THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

FATIGUE PROPERTIES OF STEEL STRIP

FIRST PROGRESS REPORT

THE FATIGUE PROPERTIES IN BENDING OF AS SHEARED PRE-HARDENED AND TEMPERED CS80 SPRING STEEL STRIP

Report No. 328

by

A.R. Hood B.Sc., M.Met.

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SUMMARY

The fatigue properties of CS80 (0.5 mm x 20 mm) spring steel strip, hardened and tempered to 478 HV10, roller straightened and with as sheared edges have been investigated in a buckling mode.

Results showed that the fatigue properties were dependent upon the strip orientation with respect to shear lip and strip curvature. With the shear lip, i.e. convex surface, of the strip in tension the minimum fatigue properties of the strip were determined at initial stress levels of 100, 200 and 300 N/mm^2.

The increase in fatigue limit from 550 N/mm^2 at 100 N/mm^2 initial stress, to 625 N/mm^2 at 300 N/mm^2 initial stress did not show the Goodman type relationship normally found for spring materials.

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1. INTRODUCTION

In the fatigue testing of spring steel strip as opposed to coil springs, extra problems are encountered. Firstly, data obtained in one stressing mode e.g. reverse bending, is not accurately applicable to strip usage in a different stressing mode e.g. single sided bending. Secondly, the results of fatigue tests are often influenced greatly by the end mountings of the strips under test unless specially shaped specimens are employed. Furthermore, the use of shaped specimens precludes the testing of strip having commercially produced edges (i.e. produced by the strip manufacturer, or alternatively, by the spring maker during the production of flat springs).

A strip fatigue testing rig has been further developed and a new model constructed at SRAMA to test strip up to 25 mm wide in a buckling mode, with the load being eccentrically applied. This ensures that the maximum bending stress is experienced at the centre of the plain strip sample, thereby avoiding the difficulties associated with premature failure due to fretting. In addition, the test method developed enables strip having "shop floor" produced edges to be tested which is of considerable advantage over other methods of testing since the edge condition of strip can influence greatly the fatigue resistance of the material.

An analysis of this particular type of loading has shown that the additional stress resulting from the end loading of the strip was negligible when compared with the bending stress generated from the flexure of the specimen. The fatigue data obtained from such a method of testing is therefore applicable to the design of flat springs where the mode of stressing is, in the majority of cases, one side of zero.

In this, the first programme of work carried out on the new rig, S/N curves have been produced at three initial stress levels for as sheared pre-hardened and tempered CS80 strip.

MATERIAL

Tests were carried out on 0.5 mm x 20 mm CS80(1) steel strip hardened and tempered to 478 HV10, supplied in 2-3 m straight lengths (roller straightened), with as sheared edges.

The chemical analysis of the material (Table I) conforms to the relevant specification(1) and the tensile properties are set out in Table II.

Figs. 1 and 2 illustrate the inclusion content of the strip and the microstructure of the matrix respectively, while Fig. 3 shows a representative 'Talysurf' trace of the strip surface transverse to the rolling direction. All these features are consistent with this grade of hardened and tempered spring steel strip.

FATIGUE TESTING

Strip specimens were tested in a buckling mode using jigs designed and constructed at SRAMA, the design of the jigs being based on the method of eccentric loading of struts (Fig. 4).

The main advantage of this method is that the point of maximum stress is at the centre of the strip away from the mounting points. In practice it was found that all fractures occurred in the central portion of the strip.

The operative length of the specimens (60 mm) was chosen to give a natural frequency of 10Hz which, at the testing frequency of 25Hz is half way between the natural and first harmonics and, therefore, should not induce dynamic stresses.

The loading points are kept in line by means of guide rods (Fig. 5) to prevent movement perpendicular to the point of loading.

An eight station forced motion fatigue testing machine was fitted with strip testing jigs (Fig. 6), and batches of strips tested at appropriate stress combinations for the production of S/N curves at initial stress levels of 100, 200 and 300 N/mm^2 (Figs. 7, 8 & 9). From the S/N curves a modified Goodman diagram has been constructed and is shown in Fig. 10.

As the fatigue machine required to be adjusted in terms of machine stroke rather than load applied, the strip end deflection values corresponding to the required stresses were obtained by a combination of calculation and experiment. (See Appendix).

4. RESULTS AND DISCUSSION

For strip of this thickness and width two production routes are available, namely:-

(i) hardening and tempering then rotary slitting (in some cases followed by edge dressing)

(ii) rotary slitting, edge dressing if required, followed by hardening and tempering.

The particular route will depend on a number of factors such as quantity of material being processed, furnace size in relation to the economics of furnace loading etc.

It is pointed out that the work described in this report is the first phase of work to be undertaken on the subject of the fatigue properties of steel strip which will cover eventually such variables as composition, hardness and edge condition. Although fatigue studies have been carried out it should not be implied from this that the strip under investigation having a rotary sheared edge is suitable for dynamic operations. The choice of such an edge condition was largely made to enable comparisons to be made with fatigu data for other more suitable edge conditions which will eventually be produced in the future. The data obtained does, however, illustrate the danger of using material produced by this particular production route (e.g. prehardened and tempered strip rotary slit to small widths) and should serve as a warning to manufacturers in those cases where small order quantities may not on the face of it warrant the use of strip having a more acceptable edge condition and stress distribution.

It was found during testing that very different properties were obtained depending on the orientation of the strip samples:-

(i) despite roller straightening a slight curvature was still present, (stress relief tests at 300°C decreased the curvature, indicating the presence of residual stresses),

(ii) there was a slight lip (burr) present on the convex surface of the strip.

The results expressed in this report (Figs. 7, 8 & 9) are for the burred, i.e. convex, surface of the strip in tension, giving minimum fatigue strength values. Full curves for the strip with the burr in compression could not be obtained in the time available but the results from the few tests which were carried out suggested that the fatigue limit was raised to above 900 N/mm^2 at an initial stress of 300 N/mm^2 compared to 625 N/mm^2 with the burr in tension (Fig. 9).

As the slitting wheel cuts into the material a compressive stress is induced in the sheared edges and the strip acquires a curvature known as 'slitting set'. Because of the manner of production of the residual stresses, the tensile component is present on the same surface of the strip as the shear lip which itself acts as a severe stress raiser.

While roller straightening will remove much of the curvature it probably merely complicates the residual stress patterns present, and the results of this work indicate that a tensile stress is still present in the burred side of the material.

The poorer fatigue properties of strip with the burred side in tension has been cited elsewhere(2), but the effect of residual stress is less well documented as the two effects tend to mask each other.

Supplementary tests on similar strip having dressed edges were commenced as an extension to the work covered by this report. The results obtained suggested that there is almost certainly some contribution from residual stress, as even round dressed strip showed poorer properties with the convex surface of the strip in tension. However, it is not uncommon practice to produce strip for small clocksprings by slitting narrow strip from wider pre-hardened and tempered stock material and then edge dressing by grinding or by some other suitable technique. In such cases, it would appear essential to remove sufficient material to obliterate the effects of the deleterious residual tensile stresses if the inherent fatigue resistance of the material is to be maintained.

Whether the loss in fatigue strength is due to edge effects, residual stresses or both, there is no doubt that in this instance these effects over-ride the expected fatigue properties for material of this type.

Previous work undertaken by the SRAMA has been concerned with the fatigue testing of three sets of CS80 (0.25 mm x 17.5 mm) strip, hardened and tempered to 454, 520 and 612 HV(3). In this case the test specimens were cut from coils supplied in the bright polished condition with commercially dressed edges. No mention is made of orientation effects and the results, from zero initial stress tests, gave a fatigue limit of about 940 N/mm^2 compared to a value of 510 N/mm^2 obtained by extrapolation to zero initial stress of the current fatigue data (Fig. 10).

Again, variations in strip dimensions and testing procedure make direct comparison of results difficult, but it is interesting that, in the current work, the few tests run on round dressed strip with the convex surface of the strip in compression gave a fatigue limit of about 900 N/mm^2 at an initial stress of 100 N/mm^2. This seems to correlate reasonably well with previous data for CS80 strip of similar hardness(3).

As the results obtained in the present project suggest that the fatigue limit for stressing in a buckling mode can be raised by more than 300 N/mm^2 simply by using the strip in the optimum orientation, this is clearly an aspect of strip fatigue which merits further investigation.

The problem of residual stress can, of course, be avoided by slitting strip and edge dressing to the required dimensions before hardening and tempering.

5. CONCLUSIONS

1. The fatigue properties of as sheared, roller straightened CS80 narrow strip when produced from wider pre-hardened and tempered strip showed a considerable dependence on the orientation of the strip with respect to the shear lip and to the strip curvature.

2. The minimum fatigue limits for the CS80 strip in the least favourable orientation (with shear lip, i.e. convex, surface of the strip in tension) were 550, 575 and 625 N/mm^2 at initial stresses of 100, 200 and 300 N/mm^2 respectively.

3. The method of strip testing employed showed great promise as a sensitive and accurate tool for the elucidation of the effect of variables on strip fatigue properties.

6. RECOMMENDATIONS FOR FURTHER WORK

The results of this phase of the work suggest that this method of strip fatigue testing is suitable for the investigation of variables such as:-

(i) edge preparation
(ii) surface condition
(iii) strip dimensions

(iv) material variables e.g. hardness, chemical analysis, inclusions content

(v) residual stresses

7. REFERENCES

1. BS 1449: Part 3B: 1964. British Standard Specifcation for Steel Plate, Sheet and Strip. Part 3B. "Cold Rolled Mild and Carbon Steel Strip".

2. Persson G. "Good steel - good springs". The Spring Journal 137, Dec. 1979, pp 5-26.

3. Gray S.D. "The fatigue properties of 0.25 mm (0.010 in) pre-hardened and tempered high carbon steel strip". SRAMA Report No. 214.

8. APPENDIX:- DERIVATION OF STRIP END DEFLECTIONS

The applied tensile stress (σ) was related to the bending moment (M) and compressive force (P) using$^{(1)}$

$$\sigma = \frac{Ma}{2I} - \frac{P}{ab} \qquad \text{..........} \quad \text{(i)}$$

Where a = strip thickness (0.5 mm)

I = sectional second moment of area = $\frac{ba^3}{12}$

b = strip width (20 mm)

The maximum bending moment (M_{max}) was then related to the load (P) applied using$^{(1)}$

$$M_{max} = Pe \sec \left(\frac{Pl^2}{4EI}\right)^{\frac{1}{2}} \qquad \text{..........(ii)}$$

Where e = eccentricity (see Fig. 4) (10 mm)

E = Young's modulus (taken as 2.05×10^5 N/mm^2)

l = length of test strip (60 mm)

In order to allow setting of the fatigue test machine the strip end deflection corresponding to each stress was required. Firstly, the deflection of the strip centre (d_c) was obtained using(1)

$$d_c = e\left[\frac{2\sin\left(\frac{kl}{2}\right)\left[1-\cos\left(\frac{kl}{2}\right)\right]}{\sin kl}\right] \qquad \text{..........(iii)}$$

Where $k = \left(\frac{P}{EI}\right)^{\frac{1}{2}}$

The end deflection corresponding to each centre deflection was obtained experimentally. One of the strip support jigs was incorporated into a Comaco load tester (Fig. a) and two dial gauges set up, one to measure deflection of the strip centre and one to measure the end deflection. Loads were applied to the strip and the centre deflections and corresponding end deflections read off on the appropriate dial gauges.

A graph was produced relating centre deflection and end deflection. Data from this graph were then combined with a table of centre deflections and corresponding applied stresses (prepared using a computer programme on equations (i), (ii) and (iii) and a graph of stress vs. end deflection obtained. Values of end deflection for each applied stress were then simply read off on this graph as required.

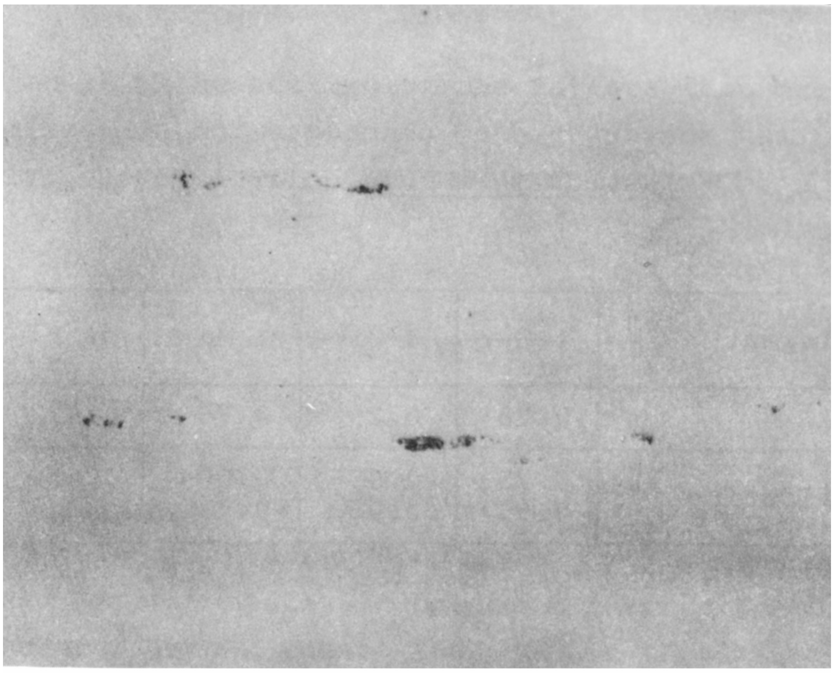
1. Case, J. and Chilver, A.H. "Strength of Materials and Structures". Arnold (1971) 2nd Edition.

TABLE I CHEMICAL COMPOSITION

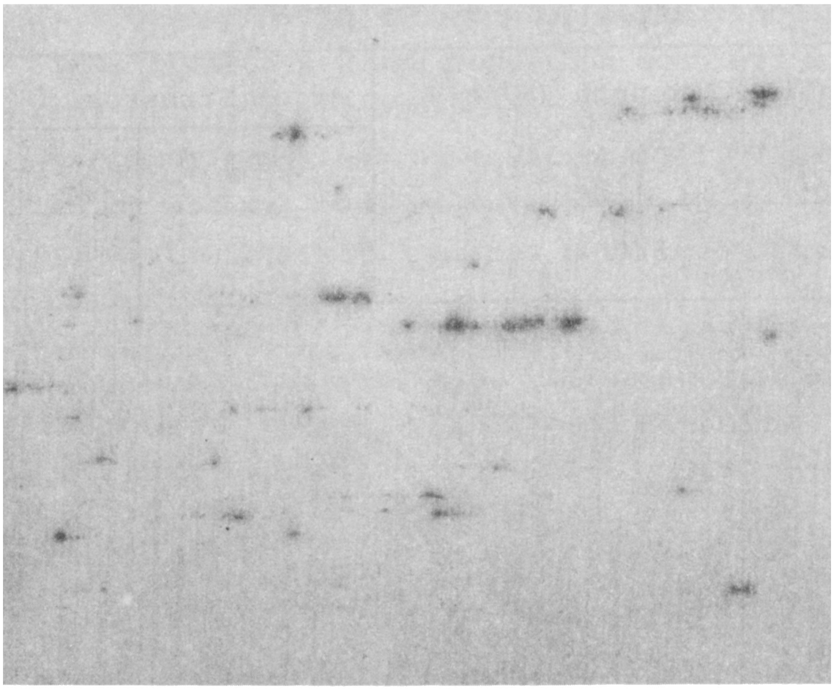
Element	% C	% Si	% Mn	% P	% S
Actual	0.78	0.25	0.76	0.012	0.032
Specification(1)	0.75- 0.85	0.05- 0.35	0.50- 0.90	0.050 max	0.050 max

TABLE II TENSILE PROPERTIES

Tensile Strength (N/mm^2)	Proof Stresses (N/mm^2)	
R_m	$R_{p0.1}$	$R_{p0.2}$
1540	1400	1415



(a) as polished



(b) lightly etched in Nital

FIG.1. INCLUSION CONTENT OF STRIP (x 150)

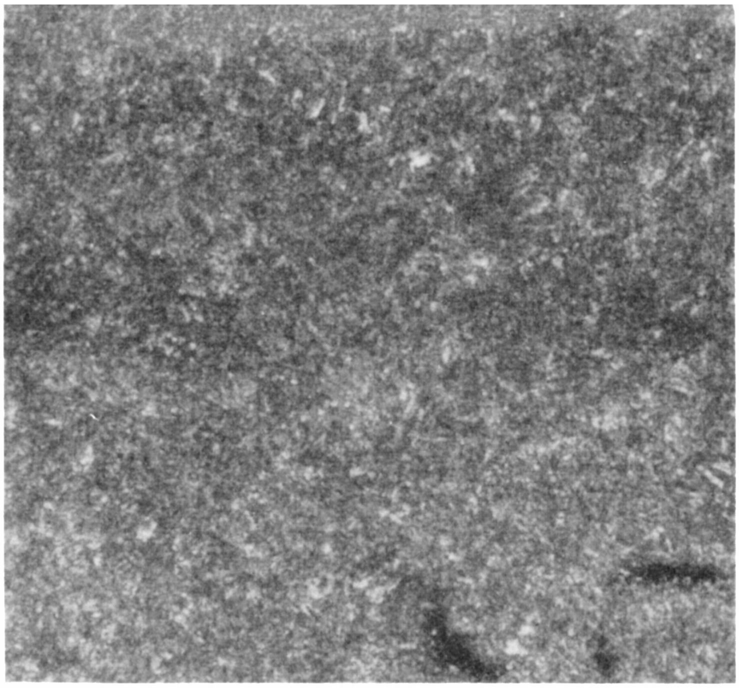


FIG.2. MICROSTRUCTURE OF STRIP MATRIX (x 150)

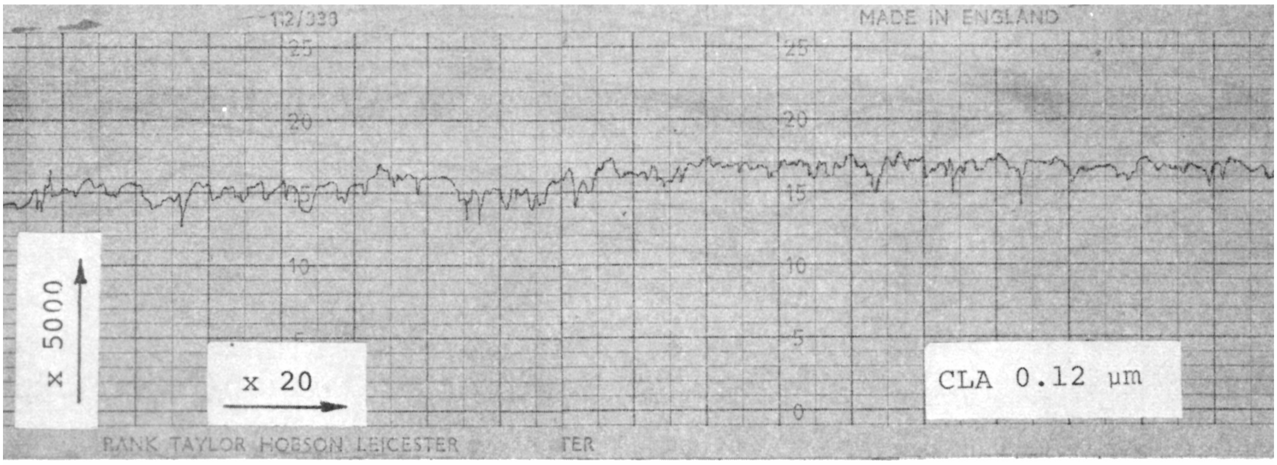


FIG.3. 'TALYSURF' TRACE OF STRIP SURFACE

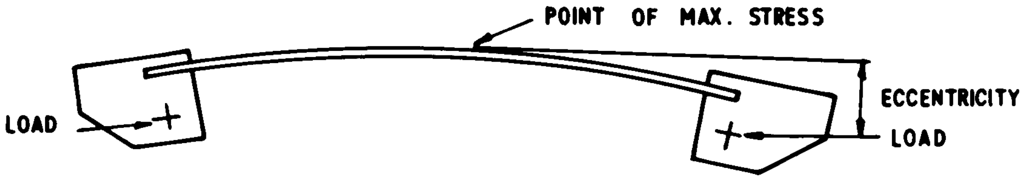


FIG. 4. METHOD OF ECCENTRICALLY HOLDING STRUTS.

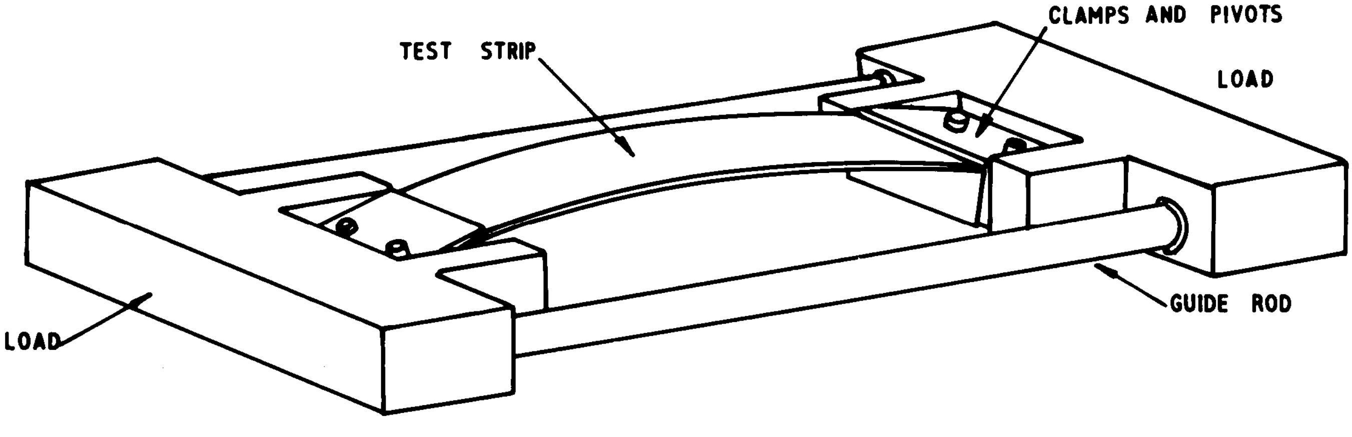


FIG. 5 FATIGUE TEST JIG.

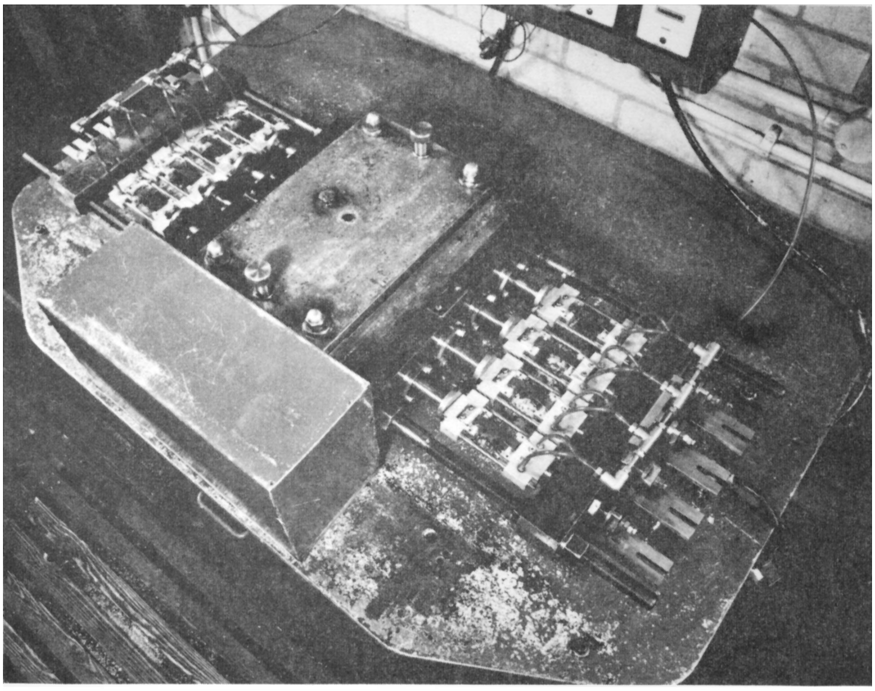


FIG.6 STRIP FATIGUE TESTING MACHINE

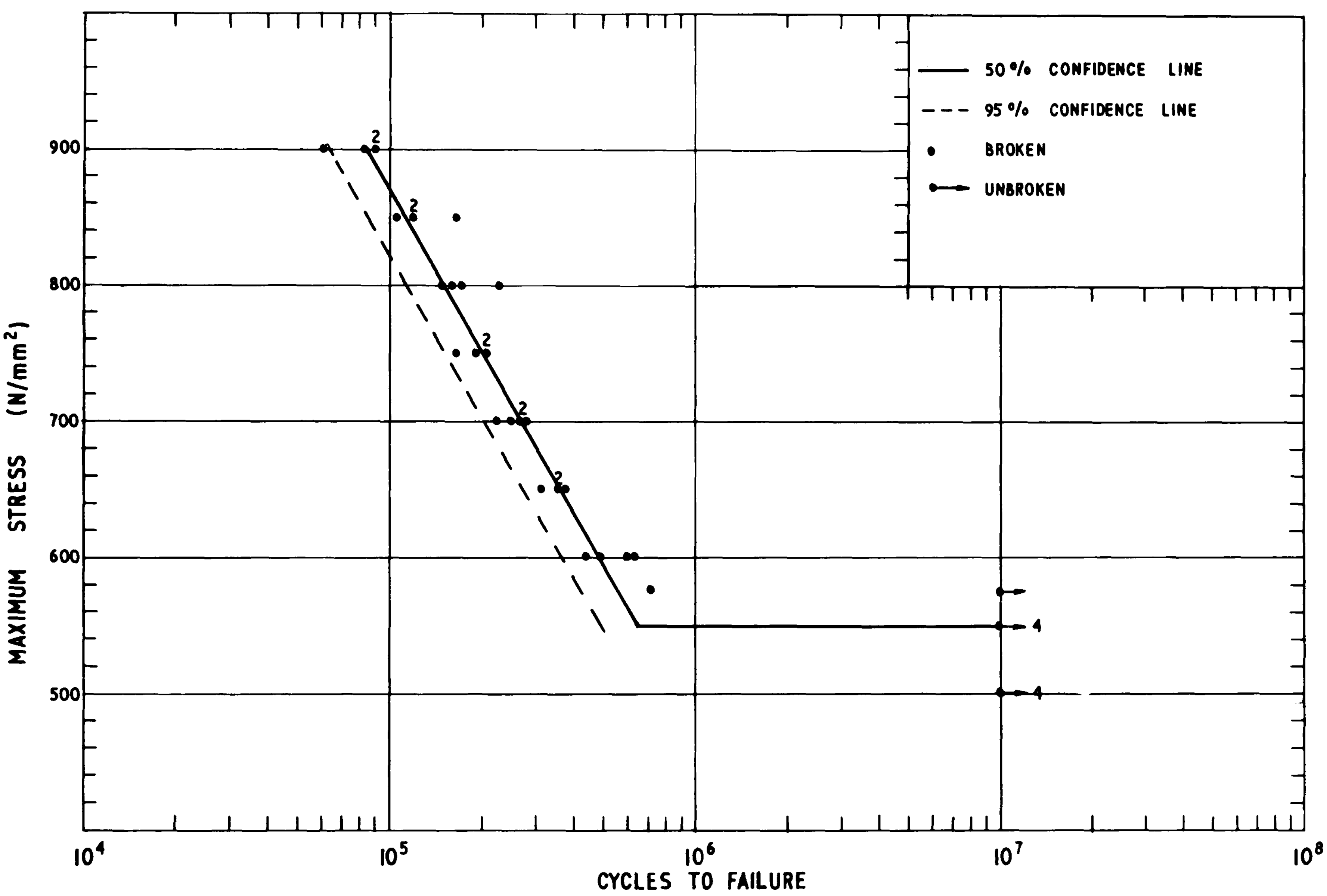


FIG. 7. S/N CURVE FOR CS80 STRIP AT AN INITIAL STRESS OF 100 N/mm²

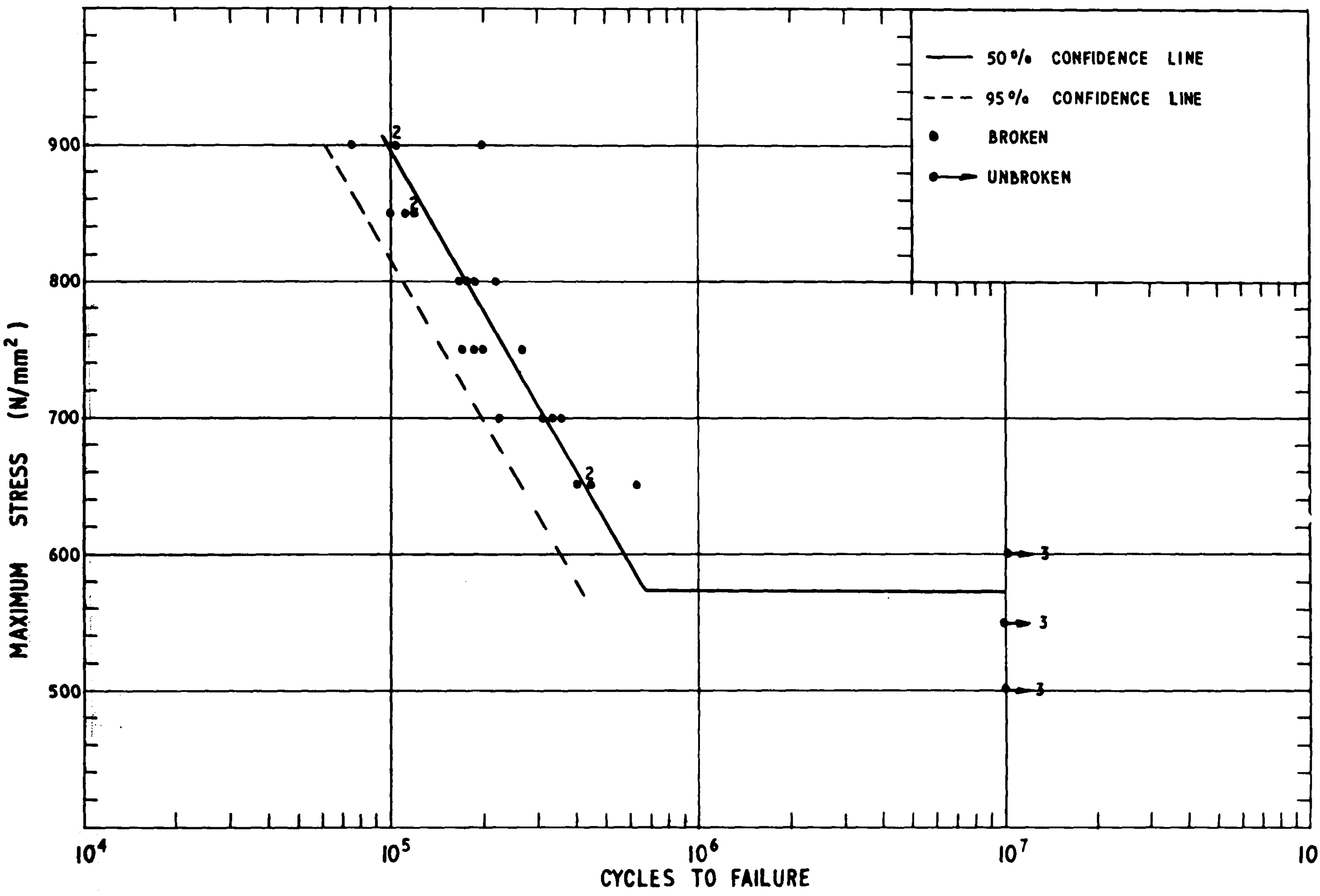


FIG. 8 S/N CURVE FOR CS 80 STRIP AT AN INITIAL STRESS OF 200 N/mm²

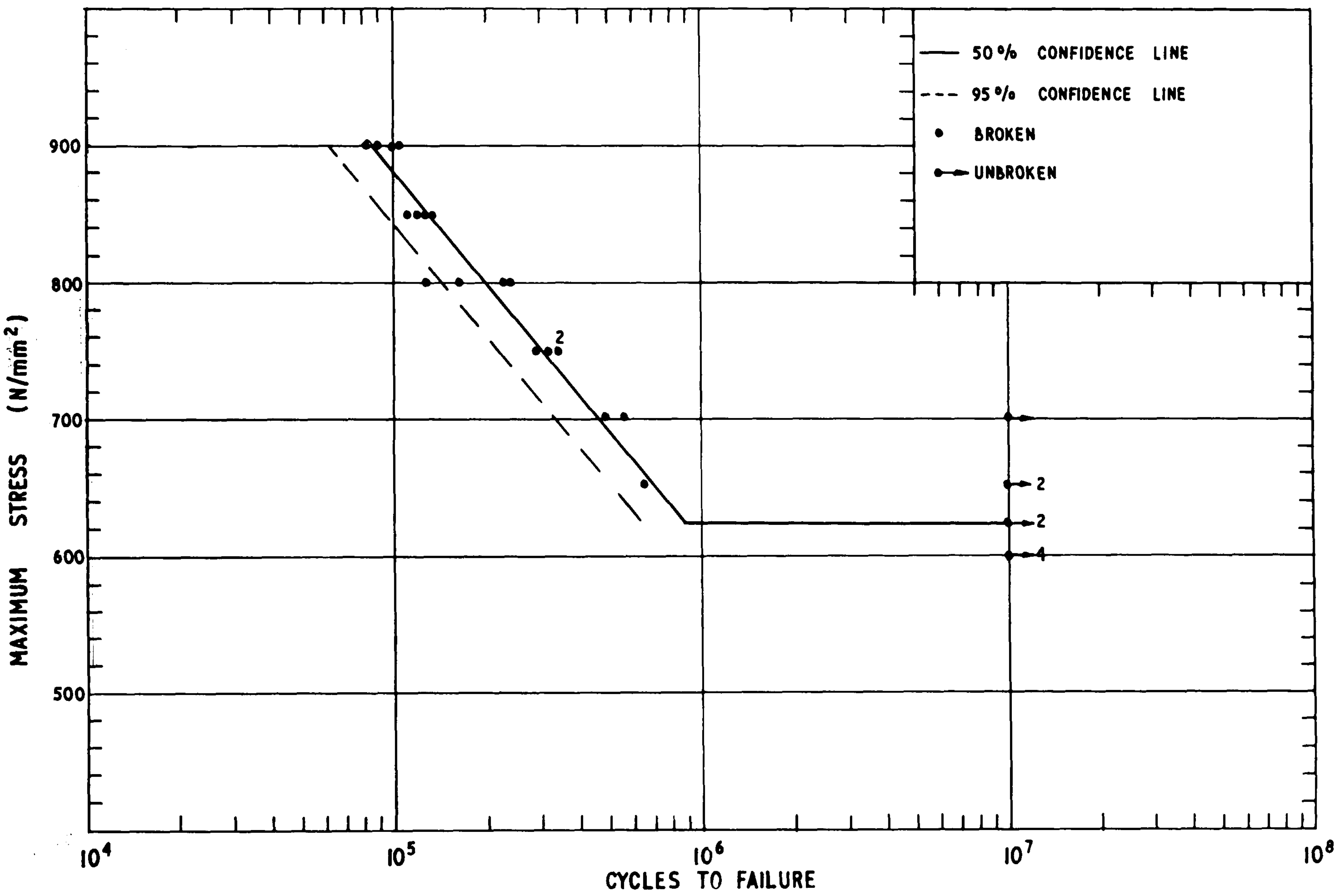


FIG. 9 S/N CURVE FOR CS 80 STRIP AT AN INITIAL STRESS OF 300 N/mm^2

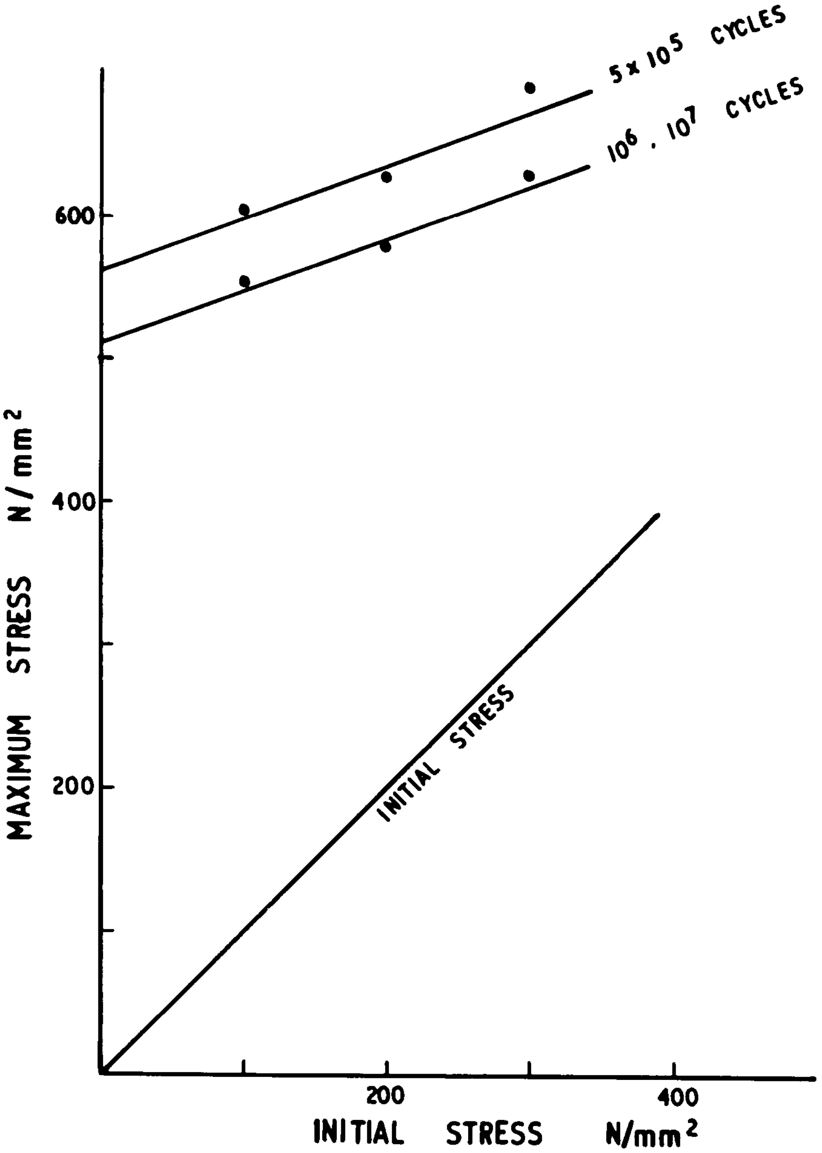


FIG. 10. MODIFIED GOODMAN DIAGRAM FOR NARROW STRIP SHEARED FROM PREHARDENED AND TEMPERED CS 80 MATERIAL (50% CONFIDENCE).

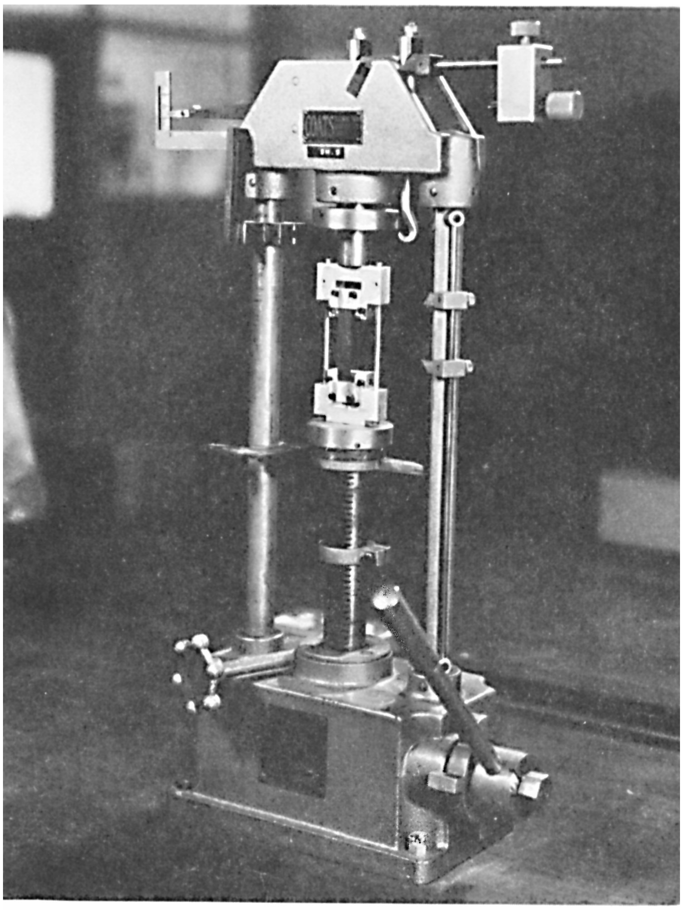


FIG. (a) LOAD TESTING OF STRIP