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TECHNISCHE HOGESCHOOL – DELFT

RAPPORT Nr. SSL 163

BETREFFENDE:

Interim-report about the influence of flame-cutting on the fatigue-properties of steels.

SHIP STRUCTURES LABORATORY.
Delft University of Technology.

Report no. **SSL 163**

INTERIM-REPORT ABOUT THE INFLUENCE OF FLAME-CUTTING ON THE FATIGUE-PROPERTIES OF STEELS.

I. Measurement of residual stresses.

II. Fatigue results.

III. Influence of prestraining.

I. The measurement of residual stresses due to flame-cutting.

One of the important factors determining the fatigue behaviour of flame-cut specimens is the residual stress-pattern.
The Ship Structures Laboratory has developed a simple method, with which the stresses below 0,1 mm distance from the surface can be estimated.
The reproducibility of the results obtained up to this moment is very satisfactory. But extrapolation to a depth of 0 mm (flame-cut surface) in order to estimate the edge stresses, leads to inaccurate results. One only finds an order of magnitude of the edge stresses. ~~Röntgen diffraction measurements will soon complement the present data.~~

Basically the method consists of applying strain-gauges of small length at the flame-cut edge and gradually sawing a notch as close as possible to the end of the gauges.

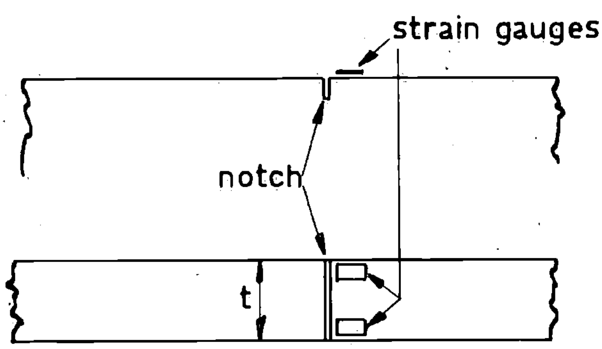

FIG. 1

Due to the notching, the stresses are able to relax; gauges of 2, 3 and 5 mm length have been used.

For the conversion of the measured strains, - at various notch depths -, into the actual residual stresses, calibration curves are needed, representing gauge output as a function of notch depth for a known stress-field. They were obtained by gradually sawing a notch near applied strain gauges, in a tensile stressed prismatical bar.

The before mentioned curves, obtained from gauges on flame-cut specimens, could next be corrected ~~in the following way.~~ as illustrated with the following example.
Let the output of a gauge on a flame-cut specimen diminish by 70 microstrain when the notch is deepened from 0,2 to 0,4 mm, and let the output of a similar gauge on the prismatical bar by the same process diminish by 100 microstrain. Then the average residual stress in the flame-cut bar between 0,2 and 0,4 mm distance from the edge will be 70/100 × the nominal stress in the prismatical bar; this value is plotted at a notch depth of 0,3 mm, being the average of 0,2 and 0,4 mm.

Of course the gradients of stresses in the flame-cut bar and the calibration bar are quite different, and this will have an influence on the accuracy of the estimates. But as the steps in the saw-cutting of the flame-cut bar are small, the mentioned influence will be of second order.

Figures 2a to 2d show ~~the~~ directly recorded values for 3 ~~materials~~ steels 42, flame cut by the Dutch Steelworks (Hoogovens) and one St. 52, flame-cut by Aval under carefully controlled conditions.

Figures 3a-b are calibration curves for 2, 3 and 5 mm strain gauges near the notch and one 5 mm gauge situated at 10 mm from the notch.

It has become standard practice to use 3 mm gauges for cases where especially information about the outer layers is needed. A 5 mm gauge near a notch is used for the residual stresses in a layer of about 5 mm deep.
The gauge situated at 10 mm from the notch is used in order to get an idea about the whole residual stress pattern, (up to 15 mm from the surface).

Figures 4-7 finally show the obtained residual stress patterns.
It can be seen that for material Fe 52 (Hoogovens-cut) appreciable compressive stresses (up to 9 kN/cm^2) in a layer of max. 0,4 mm deep, seem to be present.
The "Aval"-cut bars (St. 52 NS 47) have been provided with gauges at the upper and lower edge. At the upper edge, where the temperature during cutting was highest, the compressive stresses are most pronounced.
(~~See also Chapter III~~). It is evident that when the average stresses (at half plate thickness) are small, nevertheless appreciable edge stresses can be present.

II. <u>Results of fatigue tests.</u>

a. <u>Flame-cut bars</u>: 1000 × 100 × 25 mm have been tested in repeated tensile loading at 250 cycles/minute.

The specimens, cut by the Hoogovens in normal fabrication practice, generally fractured in the part between the cross-heads of the Amsler 100 tons pulsator.
A few times, a crack started in the clamped parts. The test then was interrupted and the distance between the cross-heads was reduced, so that the cracked part became nearly unloaded during subsequent testing.

Comparing the three Hoogovens-cut materials, it is evident that Fe 52 is by far the best (fig. 8). This will be partly due to the high yield point, because the influence of it particularly counts in repeated tensile loading. But the high compressive residual stresses may also have attributed to the result. In fact prestraining largely eliminated the advantage of Fe 52 over St. 42 grade A. (See Chapter III).

St. 42 grade A and D behaved rather similarly. The small difference might be due to some difference in the measured residual stresses at the flame-cut edges. The fatigue limits of the three materials are about 15,5 kN/cm^2. (As far as is permitted to conclude from a small number of specimens).

b. <u>Aval-cut bars</u>. (Fe 52/NS 47).

The performance of the "Aval"-cut bars was excellent. (Fig. 9). (Fat. limit 18 kN/cm^2).
The main cause will be the very smooth surface of the specimens, but the influence of the compressive residual stresses at the edges will also have been favourable.

III d

~~III. Influence of prestraining on the fatigue behaviour.~~

Some "~~Hoogovens-cut~~" specimens have been prestrained 0,5%, 1% or 3% at temperatures of -10°C or -30°C.
Such a treatment eliminates the residual stresses, and may give rise to small cracks in the hard flame-cut surface.

When in the outer layer compressive residual stresses are present, the effect of prestraining may be expected to be unfavourable.

When tensile stresses are present, it may be beneficial, although this may be counterbalanced by the development of small cracks.
The latter will be more manifest at larger strains (larger probability of cracking) although, when cracks should initiate at low strains (f.i. 0,5%), prolonged plastic straining up to 3% may be more or less beneficial (over stressing influence)

Looking at the results (fig. 10c), the St. 42 grade D specimens seem to improve by straining 0,5%. This might be expected because these specimens showed tensile residual stresses at the flame-cut edges.
This favourable effect disappears when larger strains (1% and 3%) are applied. Strain hardening will be responsible for this, because the straining itself did not give rise to small cracks.

For St. 42 grade A, (fig. 10b), the straining had little effect, which ~~is~~ confirms ~~in line~~ with the fact that only small compressive residual stresses were present at the edges.

Material Fe 52 suffered clearly from the prestraining, as ~~was expected~~ is in line with ~~on account of~~ the presence of large compressive residual stresses at the edges. (fig 10a)
But it is remarkable that prestraining at 1% and 3% reduced the strength much more than at 0,5% because in not any case ~~Again strain hardening must be the cause, because no~~ cracking had been ~~was~~ observed after the prestraining.

(It should be observed that the Hoogovens-cut specimens had only been provided with strain gauges at half plate thickness and not at the upper and lower edge of the flame-cut surface.
In figure 7 for the Aval-cut specimens it can be seen that when the average stresses (at half plate thickness) are small, nevertheless appreciable tensile, and in this case particularly compressive stresses may be present).

Delft, ~~November~~ March 1973,

[signature]

Prof.ir. J.J.W. Nibbering.

R. Vonk

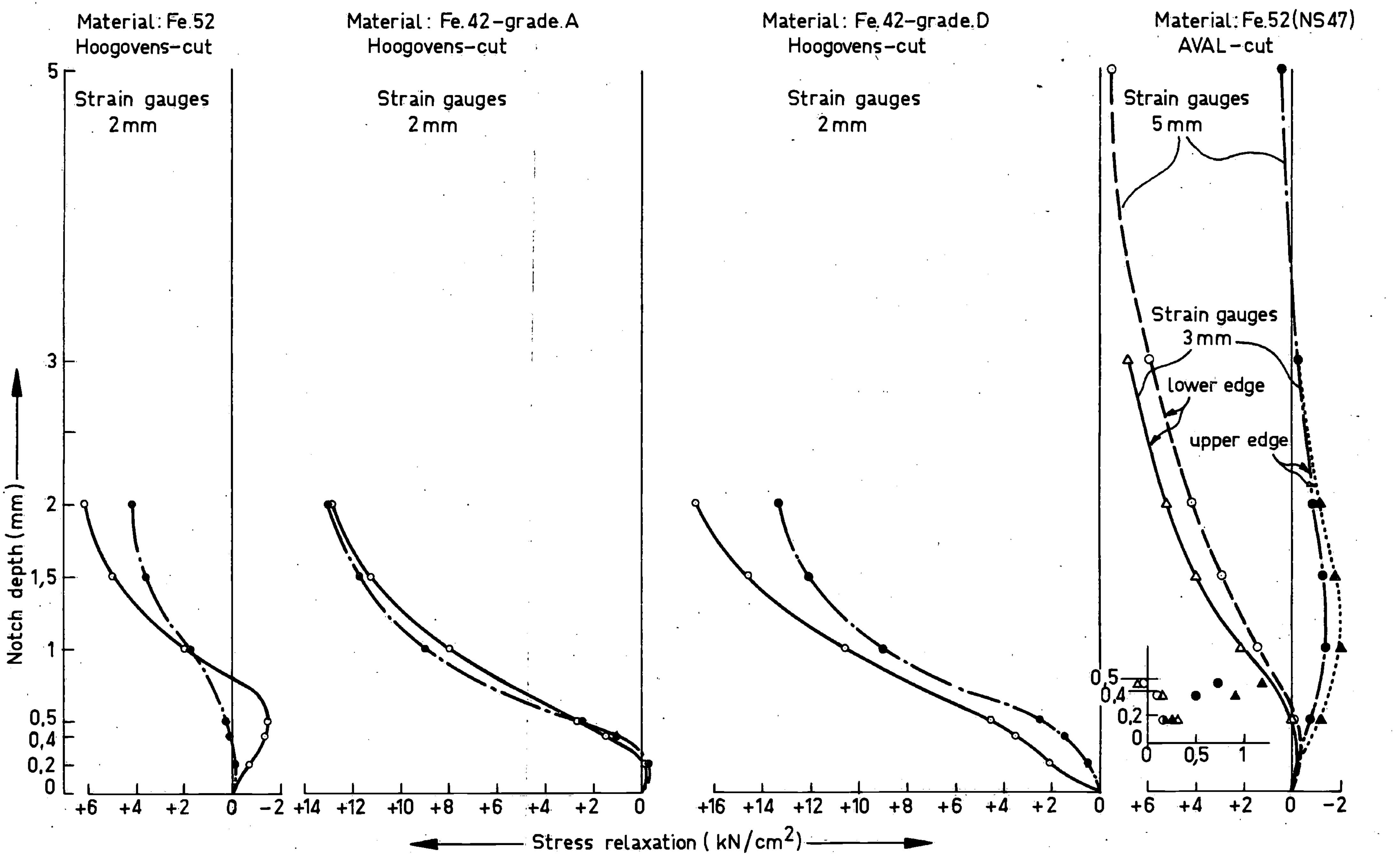

FIG. 2a-2d STRESS RELAXATION DUE TO NOTCHING IN FLAME-CUT SPECIMENS.

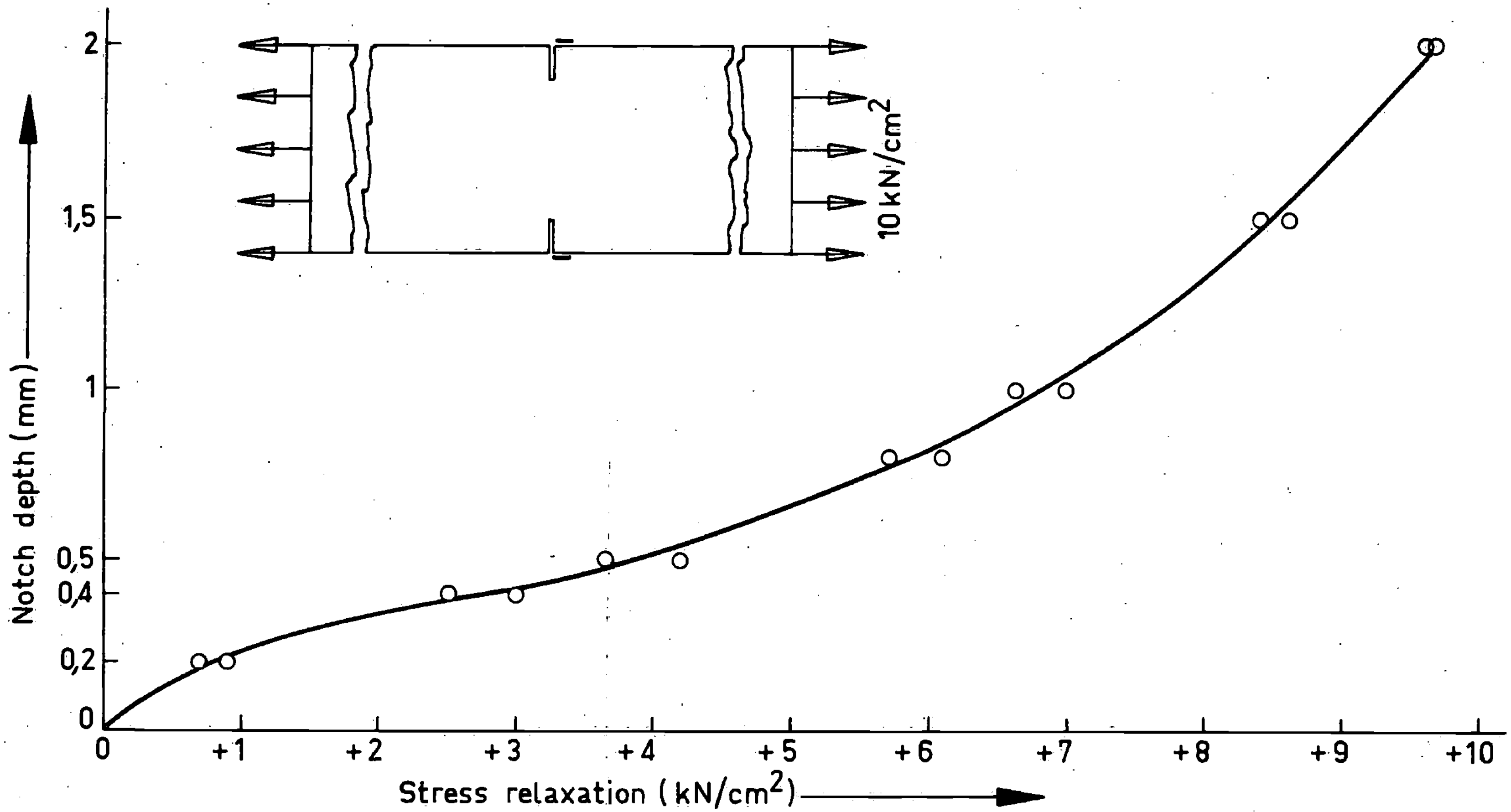

FIG.3a STRESS RELAXATION FOR STRAIN GAUGE OF 2mm LENGTH, DUE TO NOTCHING OF A STRESSED BAR.

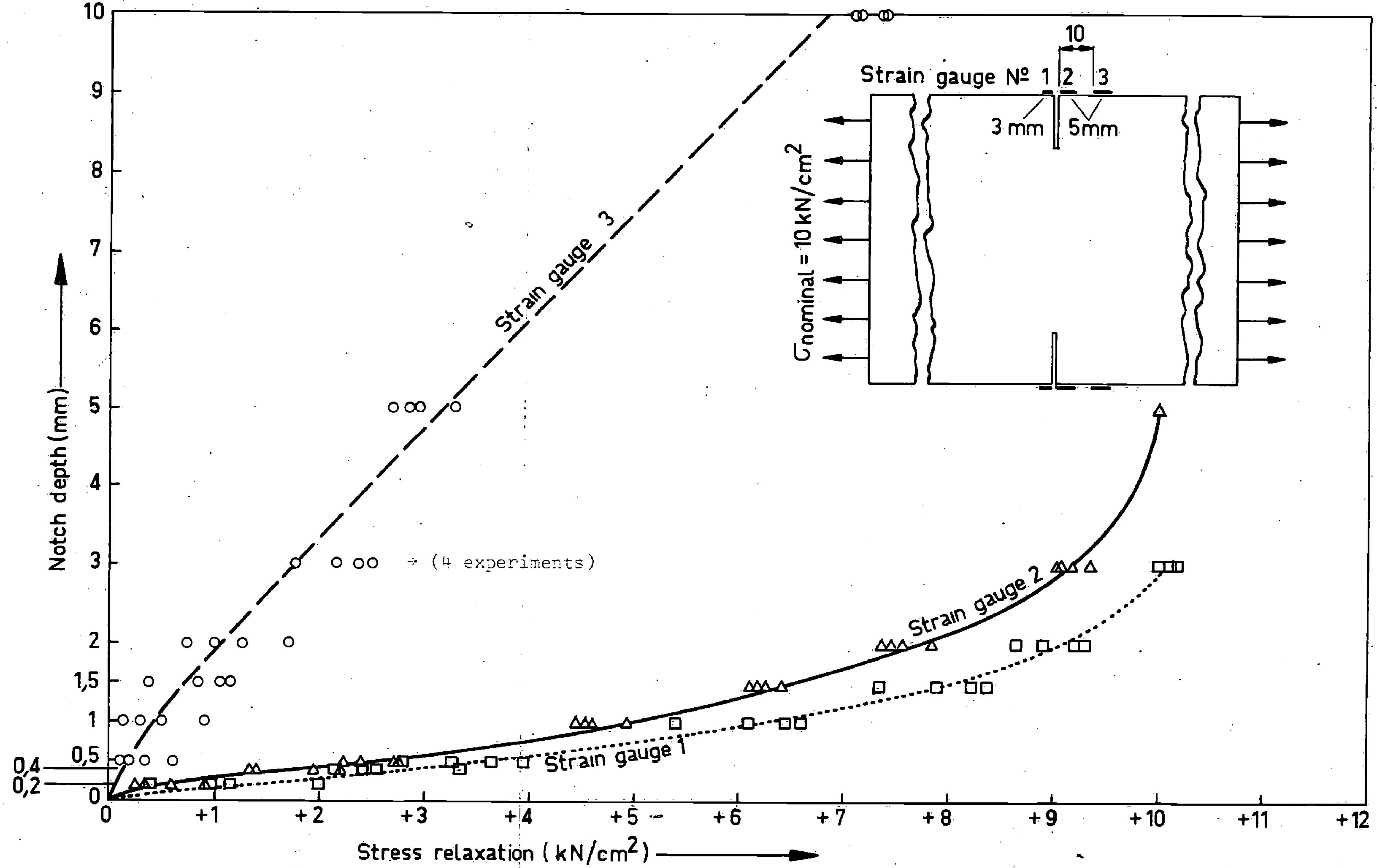

FIG. 3b STRESS RELAXATION FOR STRAIN GAUGES, DUE TO NOTCHING OF A STRESSED BAR.

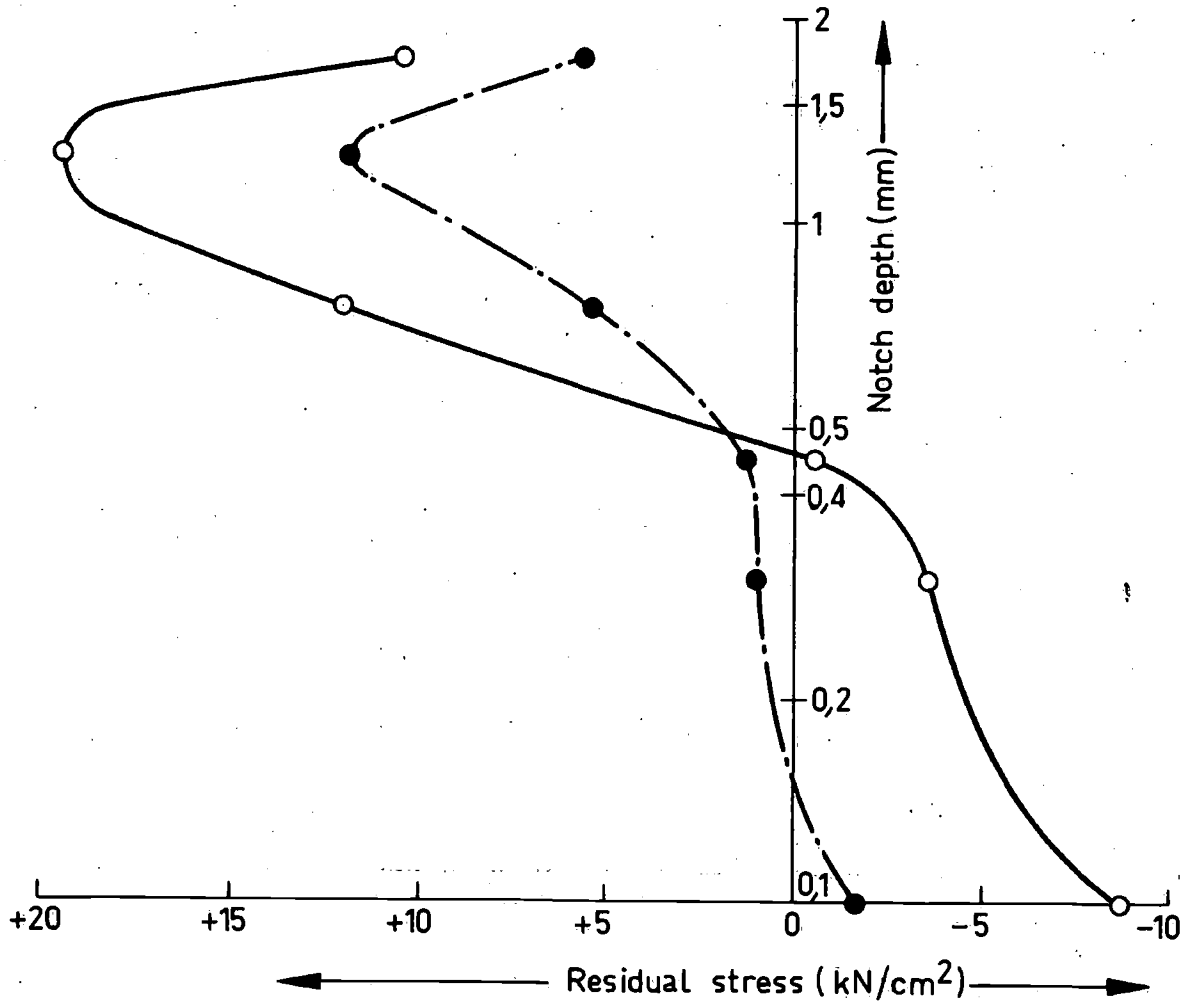

FIG.4 RESIDUAL STRESSES AT VARIOUS DISTANCES FROM FLAME-CUT EDGE IN Fe.52 MATERIAL. (MEASURED IN TWO DIFFERENT SPECIMENS)

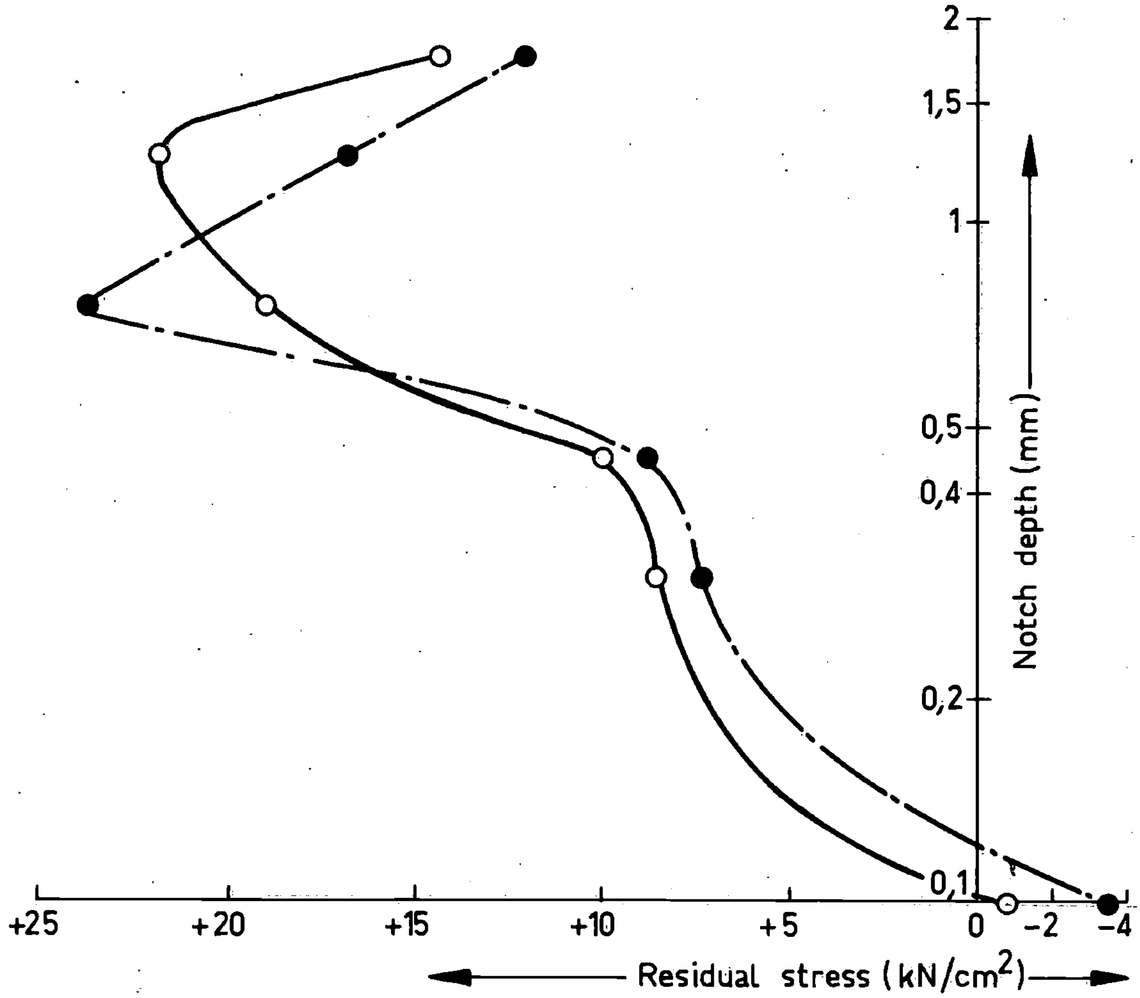

FIG. 5 RESIDUAL STRESSES AT VARIOUS DISTANCES FROM FLAME-CUT EDGE IN Fe.42 GRADE. A MATERIAL.
(MEASURED IN TWO DIFFERENT SPECIMENS)

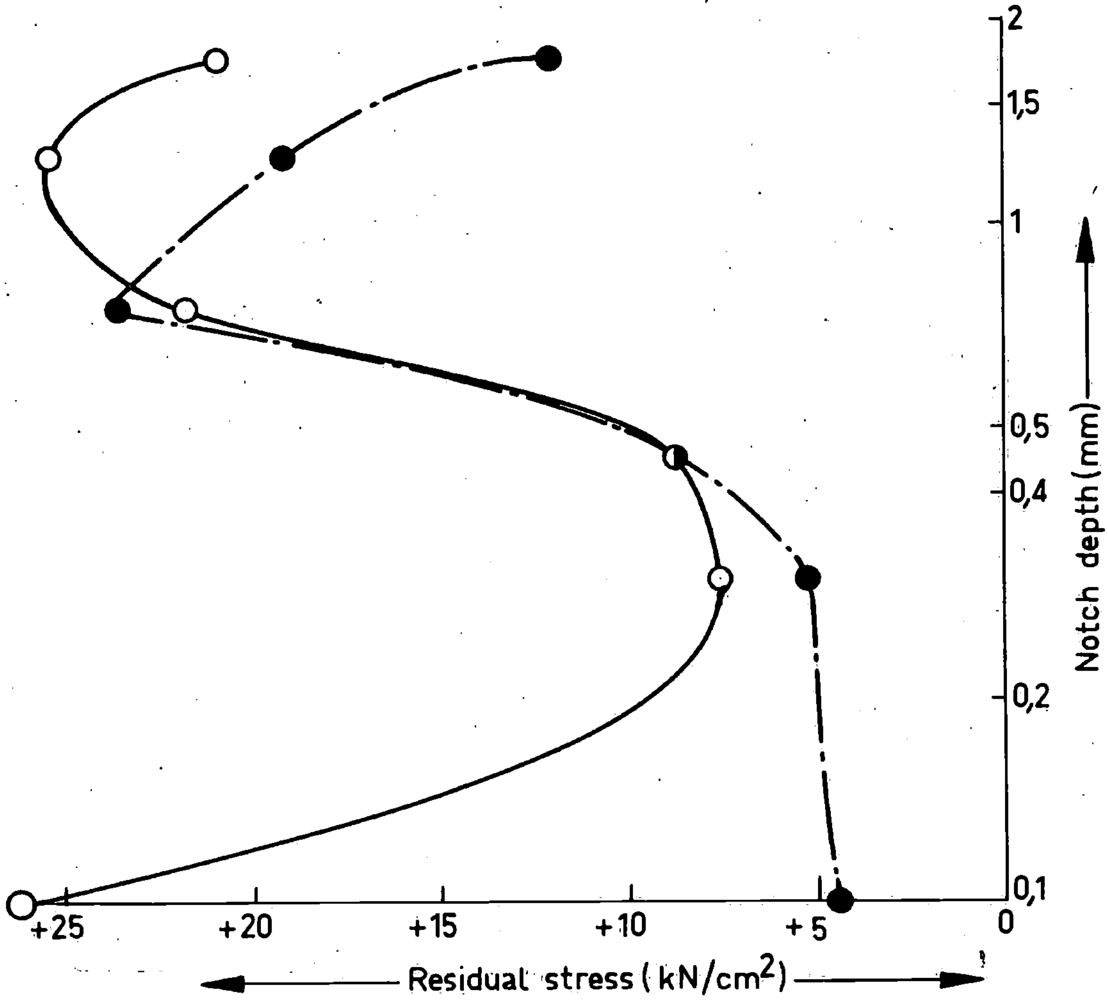

FIG.6 RESIDUAL STRESSES AT VARIOUS DISTANCES FROM FLAME-CUT EDGE IN Fe.42 GRADE. D MATERIAL. (MEASURED IN TWO DIFFERENT SPECIMENS)

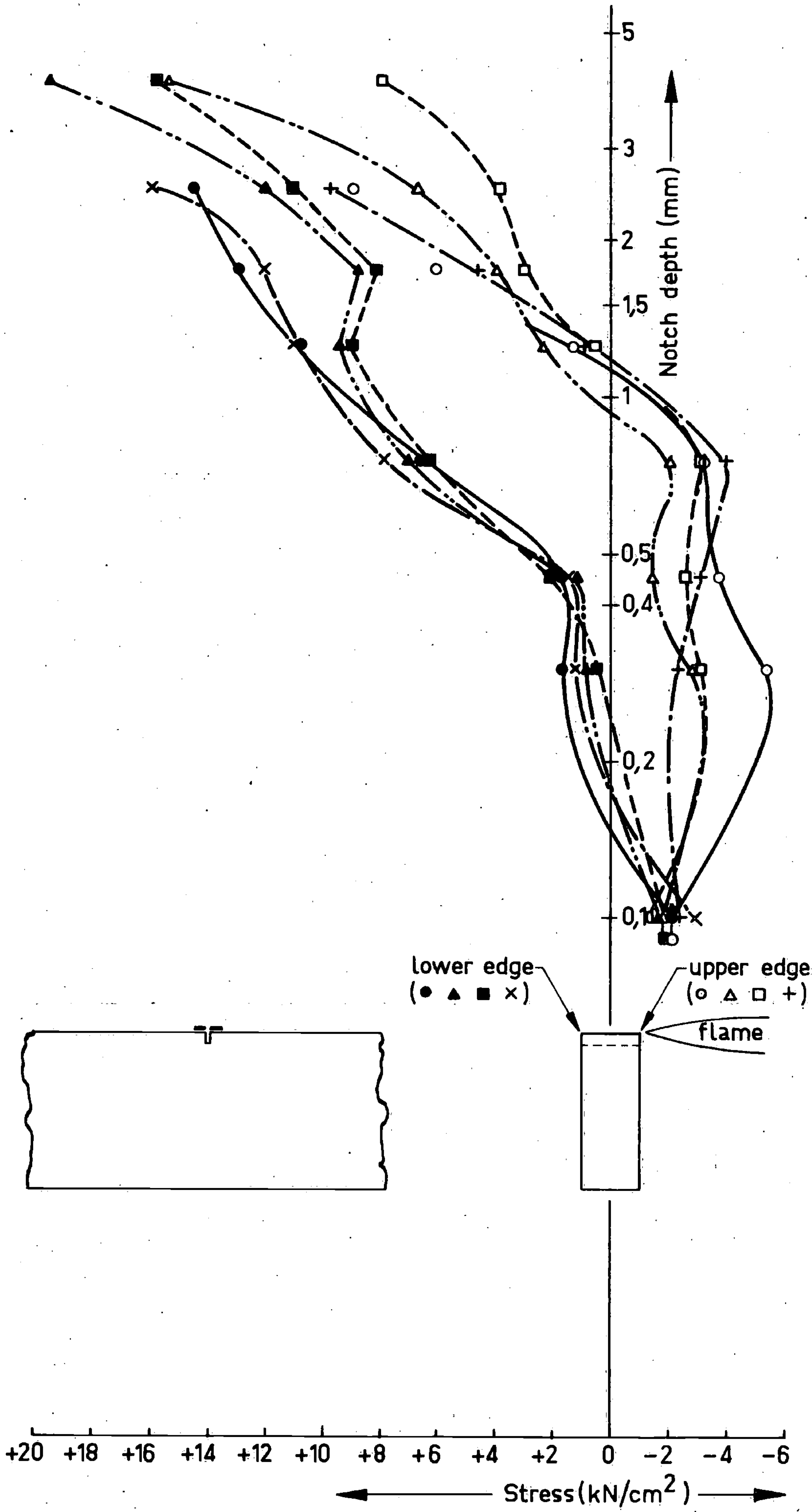

FIG.7 RESIDUAL STRESSES IN A FLAME-CUT BAR AS MEASURED WITH THE AID OF STRAIN GAUGES NEAR GRADUALLY DEEPENED NOTCHES. Fe.52 (NS 47) AVAL-CUT (MEASURED IN FOUR DIFFERENT SPECIMENS.)

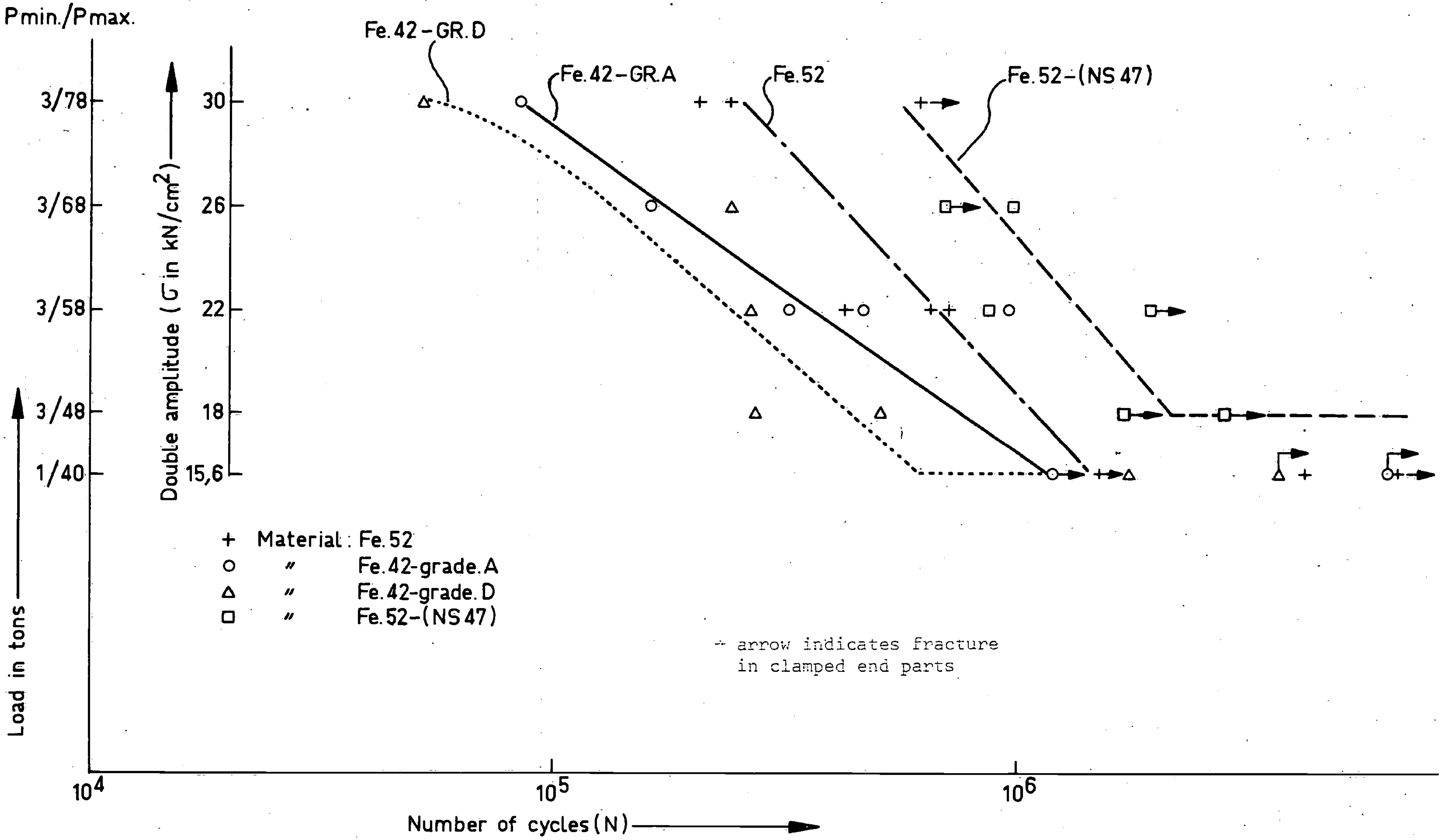

FIG 8 COMPARISON OF ALL FATIGUE-RESULTS OF NON PRESTRESSED BARS (COMPLETE FRACTURE)

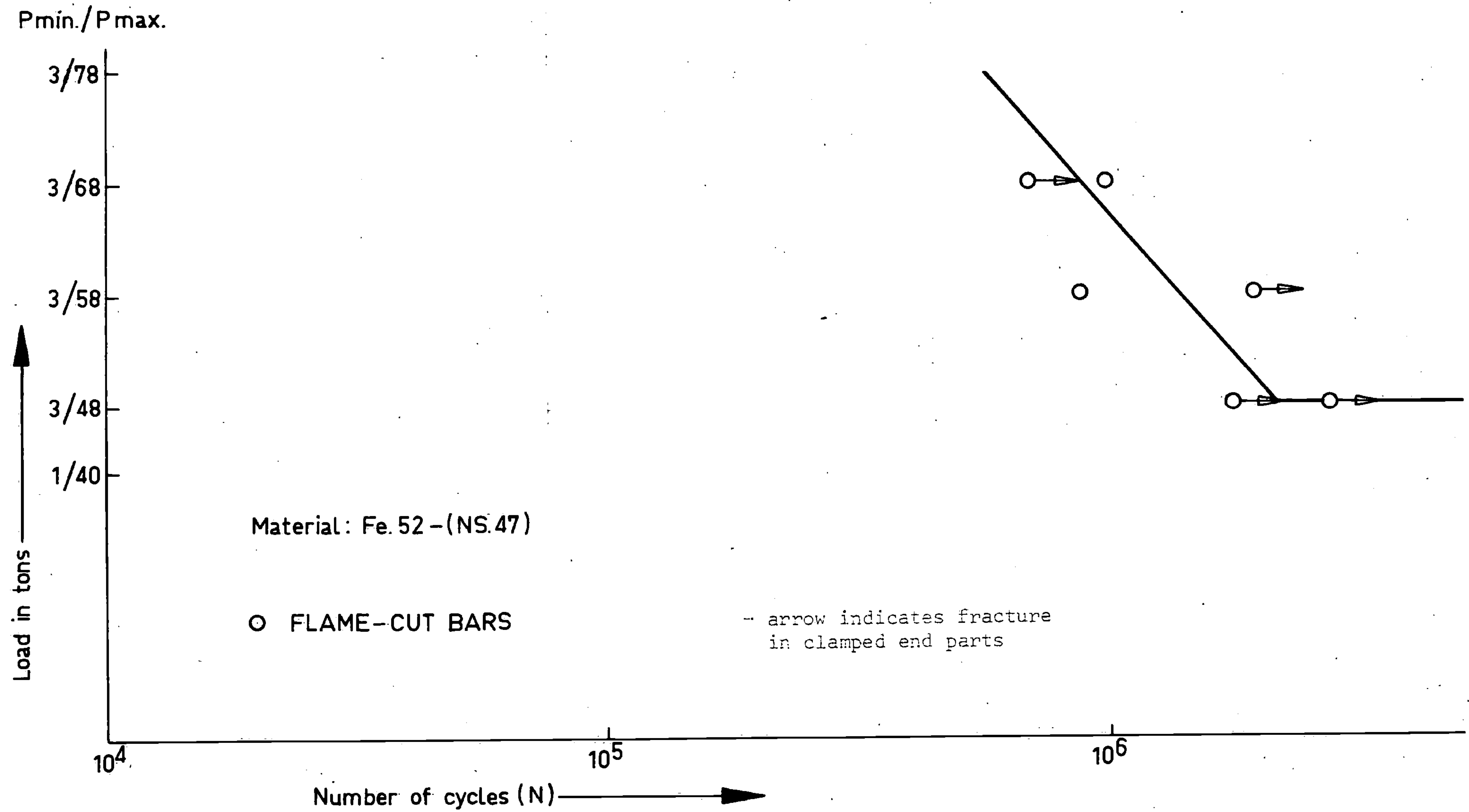

FIG.9 FATIGUE RESULTS OF FLAME-CUT AND PLANED BARS (COMPLETE FRACTURE)

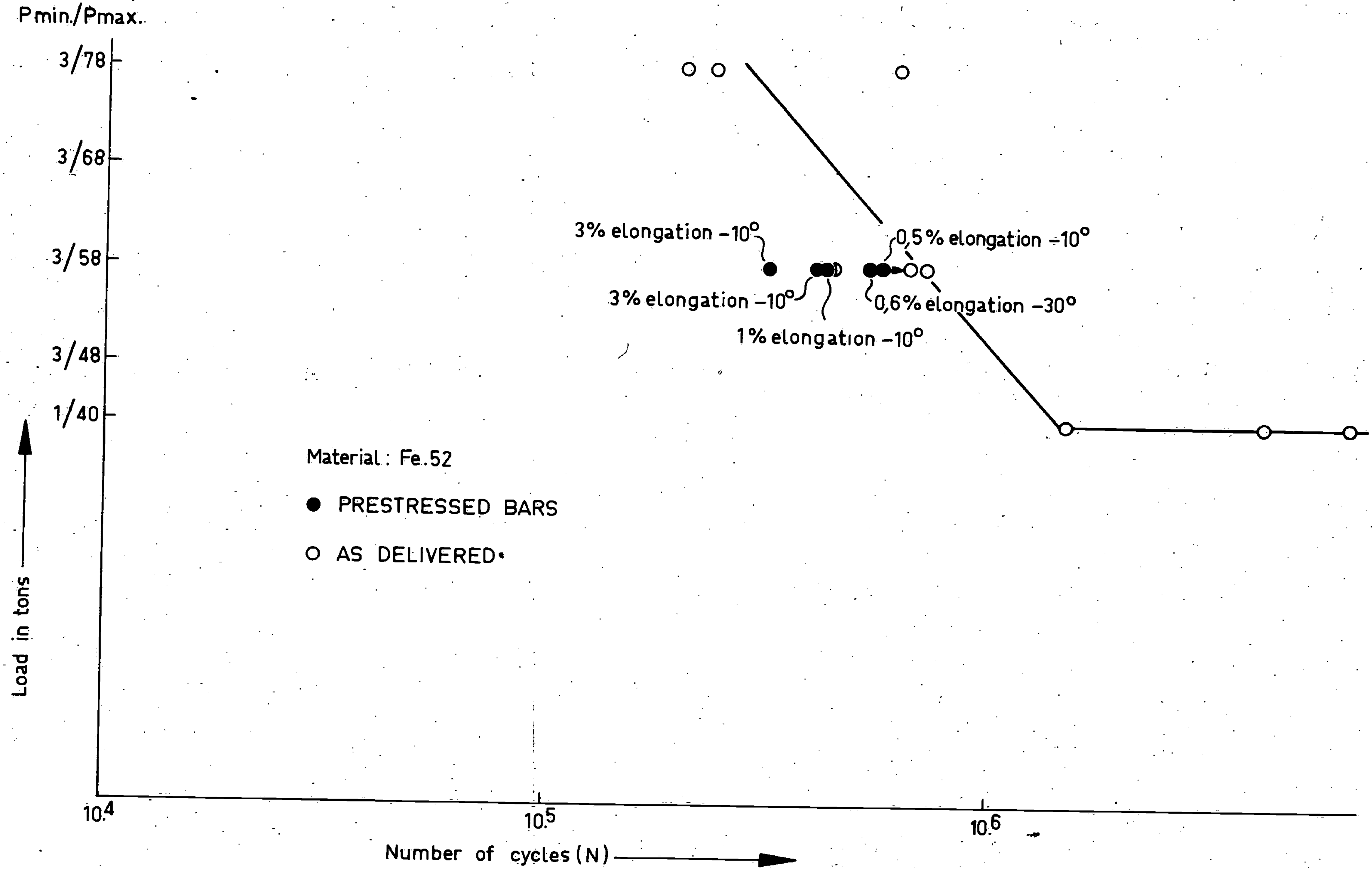

FIG.10 a FATIGUE RESULTS OF FLAME-CUT AND PRESTRESSED BARS. (COMPLETE FRACTURE)

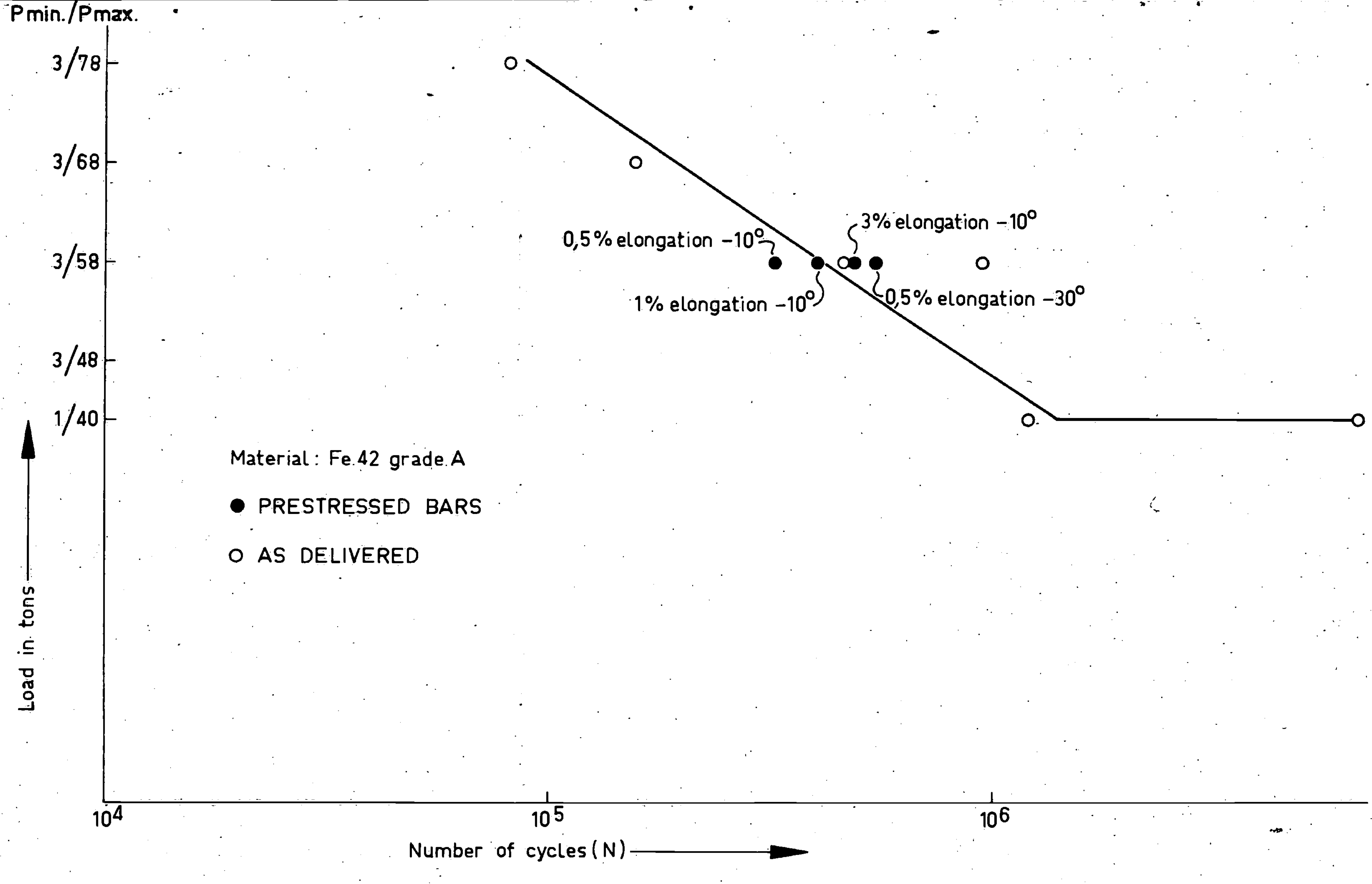

FIG.10b FATIGUE RESULTS OF FLAME – CUT AND PRESTRESSED BARS. (COMPLETE FRACTURE)

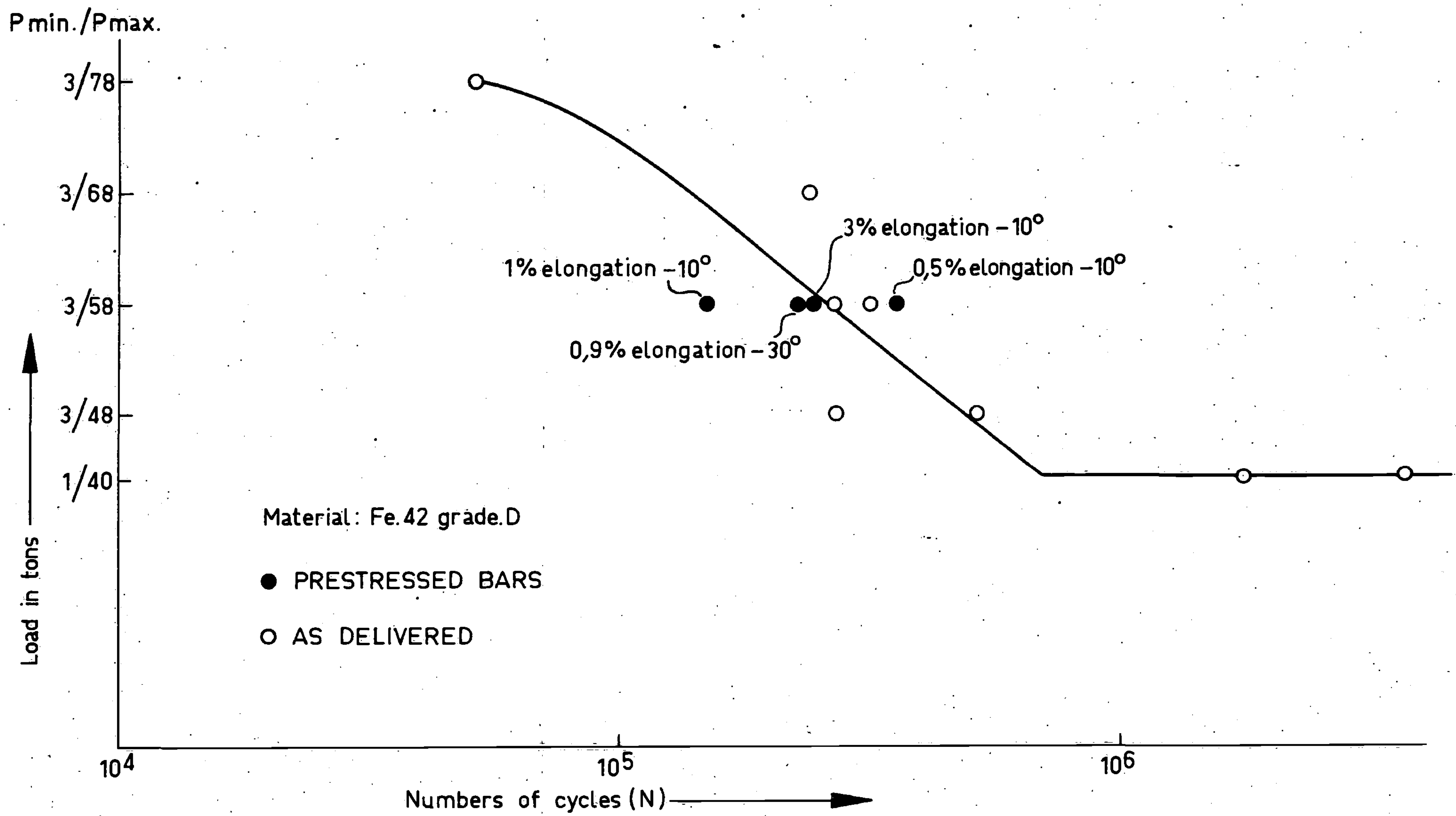

FIG.10c FATIGUE RESULTS OF FLAME-CUT AND PRESTRESSED BARS (COMPLETE FRACTURE)