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The Effect of Flight-by-Flight Load and Temperature Sequences on Residual Static Strength of Notched Specimens in CM003 (RR58) Aluminium Alloy

by

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THE EFFECT OF FLIGHT-BY-FLIGHT LOAD AND TEMPERATURE SEQUENCES ON RESIDUAL STATIC STRENGTH OF NOTCHED SPECIMENS IN CM003 (RR58) ALUMINIUM ALLOY

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SUMMARY

The effect of flight-by-flight load and temperature sequences on residual static strength was investigated by tests of thin notched specimens in CM003 (RR58) plate material. The effects of different fatigue stress levels, temperatures and numbers of flight cycles were studied.

Overall the scatter in static strength was very small. Fatigue loading itself did not cause appreciable loss in static strength, but when fatigue loading was coupled with heating cycles to a maximum temperature of 125°C the static strength was reduced by a small but statistically significant amount. Reduction in residual strength was sensitive to number of temperature cycles and maximum temperature but appeared to be insensitive to overall stress level and creep strain.

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* Replaces RAE Technical Report 76004 - ARC 36736

CONTENTS

Conversions: 1000 $lb(f)/in^2 = 6.894 MN\ m^{-2} = 0.689 Hb$

1 INTRODUCTION

The accumulation of fatigue damage during the service life of an aircraft is accompanied by a decline in the residual static strength of the structure which is a determining factor in fail safe design. For a supersonic transport aircraft there is the possibility that periodic exposure to kinetic heating will bring about changes in the material which will alter the rate of damage and the nature of the damage and thus affect the residual static strength characteristics.

Previous work[1,2] on measuring the residual static strength of fatigue-cracked lug specimens of four aluminium-copper alloys showed that a single period of heating applied at some stage of the fatigue test did not significantly affect the relationship between residual static strength and crack area. Day[3] has shown that for clad sheet specimens of DTD5070A (RR58) heating for up to 30000h at 120°C with and without static loading had no significant effect on the room temperature static properties of plain specimens. In this present work, the residual static strength of notched specimens is assessed after exposure to extensive load and temperature cycling. Fatigue loading was applied as a flight-by-flight sequence with heating applied under the steady load condition associated with the cruise phase of the flight cycle. Different stress levels, temperatures, and numbers of heating periods were applied before strength tests.

It is shown in the following sections that the effect of the flight-by-flight load and temperature sequences on residual static strength was small, but statistically significant. Residual strength was sensitive to temperature and to the number of heating periods but not to the fatigue stress level, although it should be appreciated that even under the highest stress level no observable fatigue damage was noted.

2 MATERIAL AND SPECIMEN

The material was a fully heat treated aluminium alloy to specification CM003 (RR58) in the form of 3in thick plate. The chemical composition and tensile properties as stated by the manufacturer are given in Table 1.

Notched specimens (see Fig.1) were extracted from a fixed depth in the plate with the grain of the material in the transverse direction. The single depth was chosen to avoid possible variations in static strength through the thickness of the plate. For fatigue testing, axial loading was applied through pin jointed end plates bolted to the specimen.

All specimens were painted black with a matt high-temperature paint to increase heat absorption.

3 TESTING RIG

The Prototype Facility of the 'Avro Rig'[4] was used for testing. In these rigs loading is by mechanical means, heating by infra-red elements and cooling by air blown over the specimen surfaces.

In the fatigue test, temperature was monitored by three thermocouples on each specimen, connected in series to give an average over the gauge length of the specimen. Temperature control was by two additional thermocouples mounted back to back on the specimen and connected in parallel to guard against thermocouple failure. All thermocouples were the T1T2 'stick-on' type, in the form of a wafer of epoxy resin cement.

Fig.2 is a view of the specimen in the rig, showing two creep extensometers fitted between extension arms bolted to the specimen. These LVDT extensometers are encased in blocks of 'Syndanio' to restrict heat flow from the specimen to the transducer, and provide measurements of specimen extension throughout the test with a nominal resolution of ±20 micro-inches on the 6.25in gauge length.

4 FATIGUE AND RESIDUAL STATIC STRENGTH TESTS

Fatigue testing to a given number of load-temperature sequences was carried out under contract by HSA Woodford, and residual static strength tests were subsequently made in Materials Department, RAE. The fatigue loading was a simplified flight-by-flight load and temperature sequence (see Fig.3), each flight containing gust cycles of constant amplitude and sinusoidal waveform. The amplitude of these gust loads was a constant proportion of the fatigue mean stress (P) of which three magnitudes were studied, 11000, 9000 and 7000 lb/in^2 based on the gross cross sectional area. In some tests the temperature was maintained constant at 40°C whereas in other tests the temperature was raised from this level to 100°C or 125°C during the period of steady load in every flight sequence. The number of flight cycles applied prior to static testing was either 5000 or 15000; these represent only small proportions of fatigue damage, amounting in no case to more than 5% of the fatigue life in tests without heating[5]. Residual static strength tests were all made in the same tensile test machine at a uniform rate of straining.

5 RESULTS

Details of residual static strength expressed as failing stress on the net cross sectional area are given in Table 2 for tests at a constant temperature of 40°C and in Table 3 for tests with maximum temperatures of 100°C and 125°C. All specimens failed through the net section at the stress concentration in the shear mode, i.e. the fracture surface was inclined at 45° to the surface of the specimen. No fatigue cracks were visible on the fracture surfaces under the optical microscope.

As described in section 3, measurements of creep extension were made throughout the fatigue tests. The readings showed an unexpected variability with time and it was necessary to fit a straight line to the customary relationship of creep strain against a cube root timescale in order to estimate mean strain at end of test. Table 4 gives creep strain at end of test expressed as percentage strain over the 6.25in gauge length.

6 DISCUSSION

The results in Table 2 show no appreciable change in static strength after fatigue testing at 40°C. Furthermore the strength is very close to the UTS quoted by the manufacturer. The estimated standard deviation of all results is 331 lb/in^2 on an arithmetic mean of 63320 lb/in^2; all the results in fact lie within ±1.3% of the mean value. This result of low scatter in notched static strength is in line with the findings of Jefferson[6] from work on a number of aluminium alloys. It is considered therefore that the effect on residual strength of the fatigue testing was negligible and that the mean of all these tests can be used to evaluate the tests with maximum temperatures of 100°C and 125°C.

The results from Table 3 have been presented in Fig.4 to show the variation in residual strength with maximum temperature of the heating cycle for the two durations of fatigue-temperature applications. It is seen that there was negligible effect for a maximum temperature of 100°C, but small reductions in strength occurred for a maximum temperature of 125°C: 0.7% after 5000 flight cycles and 1.3% after 15000 flight cycles. There appears to be no correlation within these results of percentage reduction with the magnitude of the creep stress; the range of creep strains measured was from 0.001% at the 7000 lb/in^2 fatigue mean stress condition to 0.056% at the 11000 lb/in^2 fatigue mean stress condition (see Table 4).

It will be appreciated that the reduction in static strength following cycling to 125°C was very small, viz., a maximum reduction of 2.4%, and an average reduction after 15000 flight cycles of only 1.3%. Because of the low values of standard deviation associated with the results, the mean values of residual strength for the tests at 40°C (standard deviation = 331 lb/in^2) and for the tests with 15000 flight cycles at a maximum temperature of 125°C (standard deviation = 657 lb/in^2) were found to be statistically different using the t test[7] at a 1% level of significance.

7 CONCLUDING REMARKS

Residual static strength tests have been made on thin CM003 notched specimens after application of load and temperature sequences. It was found that, after 15000 flight cycles of load and temperature with a total heating time of 15000h at 125°C, residual strength was reduced by 1.3%, a result which is statistically significant due to the very small scatter in the results. Corresponding tests with heating at 100°C showed negligible changes in static strength. Similar results were obtained for the three levels of fatigue stress investigated.

Table 1

CHEMICAL COMPOSITION OF CM003 MATERIAL

Element	% by weight
Cu	2.47
Mn	0.12
Mg	1.47
Fe	0.96
Si	0.19
Zn	0.09
Ti	0.03
Ni	1.14
Al	Remainder

Tensile properties - transverse direction

0.2% PS	58900 lb/in^2
UTS	64300 lb/in^2
Elongation	7%

Table 2

RESIDUAL STATIC STRENGTHS OF FATIGUE TESTS AT 40°C

Fatigue mean stress lb/in^2 (gross)	No. of flight cycles applied	Failing stress (σ) based on net cross section (lb/in^2)		Mean failing stress lb/in^2 (net)	Failing stress as % of static control
		Spec. No.	σ		
static control		J3G F2C	63400 63500	63450	100.0
7000	15000	F1G J2C	63800 63400	63600	100.2
9000	5000	J4G F4C	63100 63400	63250	99.7
9000	15000	F6G J4C	63500 63400	63450	100.0
11000	5000	B4G B4C	62500 63100	62800	99.0
11000	15000	F7C J1G	63500 63100	63300	99.8

Arithmetic mean of all tests = 63320 lb/in^2

Estimated standard deviation = 331 lb/in^2

Table 3

RESIDUAL STATIC STRENGTHS OF HEATED SPECIMENS

Fatigue mean stress lb/in^2 (gross)	Maximum temperature of heating cycle °C	No. of flight cycles applied	Failing stress (σ) based on net cross section (lb/in^2)		Mean failing stress lb/in^2 (net)	Failing stress as % of 40°C result*
			Spec. No.	σ		
7000	125	15000	B3G F6C	63000 61800	62400	98.5
9000	125	5000	B5G J3C	62100 63100	62600	98.9
9000	125	15000	F4G B3C	63400 62800	63100	99.7
11000	100	5000	F5C B2G	63800 63400	63600	100.5
11000	100	15000	B1G B6C	63500 63000	63250	99.9
11000	125	5000	B7G B1C	63100 63100	63100	99.7
11000	125	15000	B2C F7G	61800 62200	62000	97.9

* 40°C result is arithmetic mean of all tests with heating at 40°C - see Table 2

Arithmetic mean of all results - 62870 lb/in^2
(estimated standard deviation = 645 lb/in^2)

Arithmetic mean of all 125°C results - 62630 lb/in^2
(estimated standard deviation = 599 lb/in^2)

Arithmetic mean of all 125°C with 15000 flight cycles applied - 62490 lb/in^2
(estimated standard deviation = 657 lb/in^2)

Table 4

CREEP STRAINS MEASURED FROM TESTS WITH HEATING AT 100°C AND 125°C

Fatigue mean stress lb/in² (gross)	Maximum temperature of heating cycle °C	No. of flight cycles applied	Specimen number	Plastic strain at end of test % over 6.15in GL	Average plastic strain % over 6.25in GL
7000	125	15000	B3G F6C	0.001 0.000	0.001
9000	125	5000	B5G J3C	0.023 0.010	0.017
9000	125	15000	F4G B3C	0.026 0.009	0.018
11000	100	5000	F5C B2G	0.019 0.034	0.027
11000	100	15000	B1G B6C	0.011 0.005	0.008
11000	125	5000	B7G B1C	0.071 0.040	0.056
11000	125	15000	B2C F7G	0.030 0.006	0.019

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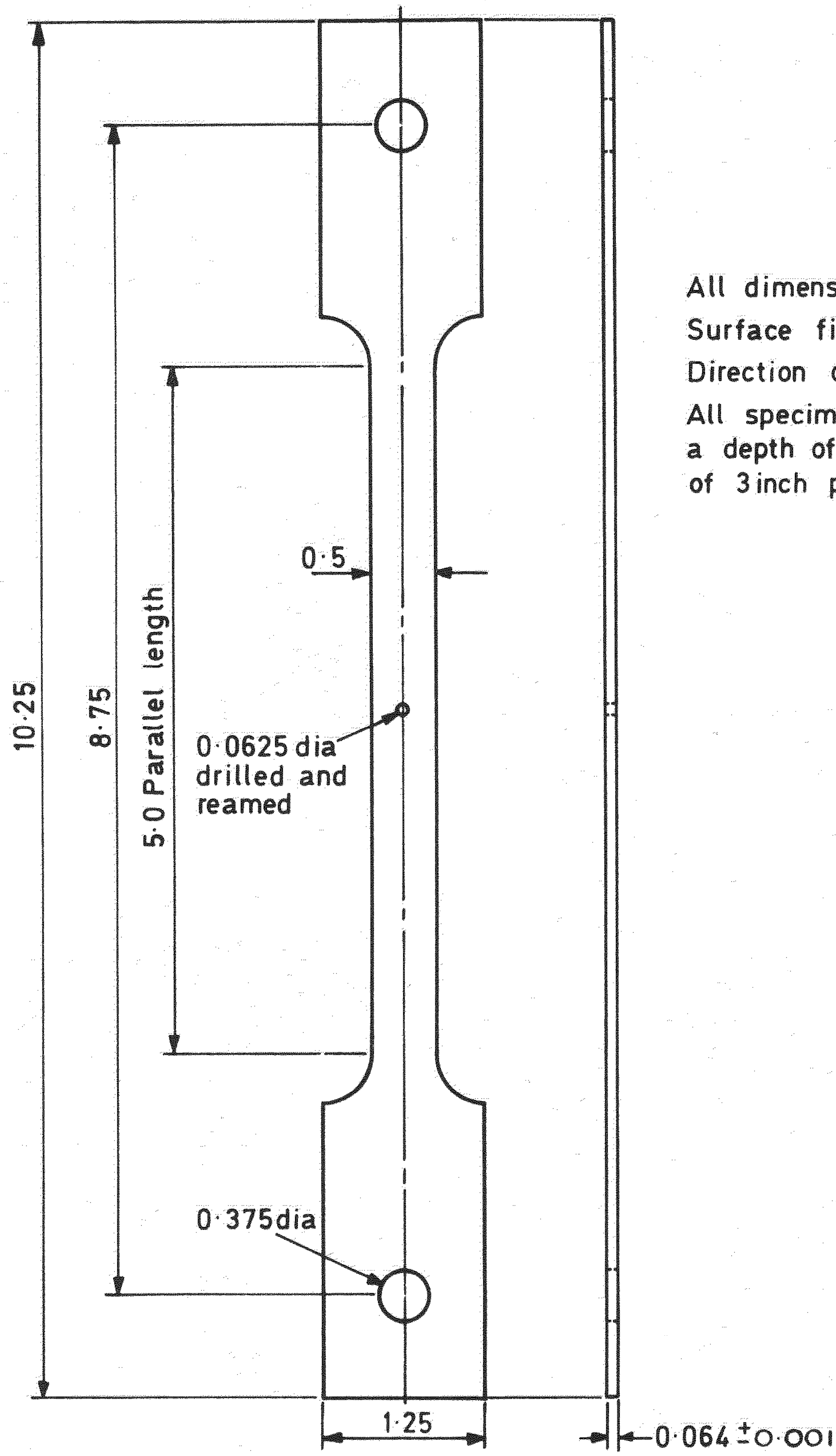


All dimensions in inches
Surface finish 40 – 60 μ inches
Direction of rolling transverse.
All specimens extracted from a depth of 1 inch from surface of 3 inch plate.

Fig. 1 Notched specimen – $K_t = 2·7$

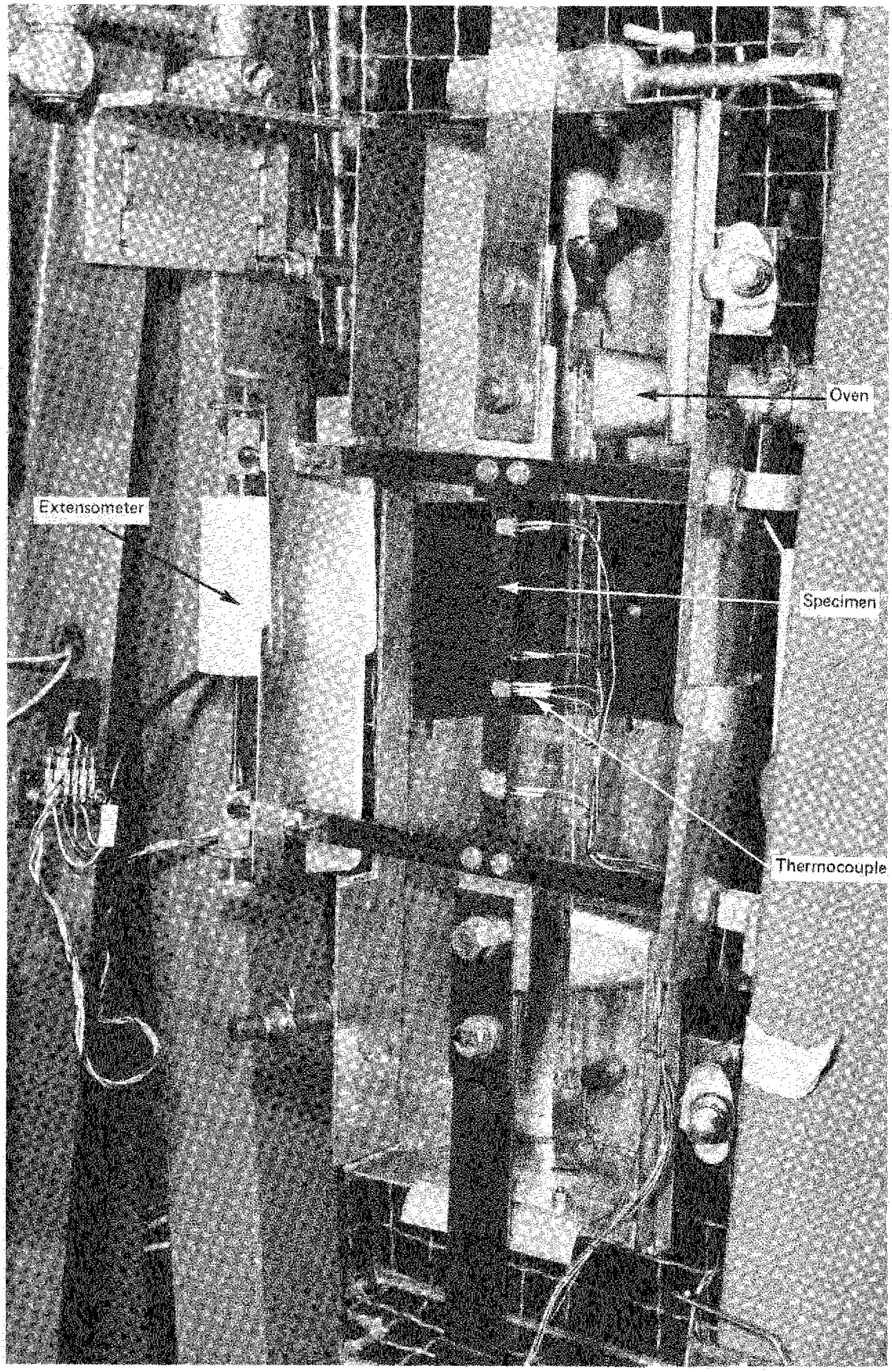
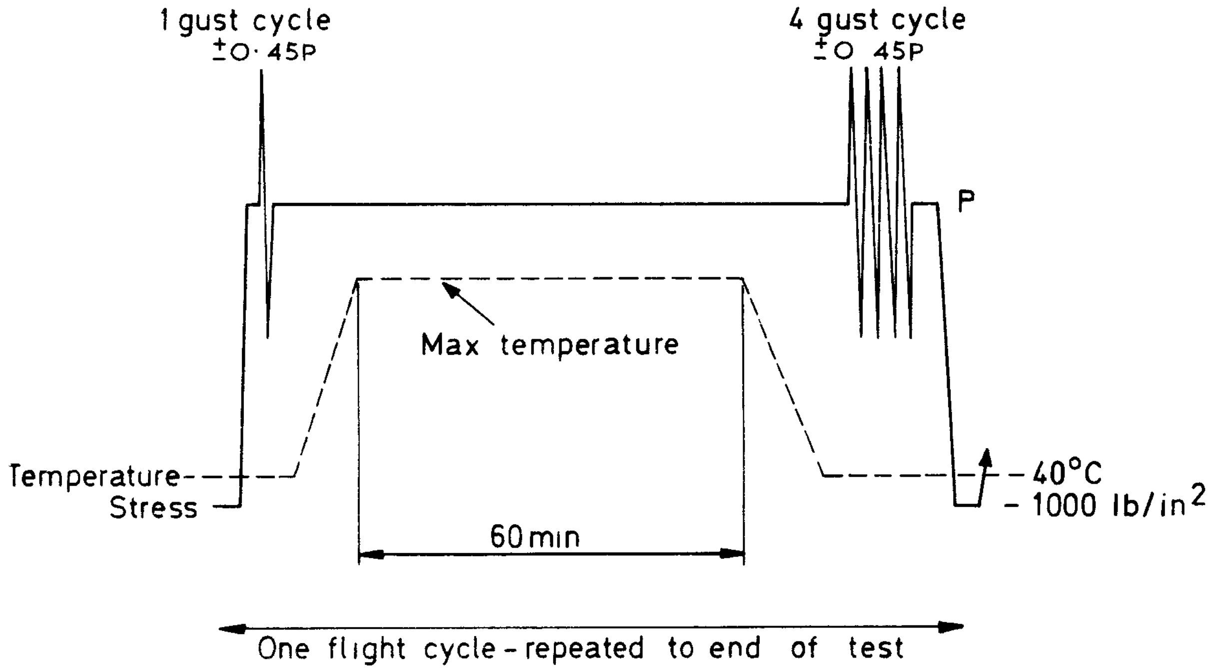


Fig.2 View of specimen showing extensometer and thermocouple attachments



Gusting frequency = 0·08 Hz
P = fatigue mean stress (conditions studied ≡ 11000, 9000 and 7000 lb/in^2 gross stress)

Fig. 3 Load - temperature sequence applied prior to residual static strength test

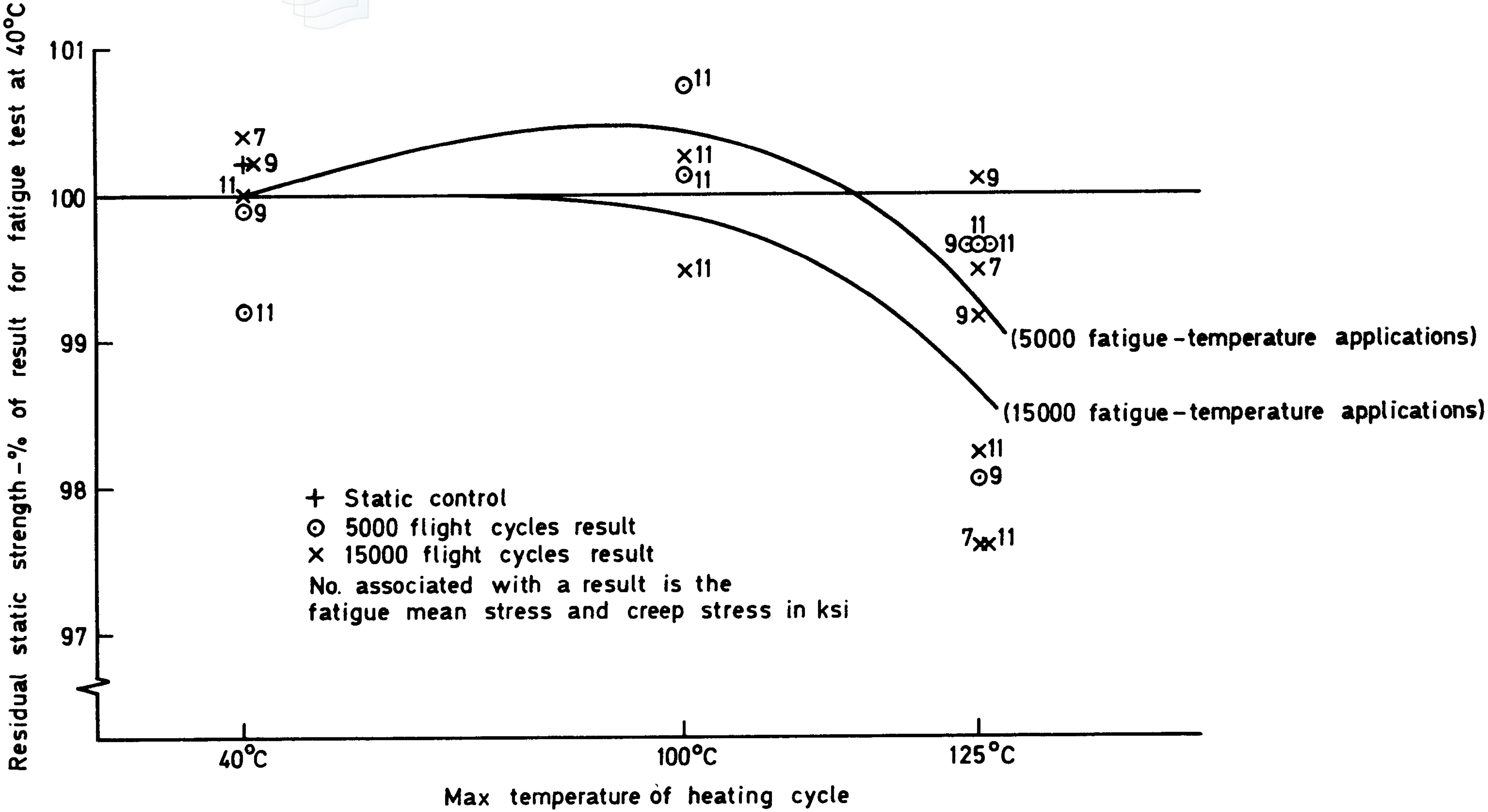


Fig. 4 Effect of temperature and number of applications of heating cycle on residual static strength

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