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by

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FATIGUE TESTS ON PLAIN SPECIMENS OF TITANIUM 6Al-4V UNDER VARIABLE AMPLITUDE LOADING

by

A. W. Cardrick
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SUMMARY

Plain specimens extracted from annealed and stress relieved titanium 6Al-4V forged bar of 330mm × 57mm section were tested at zero mean stress, under constant amplitude and narrow band random loading.

A comparison of the fatigue performance under random loading with that predicted from the constant amplitude data using Miner's rule gives a value for $\sum \frac{n}{N}$ of approximately 0.3 for endurances in the region of 10^7 cycles. This falls within the band of values between 0.15 and 0.6 commonly obtained for aluminium alloys and mild steel tested under similar conditions.

* Replaces RAE Technical Report 73029 - ARC 34609

CONTENTS

1 INTRODUCTION

The fatigue endurance of components subjected to variable amplitude loading is generally predicted from constant amplitude data using Miner's rule Briefly, this states that if n is the number of cycles applied at a given stress amplitude S_i, and if N is the number of cycles of constant amplitude that would produce failure, then $\left(\frac{n}{N}\right)_i$ is the proportion of damage caused by all the cycles applied at the level S_i. Failure is predicted when the proportions of damage caused by the various levels add up to I, i.e. when $\sum \frac{n}{N} = 1$.

Clearly, such a simple rule is subject to a number of inaccuracies and it is found that, for plain specimens of aluminium alloys and steels, values of $\sum \frac{n}{N}$ between about 0.15 and 0.6 are obtained for well-mixed load spectra, such as Gaussian narrow band random loading.

This Report presents comparable information for titanium 6Al-4V.

A limited number of plain specimens were tested under Gaussian narrow band random loading and the results indicate that the material behaves in much the same way as aluminium alloys and steels.

2 MATERIAL AND SPECIMENS

A drawing of the specimen is shown in Fig.1. Specimens were extracted longitudinally from a 33Omm wide × 57mm thick forged titanium alloy bar to DTD 5173, annealed (700°C, 2 h, air cooled) and stress relieved (625°C, 4.5 h, air cooled). The chemical composition and mechanical properties of the material are presented in Table 1.

3 FATIGUE TESTS

The specimens were tested at zero mean stress and loaded axially at a frequency of 117 Hz. A short-base Schenck fatigue testing machine, adapted for electrodynamic excitation in the manner described elsewhere[1], was used for both the constant and variable amplitude loading.

Eight tests were made under constant amplitude loading in order to extend to longer endurances, data obtained earlier from the same bar using identical specimens[2]. Results are shown in Fig.2. Curves were fitted through the endurance data using a least squares polynomial regression analysis with dependent variable log σ. In order to assess the damage due to the peak stresses in the random spectrum,it was necessary to extrapolate the constant amplitude curve in Fig.2 to an rms alternating stress of approximately 500 MN/m^2. Two curves were drawn between the test data and the point corresponding to the material tensile strength (¼ fatigue cycle) in order to represent possible upper and lower limits of fatigue strength in this region.

Seven specimens were tested under variable amplitude loading. As far as possible, stress levels were chosen to give endurances of about 10^7 cycles in order to obtain long life data without introducing too much scatter. Measurements obtained with a statistical analyser showed that at these stress levels amplitudes of up to approximately five times the rms level occurred and, as shown by the straight lines in Fig.3, the spectrum conformed closely to a Rayleigh distribution. Lives obtained under random loading are shown in Fig.4, which also shows the lives predicted by Miner's rule from tne constant amplitude data in Fig.2. As can be seen, the Miner prediction is insensitive to the extrapolation in the endurance range of interest.

4 DISCUSSION

Fig.4 shows that Miner's rule overestimates the endurance of the specimens by a factor of about 3, when the achieved endurance is approximately 10^7 cycles. The corresponding value for $\sum \frac{n}{N}$ of about 0.3 can be seen from Table 2 to be within the range of values (0.15 to 0.6) reported for aluminium alloys and mild steel[3-8] tested under the same fatigue loading. It is noteworthy that the published data shown in Table 2 indicate some increase in the value of $\sum \frac{n}{N}$ at lower endurances; the single low endurance test point shown in Fig.4 is consistent with similar behaviour in the titanium alloy specimens. This increase in $\sum \frac{n}{N}$ may be attributable to a decrease in the proportion of damage due to low amplitude cycles below the constant amplitude fatigue limit.

The values of $\sum \frac{n}{N}$ discussed are all related to well-mixed load spectra and do not necessarily compare with those obtained under single step loading, which introduces rather special effects not found in service spectra.

5 CONCLUSIONS

Specimens representative of plain components of titanium 6Al-4V have been tested under constant amplitude and also under variable amplitude loading representative of service load spectra containing large numbers of low amplitude stresses.

A comparison of the variable amplitude endurance with that predicted by Miner's rule gives a value for $\sum \frac{n}{N}$ of about 0.3 for endurances in the region of 10^7 cycles. This suggests that the material behaves in much the same way as aluminium alloys and mild steel, for which values of between 0.15 and 0.6 are commonly obtained when these are tested under similar conditions.

Table 1

MATERIAL PROPERTIES

Chemical composition and mechanical properties of annealed and stress relieved DTD 5173 forged bar of 330mm × 57mm section (from Ref.2).

Chemical composition (% by weight)

6.11 Al, 4.01 V, 0.03 Fe, 0.18 O, 0.0012 H, balance Ti

Mechanical properties

limit of proportionality	- MN/m^2	(485 MN/m^2)
0.1% proof stress	847 MN/m^2	(870 MN/m^2)
0.2% proof stress	861 MN/m^2	(880 MN/m^2)
0.5% proof stress	882 MN/m^2	(905 MN/m^2)
Tensile strength	916 MN/m^2	(944 MN/m^2)
Stiffness, E	115 GN/m^2	(115 GN/m^2)
Elongation on 4 $\sqrt{A}$	14.0%	(15.0%)

Properties prior to stress relief are shown in brackets.

Table 2

DATA FOR PLAIN SPECIMENS TESTED UNDER GAUSSIAN NARROW BAND RANDOM LOADING

Material	Mean stress MN/m^2	Approximate value of $\sum \frac{n}{N}$ at nominal endurance:-		Investigator
		10^5 cycles	$10^6 - 10^7$ cycles	
BS 2L65 aluminium alloy	0	1.1	0.6	Billingham and Ryman, Ref.3
2024-T4 aluminium alloy	110	0.2	0.2	Swanson, Ref.4
2024-T3 aluminium alloy	0	0.35	0.2	Hillberry, Ref.5
	0	0.5	0.3	Brown and Ikegami, Ref.6
	0	0.3	0.2	Fuller, Ref.7
	0	0.2	0.15	
6061-T6 aluminium alloy	0	0.5	0.3	Brown and Ikegami, Ref.6
Mild steel EN IA	0		0.4	Booth, Wright and Smith, Ref.8
Mild steel EN 15	0		0.4	

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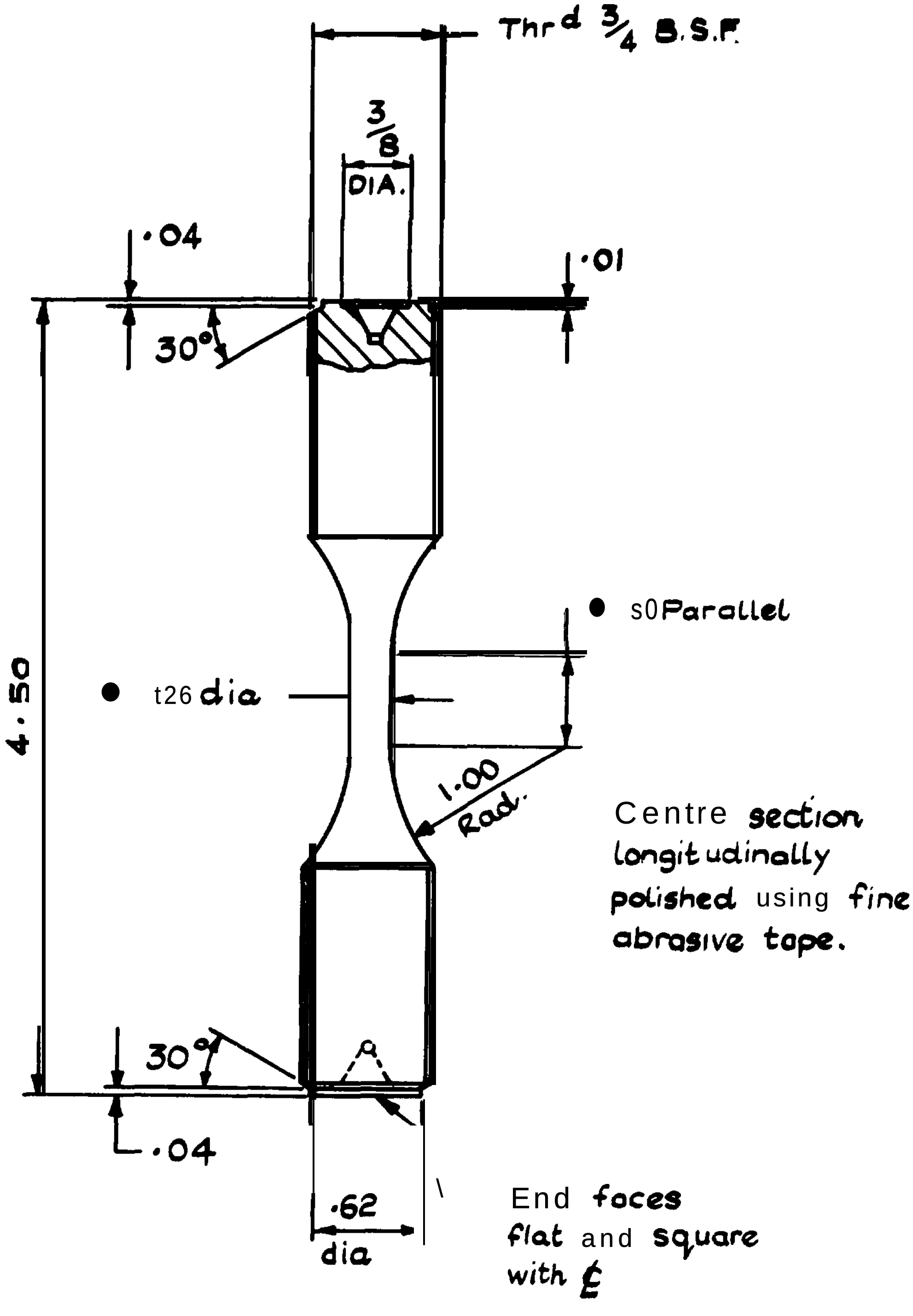

(Dimensions in inches, Preferred unit at time of manufacture)

Scale Full size

Fig. I Plain fatigue test specimen

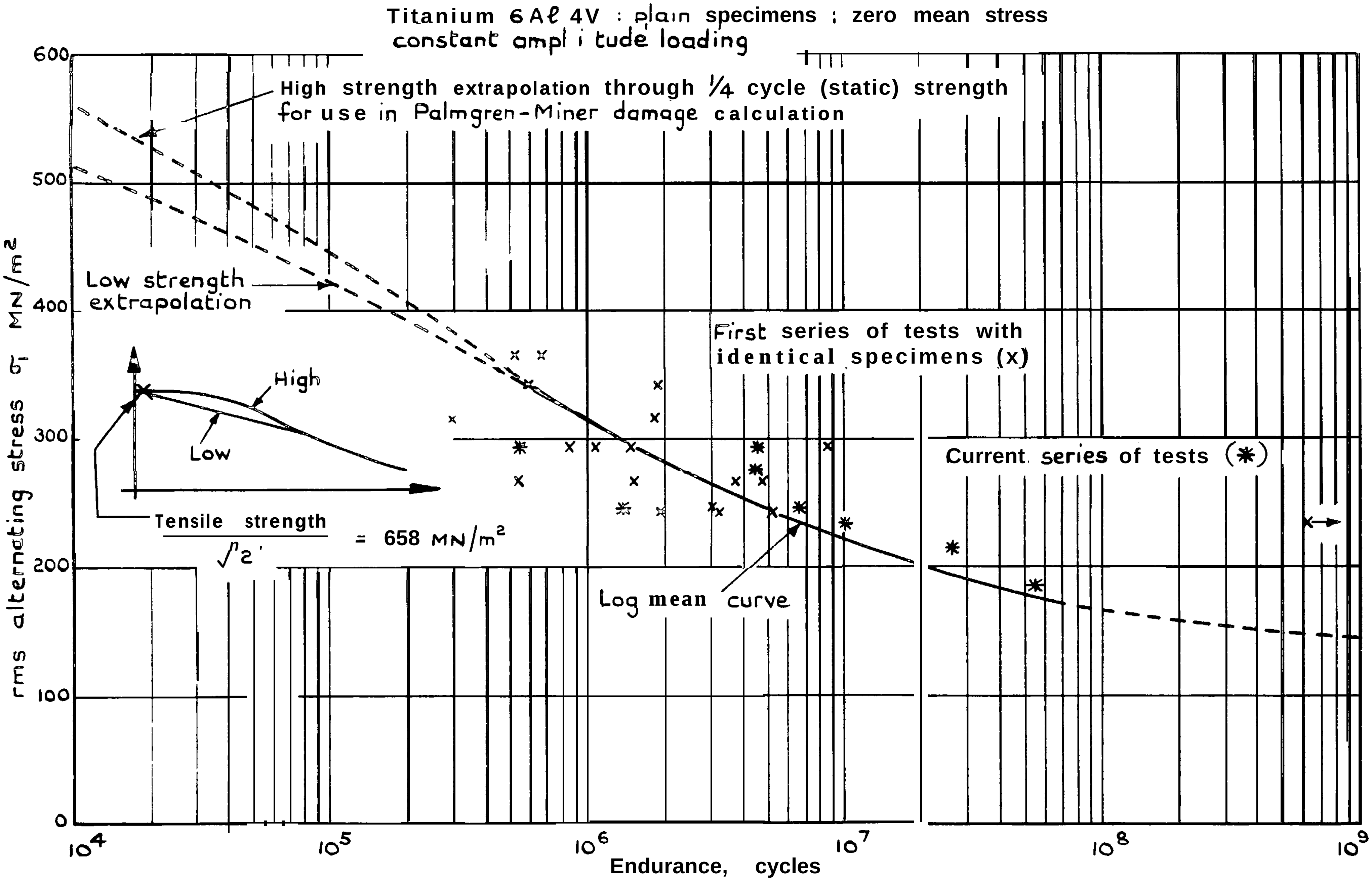

Fig.2 Endurance of specimens under constant amplitude loading

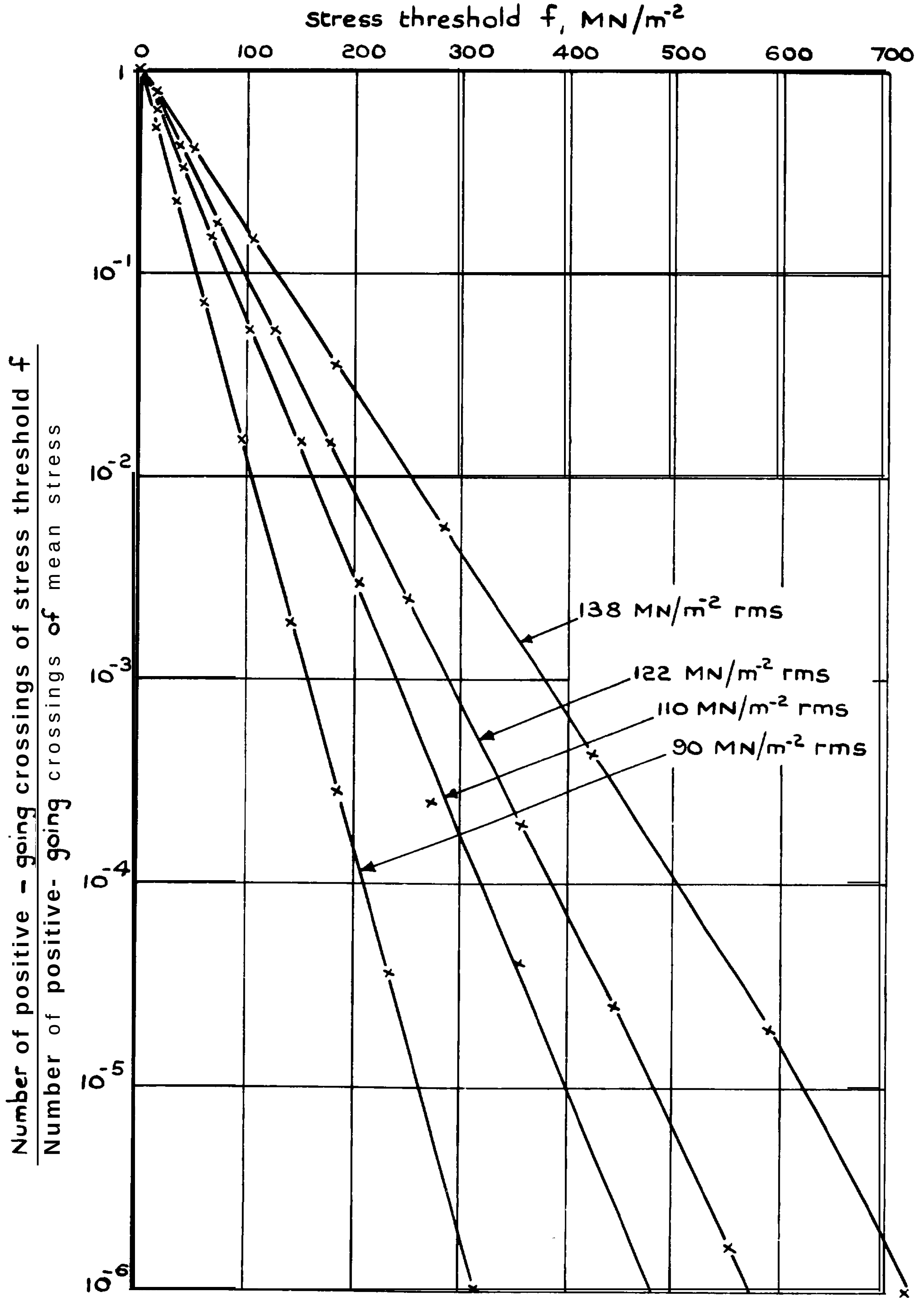

Fig.3 Measurements of cumulative level crossings under variable amplitude loading

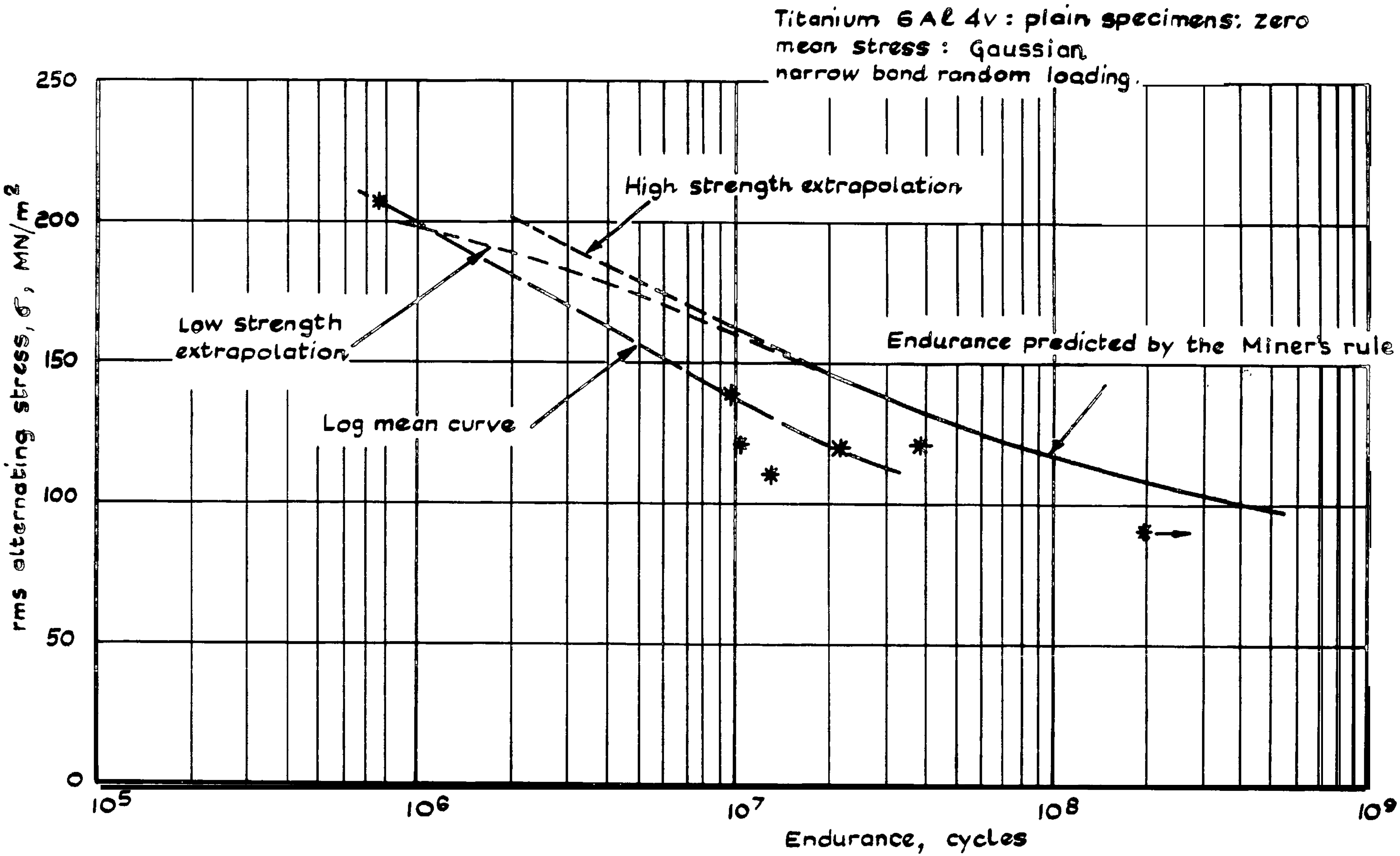

Fig. 4 Endurance of specimens under variable amplitude loading

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