extensométriques réalisées sur l'éprouvette type A en acier ST 52 (Repère MSN : 8).

La position des points de mesure est indiquée sur la figure 13.

Repères des points de mesure	1		2		3		4		5		6		7		8		9		10			
Charges en Tonnes force	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ		
	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar		
2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	
15	148	3,0	164	3,4	75	1,5	84	1,7	31	0,6	34	0,7	158	3,3	264	5,4	98	2,0	192	4,0		
30	324	6,7	354	7,3	158	3,3	174	3,6	63	1,3	72	1,5	309	6,4	486	10,0	198	4,1	362	7,4		
45	508	10,3	543	11,3	237	4,9	262	5,4	95	2,0	108	2,2	459	9,4	704	14,5	297	5,1	533	11,1		
ϵ résiduel $\Delta L/L 10^{-6}$	/		/		/		/		/		/		/		/		/		/		/	

TABLÉAU II

Repères des points de mesure	11		12		13		14		15		16		17		18		19		20			
Charges en Tonnes force	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ	ϵ	σ		
	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar	$\frac{\Delta L}{L} 10^{-6}$	hbar		
2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	
15	50	1,0	115	2,3	204	4,2	345	7,1	86	1,8	6	0,1	-18	-0,4	-200	-4,1	570	11,7	418	8,6		
30	105	2,2	206	4,2	353	7,7	685	14,1	170	3,5	-8	-0,2	-57	-1,2	-440	-9,2	1571	32,3	921	19,0		
45	154	3,2	296	6,1	533	11,1	1093	22,5	254	5,2	-28	-0,6	-92	-1,9	-700	-14,1	2854	/	1365	28,1		
ϵ résiduel $\Delta L/L 10^{-6}$	/		/		/		+ 153		/		/		/		/		+ 1035		+ 60			

TABLEAU I (Suite)

Références des points de mesure	A		B		C				D									
	directions		longitudinale	transversale	longitudinale	transversale	principales				principales							
charges en tonnes force	$\frac{\Delta L}{L} 10^{-6}$	σ hbar	$\frac{\Delta L}{L} 10^{-6}$	σ hbar	$\frac{\Delta L}{L} 10^{-6}$	σ hbar	$\frac{\Delta L}{L} 10^{-6}$	σ hbar	ϵ_1	ϵ_2	σ_1 hbar	σ_2 hbar	ϕ degrés	ϵ_1	ϵ_2	σ_1 hbar	σ_2 hbar	ϕ degrés
2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
15	158	2,6	-80	-0,9	156	3,1	-68	-0,5	140	-42	2,8	0	9,4	193	-53	4,0	0,1	6,6
30	274	5,1	-161	-1,8	306	6,0	-140	-0,9	304	-76	6,4	0,3	5,6	407	-109	8,5	0,5	7,9
45	408	7,5	-259	-3,1	462	9,1	-200	-1,4	500	-142	10,5	0,9	3,2	634	-166	13,2	0,5	7,5
ϵ résiduel $\Delta L/L 10^{-6}$	/	/	/	/	suivant directions				suivant directions									
					longitudinale	bissectrice	transversale		longitudinale	bissectrice	transversale		longitudinale	bissectrice	transversale			
					50	/	/		85	40	/							

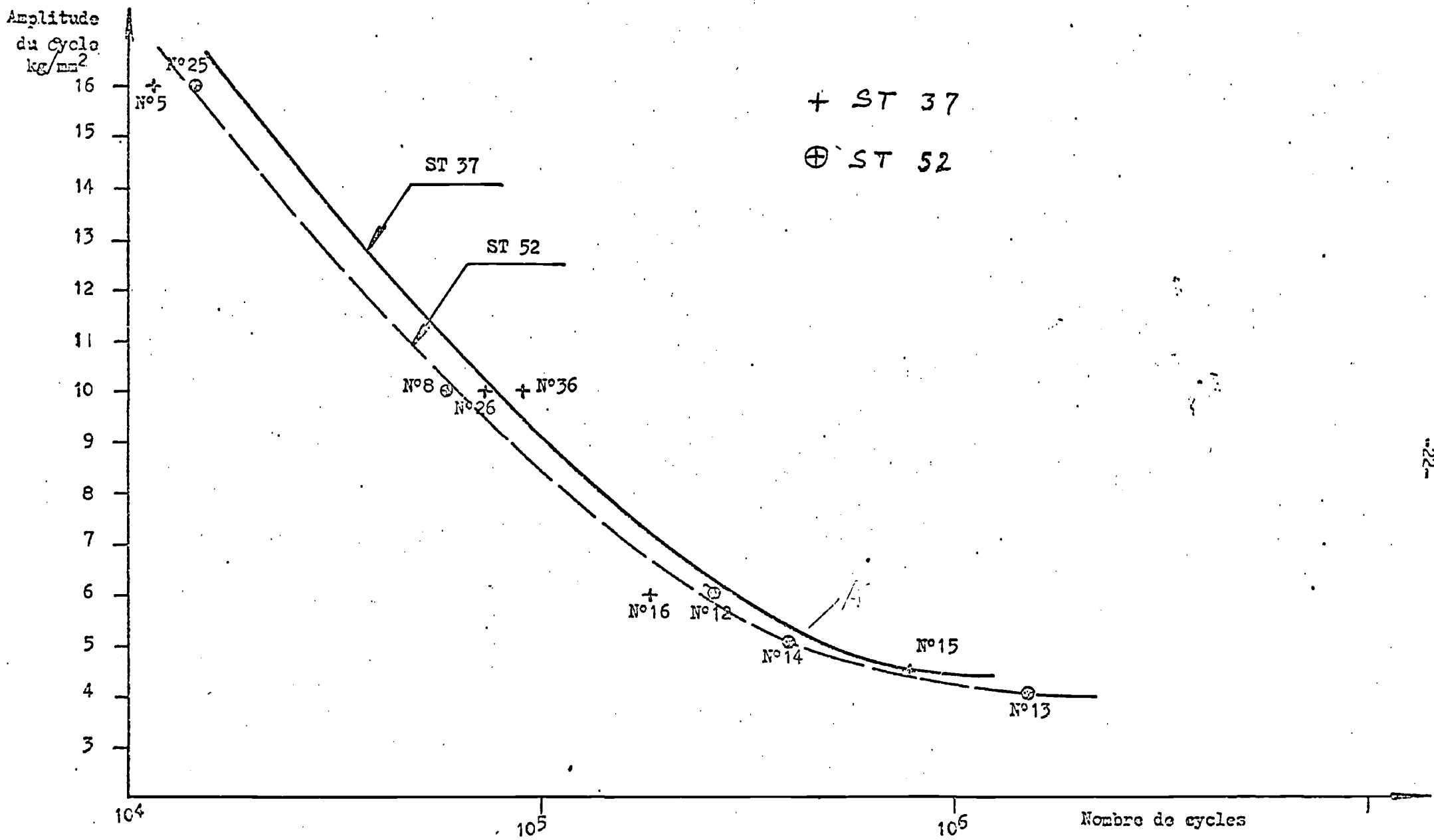
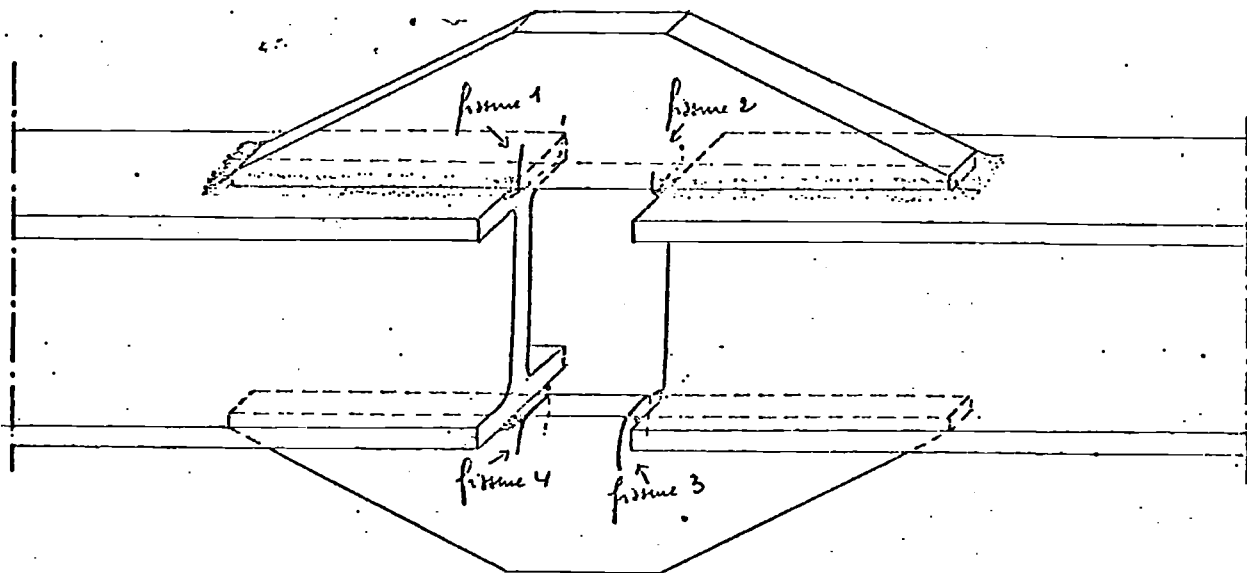


Fig.17 - Courbes de Wechler pour les éprouvettes type A sollicitées en traction ondulée .

Eprouvette type A en acier ST 52

Repere de l'éprouvette : E 9744. 17C. 107

Mode de sollicitation : Traction - Compression



Position des fissures.

Fig. 22. Repere MSN de l'éprouvette : 19.

Charge de rupture statique : { à l'ambiante : 102,5 tonnes
à zéro degré : ...

Repere MSN de l'éprouvette	Taux de travail en kg/mm ²		Nombre de cycles supportés	Observations
	Mini	Maxi		
19	-5	+10	27 300	Après 27300 cycles, quatre fissures sont observées (fissure 1 : profondeur 27 mm fissure 2 : profondeur 8 mm fissure 3 : profondeur 19 mm fissure 4 : profondeur 22 mm) sur la figure 22. Elles se sont toutes propagées dans la tôle du renfort, au pied du cordon de soudure.

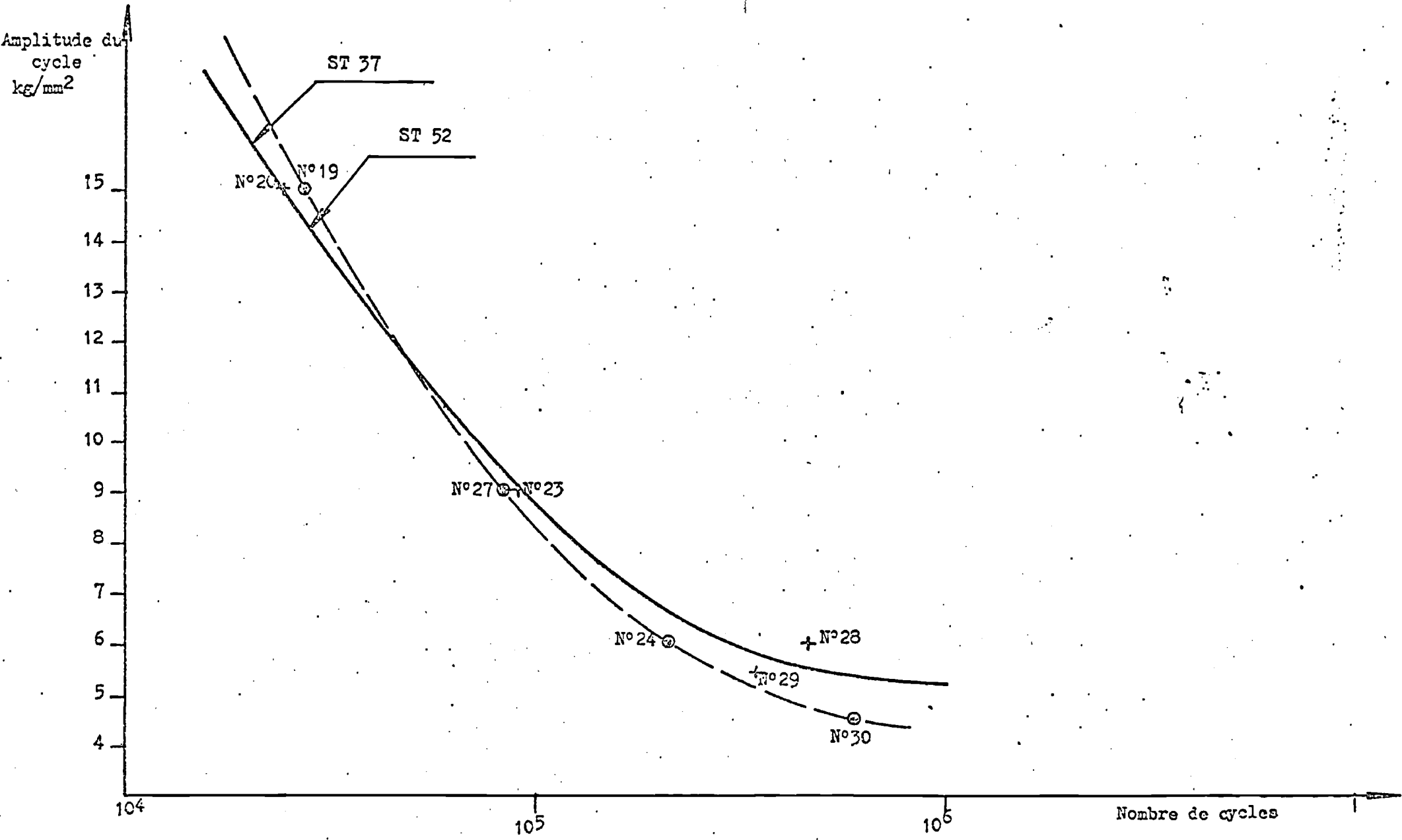
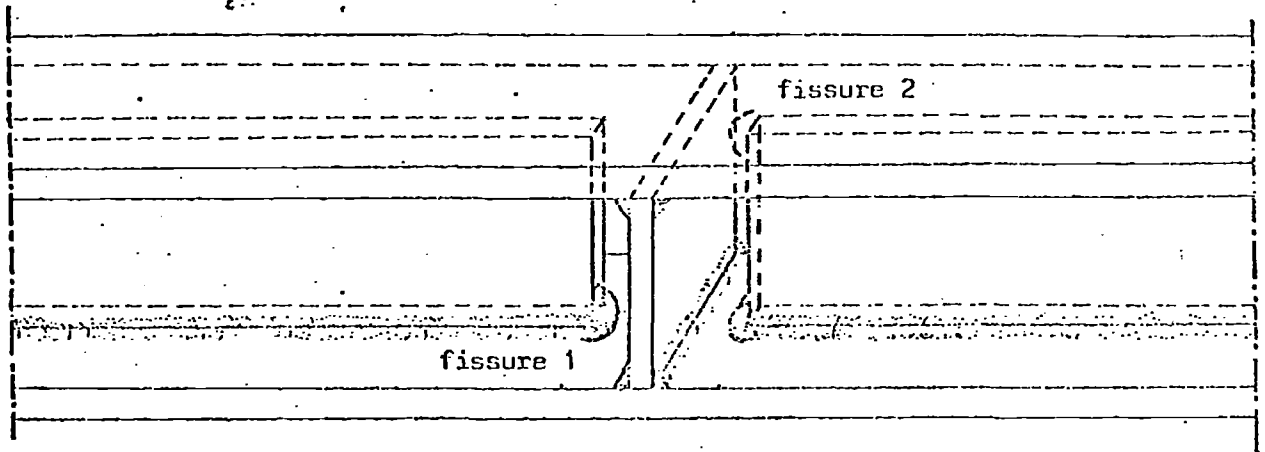


Fig.26 - Courbes de Woehler pour les éprouvettes type A sollicitées en traction-compression .

Eprouvette. type B en acier ST 37

Repere de l'eprouvette DE 9556-98-72 A

Mode de sollicitation traction ondulée.



Position des fissures

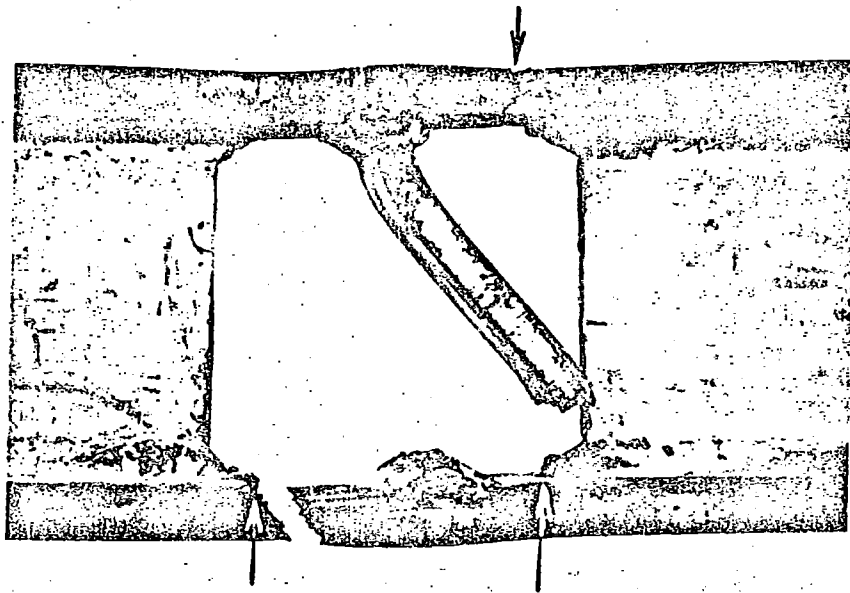
Fig 27 Repere MSN de l'eprouvette : 2

Charge de rupture statique :

- à l'ambiante : 164 tonnes
- à zéro degré :

Repere MSN de l'eprouvette	Taux de travail en kg/mm ²		Nombre de cycles supportés	Observations
	Mini	Maxi		
2	0,5	20	42 000	Après 34 000 cycles, apparition d'une fissure de 10mm de longueur environ (position 2 - figure 27). Après 42 000 cycles, cette fissure s'est développée pour atteindre 30 mm de longueur et 7 mm de profondeur et on observe l'existence d'une seconde fissure (position 1-figure 27), de 20 mm de longueur et 5 mm de profondeur.

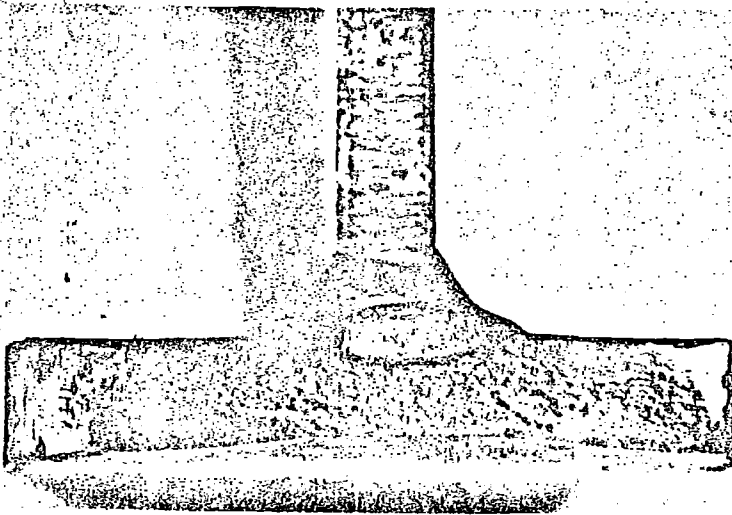
Fissure 2.



Fissure 1.

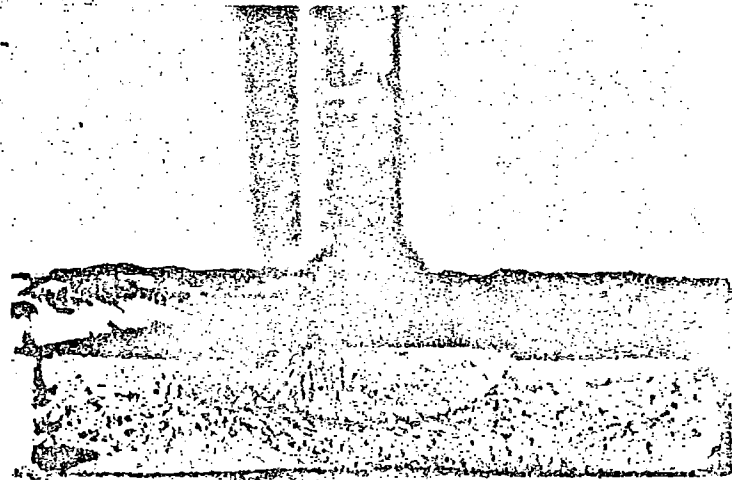
Fissure 3.

Positions des fissures. x0,4



Surface de cassure x 1.

Aspect de la cassure obtenue après rupture statique à partir de la fissure 1.



Surface de cassure x 1.

Aspect de la cassure obtenue après rupture statique à partir de la fissure 2.

Fig. 35 - Positions et surfaces des cassures après rupture statique.

Repère IBR : 4

TABEAU II

Résultats des mesures extensométriques réalisées sur l'éprouvette (type B-rsère MSN (7)).
La position des points de mesure est indiquée sur le figure 38.

N° des points de mesure	14		15		16		17		18		19		20		21		22		23		24		25	
	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar
2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
15	72	1,5	168	3,5	78	1,6	73	1,5	80	1,6	99	2,0	92	1,9	188	3,8	230	4,7	-101	-2,1	-25	-0,5	-28	-0,6
30	184	3,8	355	7,3	193	4,0	185	3,8	192	4,0	245	5,0	218	4,5	406	8,4	475	9,8	-222	-4,6	-54	-1,1	-57	-1,2
45	312	6,4	554	11,4	324	6,7	311	6,4	300	6,2	385	7,9	382	7,9	611	12,6	830	17,1	-348	-7,2	-82	-1,7	-84	-1,7
60	481	9,9	826	17,0	530	10,9	477	9,8	474	9,8	586	12,1	654	13,5	813	16,8	1533	31,5	-488	-10,0	-63	-1,3	-66	-1,4
E remanent $\Delta L/L 10^{-6}$	42		125		70		77		54		65		282		-64		515		/		56		60	

N° des points de mesure	1		2		3		4		5		6		7		8		9		10		11		12		13	
	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar	E $\frac{\Delta L}{L} 10^{-6}$	σ hbar
2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	
15	133	2,7	109	2,2	105	2,2	95	1,9	48	4,0	35	0,7	404	2,1	52	1,1	124	2,5	52	1,1	140	2,9	62	1,5	164	
30	244	5,0	234	4,8	217	4,5	198	4,1	98	2,0	79	1,6	236	4,9	140	2,9	268	5,5	140	2,9	295	6,1	162	3,3	346	
45	347	7,1	371	7,6	325	6,7	301	6,2	142	2,9	119	2,4	374	7,7	236	4,9	413	8,5	238	4,9	444	9,1	278	5,7	520	
60	479	9,9	533	11,0	475	9,0	447	9,2	228	4,7	199	4,4	552	11,4	376	7,7	614	12,6	382	7,9	654	13,5	450	9,3	751	
E remanent $\Delta L/L 10^{-6}$	-116		/		/		/		/		/		77		40		81		40		76		58		62	

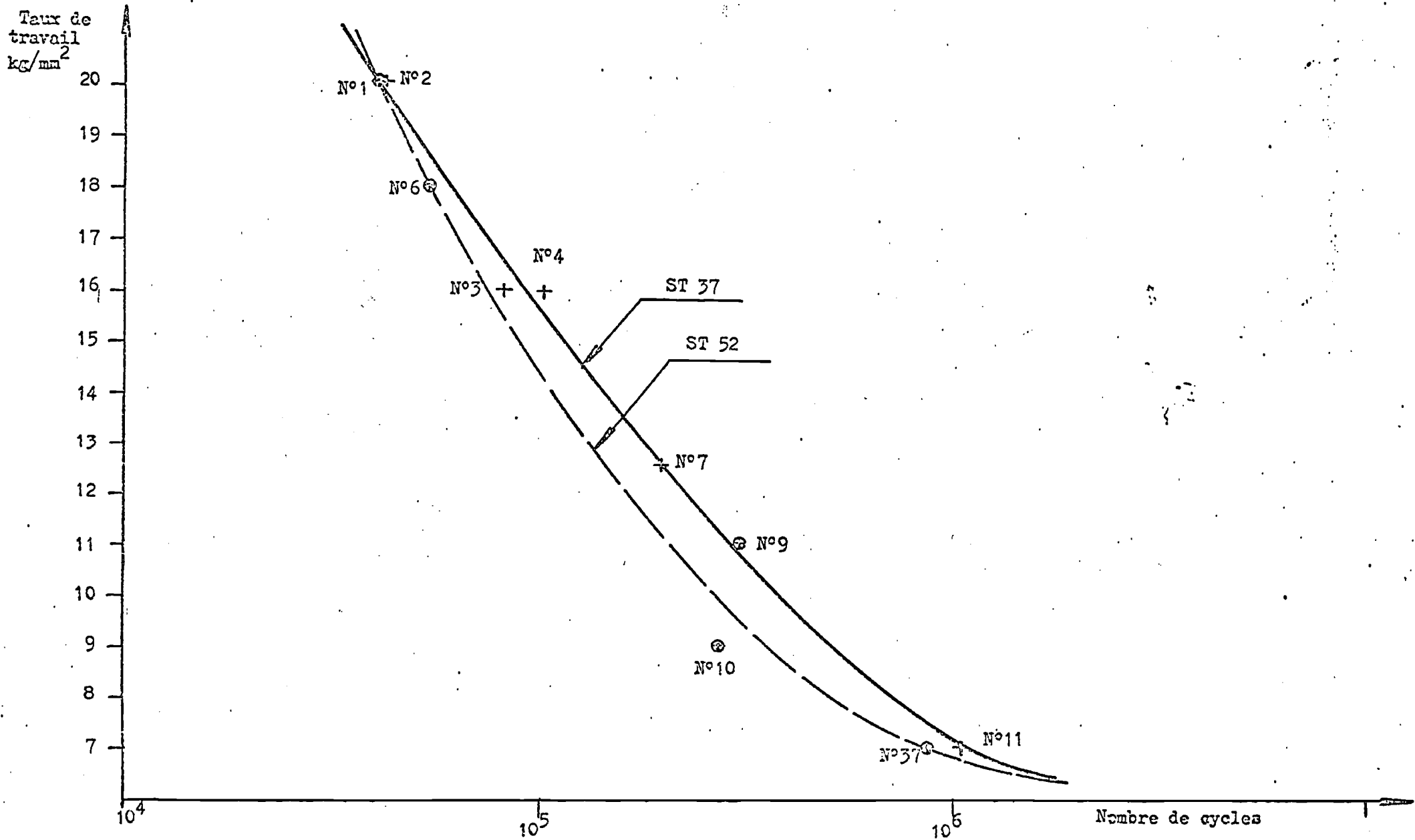
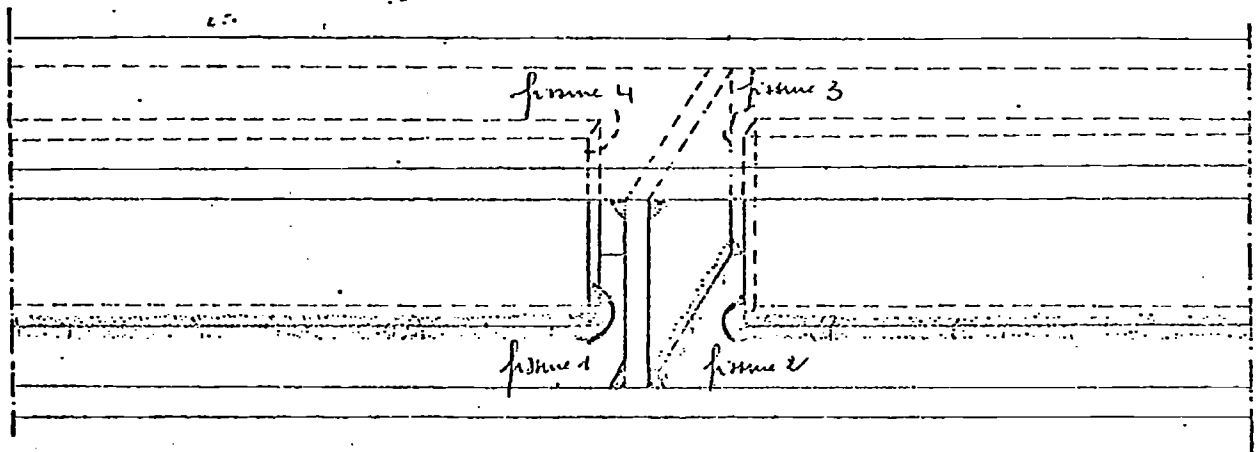


Fig. 51 - Courbes de Weehler pour les éprouvettes type B sollicitées en traction ondulée .

Éprouvette type B en acier ST 52
 Réfère de l'éprouvette E 9744.107.46C
 Mode de sollicitation traction - compression



Position des fissures.

Fig 57 . Réfère MSN de l'éprouvette : 34

Charge de rupture statique : $\left\{ \begin{array}{l} \text{à l'ambiante : } \checkmark \\ \text{à zéro degré : } \end{array} \right.$

Réfère MSN de l'éprouvette	Taux de travail en kg/mm^2		Nombre de cycles supportés	Observations.
	Mini	Maxi		
34	-6	+12	81000	Après 81000 cycles, arrêt volontaire. On observe 4 fissures au pied d'un cordons de soudure (fissures 1, 2, 3, 4 sur figure 57) la fissure 1 a 22 mm de longueur, la fissure 2 a 24 mm de longueur, la fissure 3 a 28 mm de longueur, la fissure 4 a 28 mm de longueur.

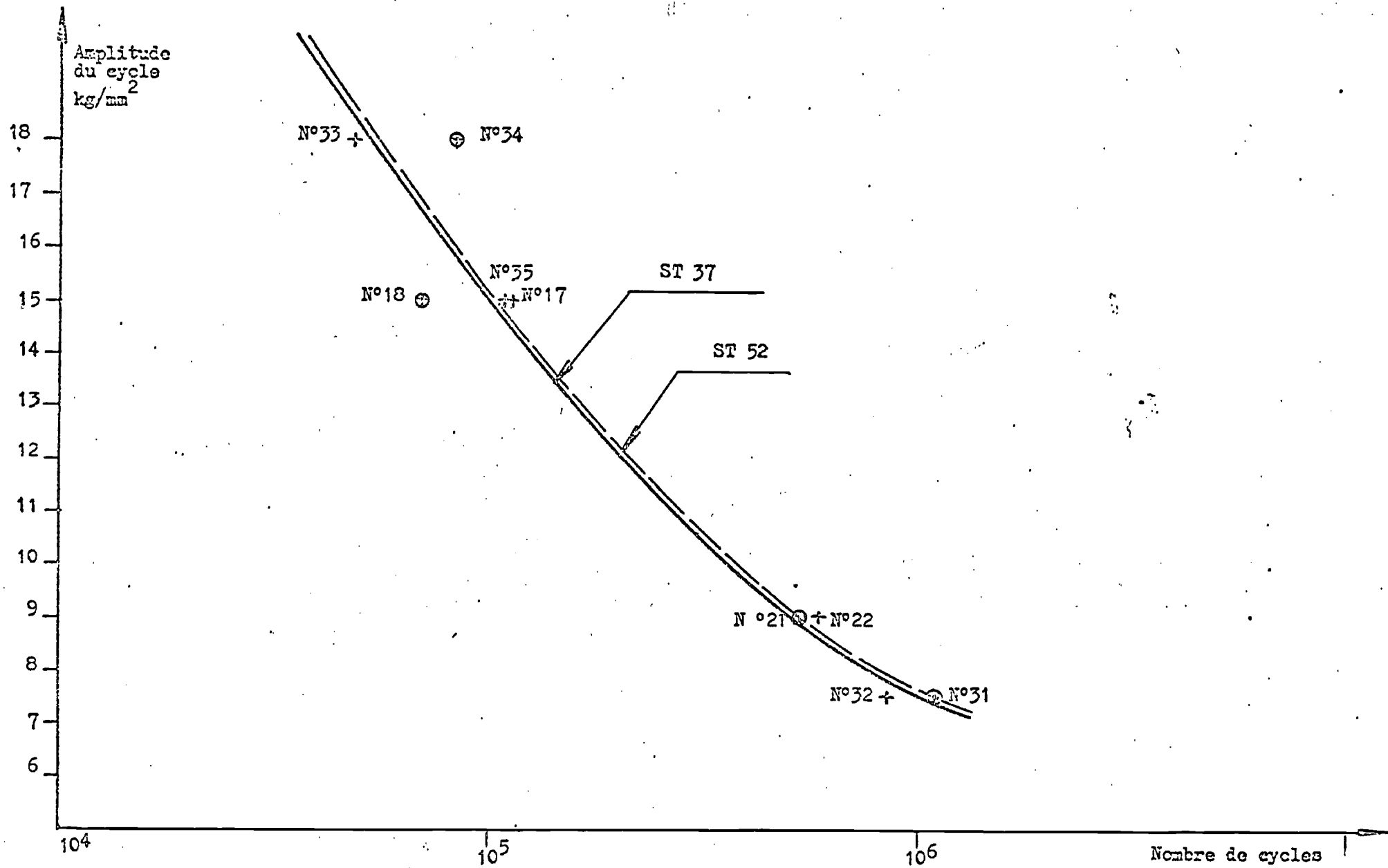


Fig.61 - Courbes de Wochler pour les éprouvettes type B sollicitées en traction-compression .

- Récapitulatif des résultats obtenus sur les éprouvettes sollicitées
en traction ondulée -

Eprouvettes sollicitées en traction ondulée

Type de l'éprouvette	Nuance de l'acier	Repère MSN de l'éprouvette	Taux de travail kg/mm ²		Nombre de cycles supportés jusqu'à obtention de la fissure.	
			Mini	Maxi		
Type A	ST 37	N° 5	0,5	16	11 400	
		N° 26	0,5	10	72 800	
		N° 36	0,5	10	89 700	
		N° 16	0,5	6	182 600	
		N° 15	0,5	4,5	790 200	
	ST 52	N° 25	0,5	16	14 700	
		N° 8	0,5	10	58 500	
		N° 12	0,5	6	266 800	
		N° 14	0,5	5	395 400	
		N° 13	0,5	4	1 515 000	
	Type B	ST 37	N° 2	0,5	20	42 000
			N° 3	0,5	16	82 200
			N° 4	0,5	16	103 000
		ST 52	N° 7	0,5	12,5	200 000
N° 11			0,5	7	1 069 000	
N° 1			0,5	20	41 800	
ST 52	N° 6	0,5	18	54 000		
	N° 9	0,5	11	305 100		
	N° 10	0,5	9	271 900		
	N° 37	0,5	7	889 500		

.../...

- Récapitulatif des résultats obtenus sur les éprouvettes sollicitées
en traction-compression -

Eprouvettes sollicitées en traction-compression					
Type de l'éprouvette	Nuance de l'acier	Repère MSN de l'éprouvette	Taux de travail kg/mm ²		Nombre de cycles supportés jusqu'à obtention de la fissure.
			Mini	Maxi	
Type A	ST 37	N° 20	- 5	+ 10	24 000
		N° 23	- 3	+ 6	91 500
		N° 28	- 2	+ 4	463 000
		N° 29	- 1,8	+ 3,6	350 000
	ST 52	N° 19	- 5	+ 10	27 300
		N° 27	- 3	+ 6	83 000
		N° 24	- 2	+ 4	210 000
		N° 30	- 1,5	+ 3	600 000
Type B	ST 37	N° 33	- 6	+ 12	48 000
		N° 35	- 5	+ 10	109 000
		N° 17	- 5	+ 10	110 500
		N° 22	- 3	+ 6	583 200
	ST 52	N° 32	- 2,5	+ 5	841 600
		N° 34	- 6	+ 12	81 000
		N° 18	- 5	+ 10	69 600
		N° 21	- 3	+ 6	530 000
		N° 31	- 2,5	+ 5	1 077 400

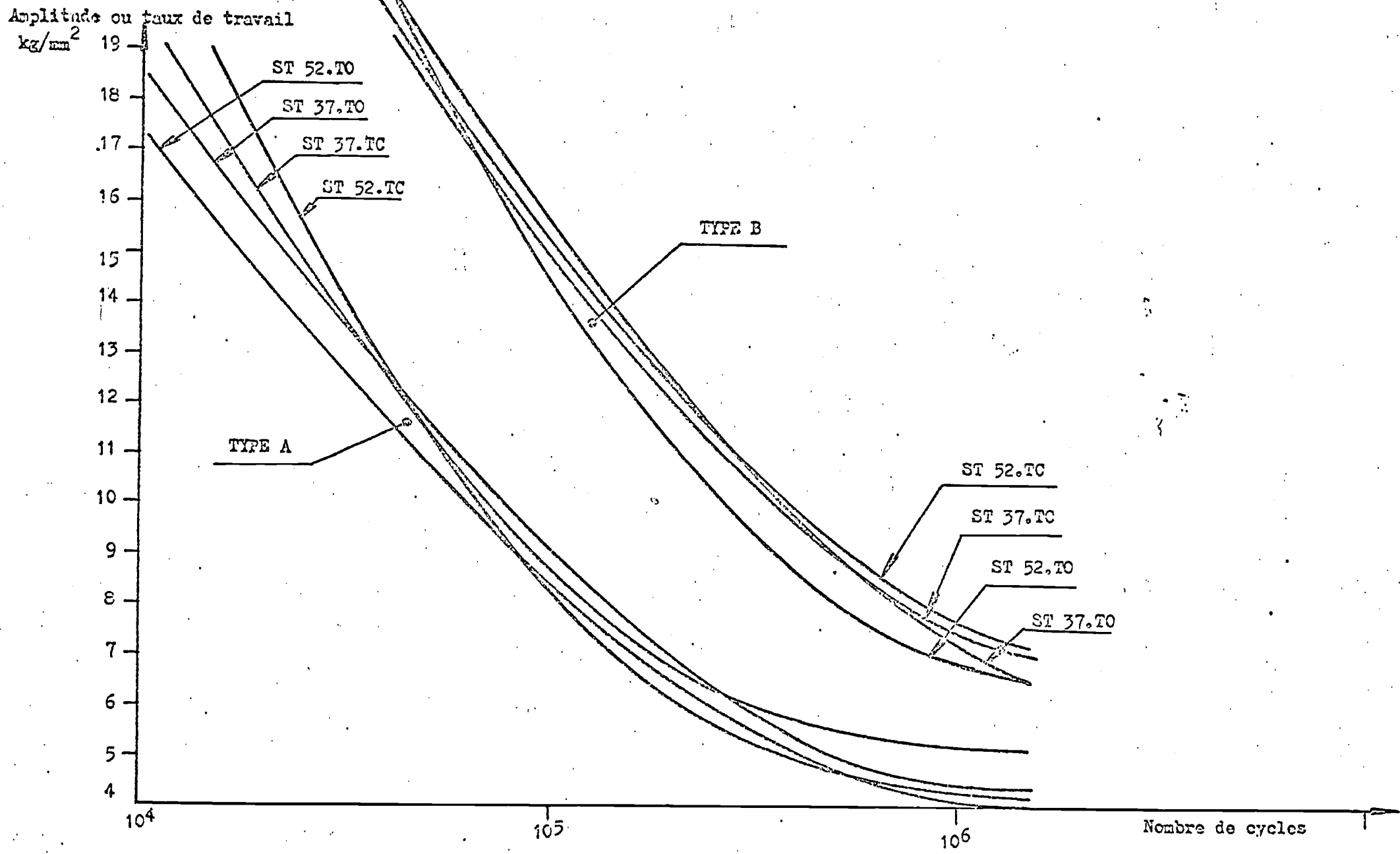


Fig.62 - Courbes de Weehler pour les éprouvettes type A et type B sollicitées en traction ondulée et traction-compression .

IV. - CONCLUSIONS

== =====

Au vu des résultats obtenus au cours des essais précédemment exposés, il apparaît :

4,1 - que les éprouvettes type B donnent de bien meilleurs résultats que les éprouvettes type A, ce qui était prévisible eu égard à la conception même des éprouvettes.

4,2 - que l'utilisation d'un acier HR ST 52 en remplacement de l'acier ordinaire ST 37 n'améliore pas sensiblement l'endurance (elle est même parfois inférieure).

4,3 - que le mode de sollicitation est sans grande influence sur le comportement à la fatigue de l'élément soudé.

Paris, le 30 Mars 1973,

L'Ingénieur Principal des Etudes et Techniques d'Armement LOPARD,-



**Laboratorium voor Weerstand van Materialen**

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Prof. ir. W. SOETETel. 28.75.71
P.C. 4894.81

VERSLAG Nr 153/4585

WS/WDL/HR

Aangevraagd door: C.B.R.N. - De Heer ir. J.J.L. VAN MAANEN, Directeur
Lakenweversstraat 21, 1050 BRUSSEL

Ten koste van: idem.

Betreft: H.T.S. Investigation
Deel C : Vermoeiingsproeven op proefstaven.**I. Proefstaven.**De vermoeiingsproeven werden uitgevoerd op 5 reeksen proefstaven.
De indeling is als volgt :

Staal	Gieting	Plaat nr	Dikte mm	Nummering proefstaven	Tekening
Gr. DR 36 lb	E 9062	96	25	A1 tot A12	72/1
	E 9062	97 + 114	19	E1 tot E12	72/2
	E 9744	107	13	B1 tot B12	72/5
Gr. D.	E 9556	109	19	C1 tot C12	72/4
	E 9556	98	13	D1 tot D12	72/3

Tekening 72/6 duidt vorm en afmetingen van de vermoeiingsproefstaven aan :

voor proeven in trek : 700 x 100 mm (2 zijdelingse kerf)
voor proeven in trek/druk : 700 x 100 mm (2 zijdelingse kerf)
voor proeven in buiging : 360 x 75 mm (1 zijdelingse kerf).

De totale kerfdiepte is 10 mm waarvan 8 mm met een dikte van 1 mm en 2 mm met een dikte van 0,25 mm.

II. Vermoeiingsproeven.

De belastingen F_{max} . en F_{min} . werden op de netto sectie berekend.

1. Vermoeiingsproeven in trek.

Proefmachine : Amsler 100 ton

Frekwentie : 250/min.

Proefst.	σ_{max} kg/mm ²	F_{max} kg	F_{min} kg	aantal pulsaties 10^3	scheurlengte (mm)	
					links	rechts
A1	+25	48.800	1000	5	0	0
				17	20	12
				19,6	breuk	

A2	+20	39.040	1000	5	0	0
				10	0	0
				15	2	0
				20	5	1
				25	10	3
				30	16	4
				35	29	5
				37,5	breuk	

A3	+15	29.280	1000	5	0	0
				10	0	0
				15	0	0
				20	0	0
				25	0	0
				30	0	0
				35	0,5	0
				40	1	0
				45	2	0
				50	5	2
				55	6	2,5
				60	7	3
				65	8,5	4
				70	10	4,5
				75	13	5
				80	17	6
85	21	6,5				
90	30	*				
95	38	*				
97,4	breuk					

* Opmerking : wanneer op een bepaald ogenblik één scheur zeer lang wordt is de lengte van de korte scheur soms niet meer meetbaar omdat deze laatste dicht gedrukt wordt.

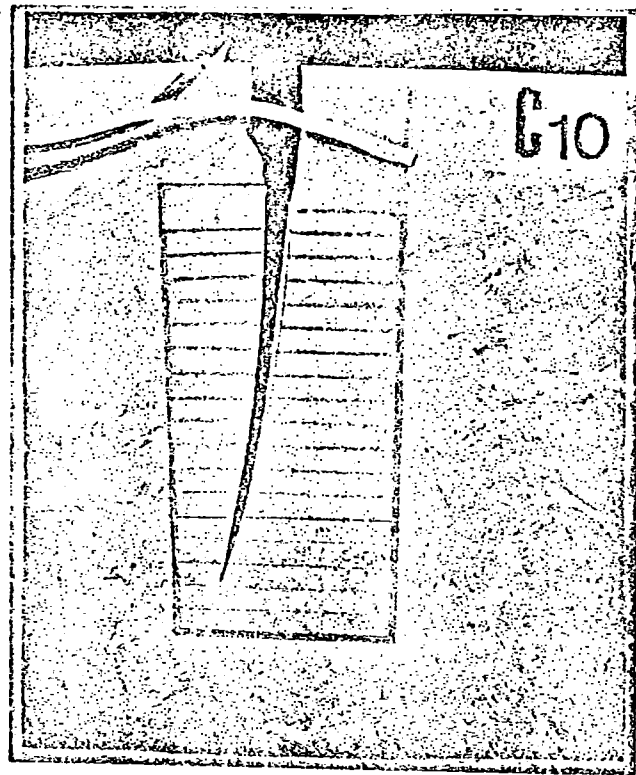
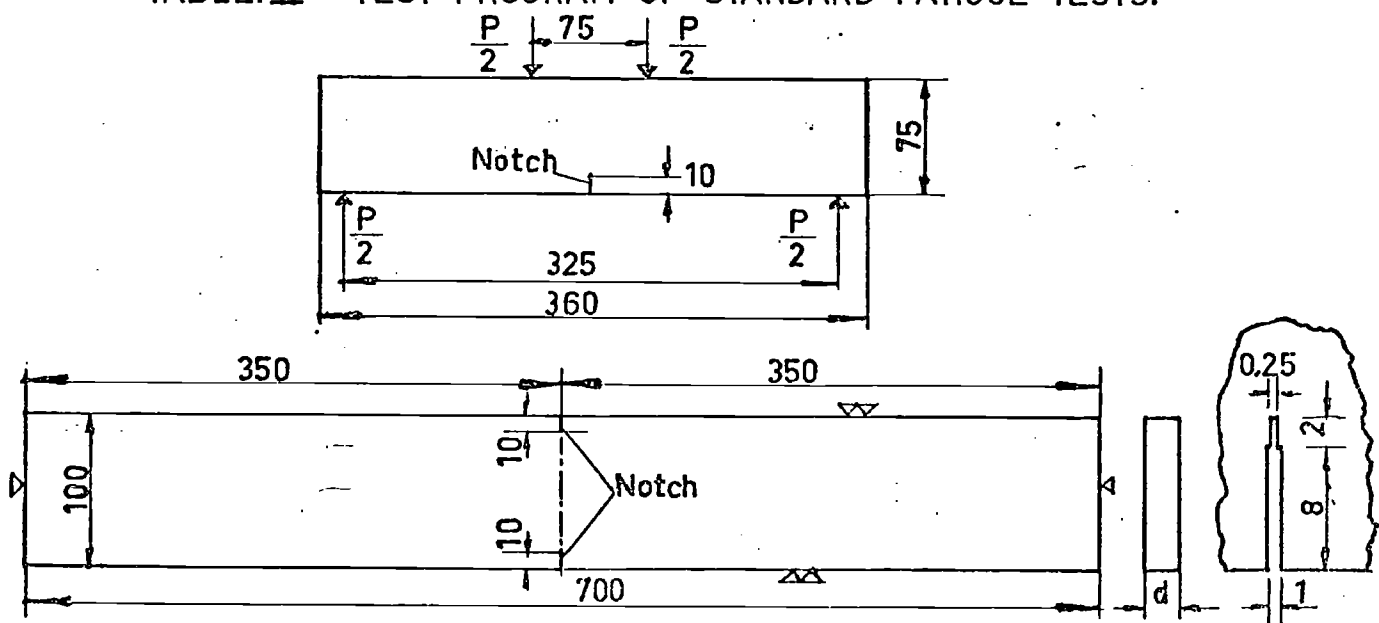


Foto R111

	σ (kg/mm ²)	Steel Gr. D		Steel Gr. DH 36 Nb.		
		t = 13	t = 19	t = 13	t = 19	t = 25
Repeated loading	0 / +13	D4	C4	B4	E4	A4
	0 / +15	D1	C1	B1	E1	A3
	0 / +20	D2	C2	B2	E2	A2
	0 / +25	D3	C3	B3	E3	A1
Alternating loading	-10 / +10	-	-	B8	-	-
	-12,5 / +12,5	D6	C6	B5	E6	-
	-15 / +15	D5	C5	B7	E8 E5	-
	-16,25 / +16,25	-	C8	-	-	-
	-17 / +17	-	-	-	E7	-
	-17,5 / +17,5	D8 D7	C7	-	-	-
	-20 / +20	-	-	B6	-	-
Bending loading	0 / +12,5	-	C9	-	-	-
	0 / +20	D10	C10	B9	E10	A10
	0 / +25	D9	C11	B10	E9	A9
	0 / +30	D11	C12	B11	E11	A11
	0 / +35	D12	-	B12	E12	A12

t is plate thickness (mm)

TABLE. II TEST PROGRAM OF STANDARD FATIGUE TESTS.



From rep. 153/4706

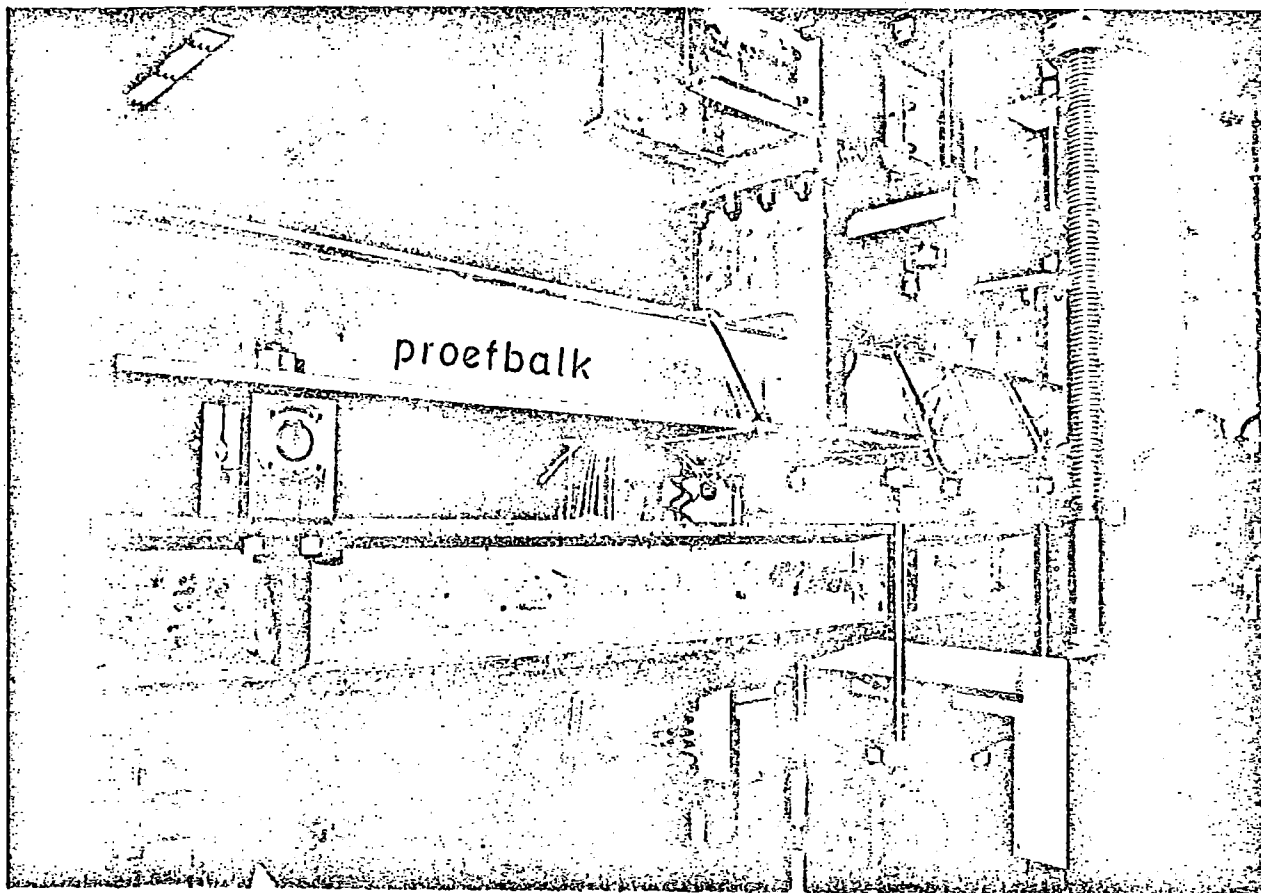


Foto 729/3

From rep. 153/4706

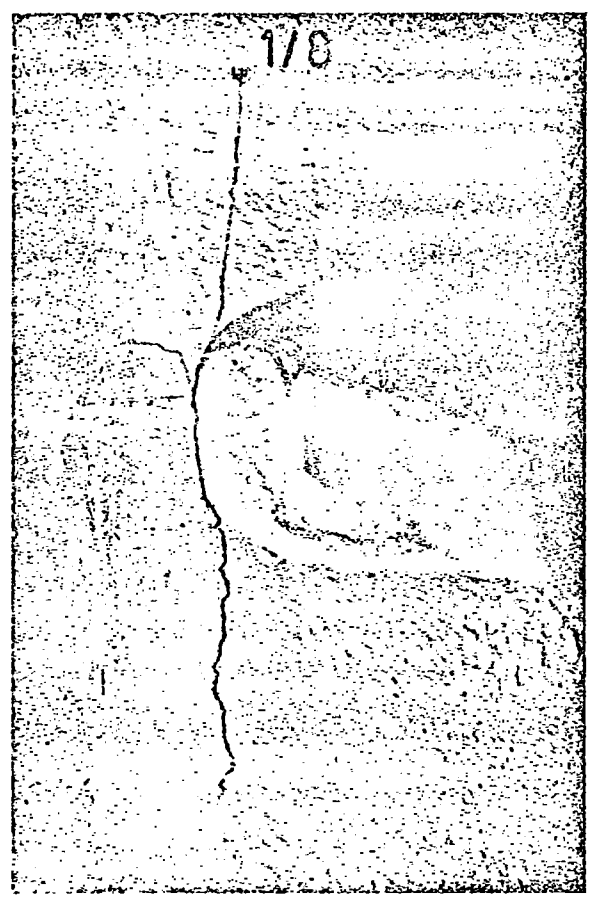


Foto 731/10

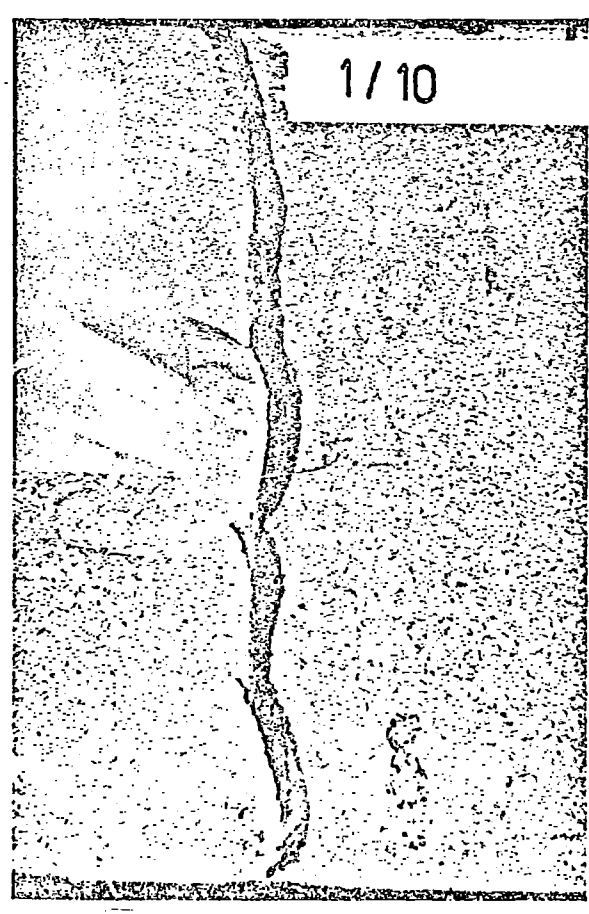


Foto 731/8

From rep. 153/4706



Foto 734/21



Foto 734/22